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Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles - Phase 2

Regulatory Impact Analysis

Final Rule

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

and

National Highway Traffic Safety Administration
U.S. Department of Transportation

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List of Acronyms

µg	Microgram
µm	Micrometers
2002$	U.S. Dollars in calendar year 2002
2009$	U.S. Dollars in calendar year 2009
A/C	Air Conditioning
ABS	Antilock Brake Systems
ABT	Averaging, Banking and Trading
AC	Alternating Current
ACES	Advanced Collaborative Emission Study
ALVW	Adjusted Loaded Vehicle Weight
AEO	Annual Energy Outlook
AES	Automatic Engine Shutdown
AHS	American Housing Survey
AMOC	Atlantic Meridional Overturning Circulation
AMT	Automated Manual Transmission
ANL	Argonne National Laboratory
APU	Auxiliary Power Unit
AQ	Air Quality
AQCD	Air Quality Criteria Document
AR4	Fourth Assessment Report
ARB	California Air Resources Board
ASL	Aggressive Shift Logic
ASPEN	Assessment System for Population Exposure Nationwide
AT	Automatic Transmissions
ATA	American Trucking Association
ATIS	Automated Tire Inflation System
ATRI	Alliance for Transportation Research Institute
ATSDR	Agency for Toxic Substances and Disease Registry
ATUS	American Time Use Survey
Avg	Average
BAC	Battery Air Conditioning
BenMAP	Benefits Mapping and Analysis Program
bhp	Brake Horsepower
bhp-hrs	Brake Horsepower Hours
BLS	Bureau of Labor Statistics
BSFC	Brake Specific Fuel Consumption
BTS	Bureau of Transportation Statistics
BTU	British Thermal Unit
CAA	Clean Air Act
CAAA	Clean Air Act Amendments

CAD/CAE	Computer Aided Design And Engineering
CAE	Computer Aided Engineering
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CBI	Confidential Business Information
CCP	Coupled Cam Phasing
CCSP	Climate Change Science Program
Cd	Coefficient of Drag
C_dA	Drag Area
CDC	Centers for Disease Control
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
CH_4	Methane
CILCC	Combined International Local and Commuter Cycle
CITT	Chemical Industry Institute of Toxicology
CMAQ	Community Multiscale Air Quality
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2eq	CO_2 Equivalent
COFC	Container-on-Flatcar
COI	Cost of Illness
COPD	Chronic Obstructive Pulmonary Disease
CoV	Coefficient of Variation
CPS	Cam Profile Switching
CRC	Coordinating Research Council
CRGNSA	Columbia River Gorge National Scenic Area
CRR	Rolling Resistance Coefficient
CS	Climate Sensitivity
CSI	Cambridge Systematics Inc.
CSS	Coastal Sage Scrub
CSV	Comma-separated Values
CVD	Cardiovascular Disease
CVT	Continuously-Variable Transmission
CW	Curb Weight
D/UAF	Downward and Upward Adjustment Factor
DCP	Dual Cam Phasing
DCT	Dual Clutch Transmission
DE	Diesel Exhaust
DEAC	Cylinder Deactivation
DEER	Diesel Engine-Efficiency and Emissions Research
DEF	Diesel Exhaust Fluid
DHHS	U.S. Department of Health and Human Services
Diesel HAD	Diesel Health Assessment Document

DMC	Direct Manufacturing Costs
DO	Dissolved Oxygen
DOC	Diesel Oxidation Catalyst
DOD	Department of Defense
DOE	Department of Energy
DOHC	Dual Overhead Camshaft Engines
DOT	Department of Transportation
DPF	Diesel Particulate Filter
DPM	Diesel Particulate Matter
DR	Discount Rate
DRIA	Draft Regulatory Impact Analysis
DVVL	Discrete Variable Valve Lift
EC	European Commission
EC	Elemental Carbon
ECU	Electronic Control Unit
ED	Emergency Department
EERA	Energy and Environmental Research Associates
EFR	Engine Friction Reduction
EGR	Exhaust Gas Recirculation
EHPS	Electrohydraulic Power Steering
EIA	Energy Information Administration (part of the U.S. Department of Energy)
EISA	Energy Independence and Security Act
EMS-HAP	Emissions Modeling System for Hazardous Air Pollution
EO	Executive Order
EPA	Environmental Protection Agency
EPS	Electric Power Steering
ERG	Eastern Research Group
ESC	Electronic Stability Control
EV	Electric Vehicle
F	Frequency
FEL	Family Emission Limit
FET	Federal Excise Tax
FEV1	Functional Expiratory Volume
FHWA	Federal Highway Administration
FIA	Forest Inventory and Analysis
FMCSA	Federal Motor Carrier Safety Administration
FOH	Fuel Operated Heater
FR	Federal Register
FTP	Federal Test Procedure
FVC	Forced Vital Capacity
g	Gram
g/s	Gram-per-second

g/ton-mile	Grams emitted to move one ton (2000 pounds) of freight over one mile
gal	Gallon
gal/1000 ton-mile	Gallons of fuel used to move one ton of payload (2,000 pounds) over 1000 miles
GCAM	Global Change Assessment Model
GCW	Gross Combined Weight
GDP	Gross Domestic Product
GEM	Greenhouse gas Emissions Model
GEOS	Goddard Earth Observing System
GHG	Greenhouse Gases
GIFT	Geospatial Intermodal Freight Transportation
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GSF1	Generic Speed Form one
GUI	Graphical User Interface
GVWR	Gross Vehicle Weight Rating
GWP	Global Warming Potential
HABs	Harmful Algal Blooms
HAD	Diesel Health Assessment Document
HC	Hydrocarbon
HD	Heavy-Duty
HDUDDS	Heavy Duty Urban Dynamometer Driving Cycle
HEG	High Efficiency Gearbox
HEI	Health Effects Institute
HES	Health Effects Subcommittee
HEV	Hybrid Electric Vehicle
HFC	Hydrofluorocarbon
HFET	Highway Fuel Economy Dynamometer Procedure
HHD	Heavy Heavy-Duty
HHDDT	Highway Heavy-Duty Diesel Transient
hp	Horsepower
hrs	Hours
HRV	Heart Rate Variability
HSC	High Speed Cruise Duty Cycle
HTUF	Hybrid Truck User Forum
hz	Hertz
IARC	International Agency for Research on Cancer
IATC	Improved Automatic Transmission Control
IC	Indirect Costs
ICCT	International Council on Clean Transport
ICD	International Classification of Diseases
ICF	ICF International
ICM	Indirect Cost Multiplier

ICP	Intake Cam Phasing
IMAC	Improved Mobile Air Conditioning
IMPROVE	Interagency Monitoring of Protected Visual Environments
IPCC	Intergovernmental Panel on Climate Change
IRFA	Initial Regulatory Flexibility Analysis
IRIS	Integrated Risk Information System
ISA	Integrated Science Assessment
JAMA	Journal of the American Medical Association
k	Thousand
kg	Kilogram
KI	kinetic intensity
km	Kilometer
km/h	Kilometers per Hour
kW	Kilowatt
L	Liter
lb	Pound
LD	Light-Duty
LHD	Light Heavy-Duty
LLNL	Lawrence Livermore National Laboratory's
LRR	Lower Rolling Resistance
LSC	Low Speed Cruise Duty Cycle
LT	Light Trucks
LTCCS	Large Truck Crash Causation Study
LUB	Low Friction Lubes
LUC	Land Use Change
m^2	Square Meters
m^3	Cubic Meters
MAGICC	Model for the Assessment of Greenhouse-gas Induced Climate Change
MCF	Mixed Conifer Forest
MD	Medium-Duty
MDPV	Medium-Duty Passenger Vehicles
mg	Milligram
MHD	Medium Heavy-Duty
MHEV	Mild Hybrid
mi	mile
min	Minute
MM	Million
MMBD	Million Barrels per Day
MMT	Million Metric Tons
MOVES	Motor Vehicle Emissions Simulator
mpg	Miles per Gallon
mph	Miles per Hour
MSAT	Mobile Source Air Toxic

MRL	Minimal Risk Level
MT	Manual Transmission
MY	Model Year
N_2O	Nitrous Oxide
NA	Not Applicable
NAAQS	National Ambient Air Quality Standards
NAFA	National Association of Fleet Administrators
NAICS	North American Industry Classification System
NAS	National Academy of Sciences
NATA	National Air Toxic Assessment
NCAR	National Center for Atmospheric Research
NCI	National Cancer Institute
NCLAN	National Crop Loss Assessment Network
NEC	Net Energy Change Tolerance
NEI	National Emissions Inventory
NEMS	National Energy Modeling System
NEPA	National Environmental Policy Act
NESCAUM	Northeastern States for Coordinated Air Use Management
NESCCAF	Northeast States Center for a Clean Air Future
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NHS	National Highway System
NHTSA	National Highway Traffic Safety Administration
NiMH	Nickel Metal-Hydride
NIOSH	National Institute of Occupational Safety and Health
Nm	Newton-meters
NMHC	Nonmethane Hydrocarbons
NMMAPS	National Morbidity, Mortality, and Air Pollution Study
NO_X	Nitrogen Oxide
NO_2	Nitrogen Dioxide
NOAA	National Oceanic and Atmospheric Administration
NO_X	Oxides of Nitrogen
NPRM	Notice of Proposed Rulemaking
NPV	Net Present Value
NRC	National Research Council
NRC-CAN	National Research Council of Canada
NREL	National Renewable Energy Laboratory
NTP	National Toxicology Program
NVH	Noise Vibration and Harshness
O&M	Operating and maintenance
O_3	Ozone
OAQPS	Office of Air Quality Planning and Standards
OC	Organic Carbon
OE	Original Equipment

OEHHA	Office of Environmental Health Hazard Assessment
OEM	Original Equipment Manufacturer
OHV	Overhead Valve
OMB	Office of Management and Budget
OPEC	Organization of Petroleum Exporting Countries
ORD	EPA's Office of Research and Development
ORNL	Oak Ridge National Laboratory
OTAQ	Office of Transportation and Air Quality
Pa	Pascal
PAH	Polycyclic Aromatic Hydrocarbons
PEF	Peak Expiratory Flow
PEMS	Portable Emissions Monitoring System
PGM	Platinum Group Metal
PHEV	Plug-in Hybrid Electric Vehicles
PM	Particulate Matter
PM_{10}	Coarse Particulate Matter (diameter of 10 µm or less)
$PM_{2.5}$	Fine Particulate Matter (diameter of 2.5 µm or less)
POM	Polycyclic Organic Matter
Ppb	Parts per Billion
Ppm	Parts per Million
Psi	Pounds per Square Inch
PTO	Power Take Off
R&D	Research and Development
RBM	Resisting Bending Moment
REL	Reference Exposure Level
RESS	Rechargeable Energy Storage System
RFA	Regulatory Flexibility Act
RfC	Reference Concentration
RFS2	Renewable Fuel Standard 2
RIA	Regulatory Impact Analysis
RPE	Retail Price Equivalent
Rpm	Revolutions per Minute
RSWT	Reduced-Scale Wind Tunnel
S	Second
SAB	Science Advisory Board
SAB-HES	Science Advisory Board - Health Effects Subcommittee
SAE	Society of Automotive Engineers
SAR	Second Assessment Report
SAV	Submerged Aquatic Vegetation
SBA	Small Business Administration
SBAR	Small Business Advocacy Review
SBREFA	Small Business Regulatory Enforcement Fairness Act
SCC	Social Cost of Carbon

SCR	Selective Catalyst Reduction
SER	Small Entity Representation
SET	Supplemental Emission Test
SGDI	Stoichiometric Gasoline Direct Injection
SHEV	Strong Hybrid Vehicles
SI	Spark-Ignition
SIDI	Spark Ignition Direct Injection
SO_2	Sulfur Dioxide
SO_X	Sulfur Oxides
SOA	Secondary Organic Aerosol
SOC	State of Charge
SOHC	Single Overhead Cam
SO_X	Oxides of Sulfur
SPR	Strategic Petroleum Reserve
STB	Surface Transportation Board
Std.	Standard
STP	Scaled Tractive Power
SUV	Sport Utility Vehicle
SVOC	Semi-Volatile Organic Compound
SwRI	Southwest Research Institute
TAR	Technical Assessment Report
TC	Total Costs
TCp	Total Cost package
TDS	Turbocharging And Downsizing
THC	Total Hydrocarbon
TIAX	TIAX LLC
TMC	Technology & Maintenance Council
TOFC	Trailer-on-Flatcar
Ton-mile	One ton (2000 pounds) of payload over one mile
TPM	Tire Pressure Monitoring
TRBDS	Turbocharging and Downsizing
TRU	Trailer Refrigeration Unit
TSD	Technical Support Document
TSS	Thermal Storage
TTMA	Truck Trailer Manufacturers Association
TW	Test Weight
U/DAF	Upward and Downward Adjustment Factor
UCT	Urban Creep and Transient Duty Cycle
UFP	Ultra Fine Particles
URE	Unit Risk Estimate
USDA	United States Department of Agriculture
USGCRP	United States Global Change Research Program
UV	Ultraviolet

UV-b	Ultraviolet-b
VHHD	Vocational Heavy Heavy-Duty
VIN	Vehicle Identification Number
VIUS	Vehicle Inventory Use Survey
VLHD	Vocational Light Heavy-Duty
VMHD	Vocational Medium Heavy-Duty
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
VSL	Vehicle Speed Limiter
VTRIS	Vehicle Travel Information System
VVL	Variable Valve Lift
VVT	Variable Valve Timing
WACAP	Western Airborne Contaminants Assessment Project
WBS	Wide Base Singles
WHR	Waste Heat Recovery
WHTC	World Harmonized Transient Cycle
WHVC	World Harmonized Vehicle Cycle
WRF	Weather Research Forecasting
WTP	Willingness-to-Pay
WTVC	World Wide Transient Vehicle Cycle
WVU	West Virginia University

Executive Summary

The Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA), on behalf of the Department of Transportation, are each finalizing changes to our comprehensive Heavy-Duty National Program. The Program will further reduce greenhouse gas emissions (GHG) and increase fuel efficiency for on-road heavy-duty vehicles, responding to the President's directive on February 18, 2014, to take coordinated steps toward the production of even cleaner vehicles. NHTSA's fuel consumption standards and EPA's carbon dioxide (CO_2) emissions standards are tailored to each of the three current regulatory categories of heavy-duty vehicles: (1) Combination Tractors; (2) Heavy-duty Pickup Trucks and Vans; and (3) Vocational Vehicles, as well as gasoline and diesel heavy-duty engines. In addition, the agencies are adding new standards for combination trailers. EPA's hydrofluorocarbon emissions standards that currently apply to air conditioning systems in tractors, pickup trucks, and vans, will also be applied to vocational vehicles.

Table 1 presents the rule-related technology costs, maintenance costs, fuel savings, other benefits, and net benefits in both present-value and annualized terms for Method A. This table shows the costs and benefits relative to the dynamic baseline. Table 2 presents the rule-related fuel savings, costs, benefits and net benefits in both present value terms and in annualized terms as calculated for Method B relative to the flat baseline.

Table 1 NHTSA's Estimated 2018-2029 Model Year Lifetime Discounted Costs, Benefits, and Net Benefits using Method A, Relative to the Dynamic Baseline [a], and Assuming the 3% Discount Rate SC-GHG Values (Billions of 2013 Dollars)

Lifetime Present Value – 3% Discount Rate	
Vehicle Program	-$23.7
Maintenance	-$1.7
Fuel Savings	$149.1
Benefits (less costs by increased vehicle use)	$72.8
Net Benefits [b]	$196.5
Annualized Value – 3% Discount Rate	
Vehicle Program	-$0.9
Maintenance	-$0.1
Fuel Savings	$5.9
Benefits (less costs by increased vehicle use)	$2.9
Net Benefits [b]	$7.8
Lifetime Present Value - 7% Discount Rate	
Vehicle Program	-$16.1
Maintenance	-$0.9
Fuel Savings	$79.7
Benefits (less costs by increased vehicle use)	$54.6
Net Benefits [b]	$117.3
Annualized Value – 7% Discount Rate	
Vehicle Program	-$1.2
Maintenance	-$0.1
Fuel Savings	$5.8
Benefits (less costs by increased vehicle use)	$4.0
Net Benefits [b]	$8.5

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] Net benefits reflect the fuel savings plus benefits minus costs.

Table 2 EPA's Estimated 2018-2029 Model Year Lifetime Discounted Costs, Benefits, and Net Benefits using Method B and Relative to the Flat Baseline and Assuming the 3% Discount Rate SC-GHG Values[a] (Billions of 2013 Dollars)

Lifetime Present Value[c] – 3% Discount Rate	
Vehicle Program	-$27
Maintenance	-$1.9
Fuel Savings	$169
Benefits [b]	$88
Net Benefits[d]	$229
Annualized Value[e] – 3% Discount Rate	
Vehicle Program	-$1.4
Maintenance	-$0.1
Fuel Savings	$8.6
Benefits [b]	$4.5
Net Benefits[d]	$11.7
Lifetime Present Value[c] - 7% Discount Rate	
Vehicle Program	-$18
Maintenance	-$0.9
Fuel Savings	$87
Benefits [b]	$62
Net Benefits[d]	$131
Annualized Value[e] – 7% Discount Rate	
Vehicle Program	-$1.4
Maintenance	-$0.1
Fuel Savings	$7.0
Benefits [b]	$3.9
Net Benefits[d]	$9.4

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] EPA estimated the benefits associated with reductions in GHGs (CO_2, CH4, and N2O) using four different values of a one ton reduction in each gas. The four values applied to each GHG are: model average at 2.5% discount rate, 3%, and 5%; 95th percentile at 3% and each increases over time. For the purposes of this overview presentation of estimated costs and benefits, however, the benefits shown here use the central marginal value: the model average at 3% discount rate, in 2013 dollars. Chapter 8.5 provides a complete list of values for the 4 estimates for each GHG. Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (marginal values, i.e. SC-GHGs, at 5, 3, and 2.5 percent) is used to calculate net present value of GHG benefits for internal consistency. Refer to Section Chapter 8.5 for more detail.

[c] Present value is the total, aggregated amount that a series of monetized costs or benefits that occur over time is worth now (in year 2013 dollar terms), discounting future values, over the lifetime of each model year vehicle, to calendar year 2015.

[d] Net benefits reflect the fuel savings plus benefits minus costs.

[e] The annualized value is the constant annual value through a 30 year lifetime whose summed present value equals the present value from which it was derived. Annualized SC-GHG values are calculated using the same rate as that used to determine the SC-GHG value, while all other costs and benefits are annualized at either 3% or 7%.

Table 3 Summary of Final 2021 Standards Including Average Per Vehicle Costs and Projected Improvement

REGULATORY SUBCATEGORY	CO_2 GRAMS PER TON-MILE	FUEL CONSUMPTION GALLON PER 1,000 TON-MILE	AVERAGE INCREMENTAL COST PER VEHICLE RELATIVE TO PHASE 1 COSTS IN MODEL YEAR 2021 [A]	AVERAGE PERCENT FUEL CONSUMPTION AND CO_2 IMPROVEMENT IN MY 2021 RELATIVE TO MY 2017
Tractors				
Class 7 Low Roof Day Cab	105.5	10.36346	$5,134	11%
Class 7 Mid Roof Day Cab	113.2	11.11984	$5,134	11%
Class 7 High Roof Day Cab	113.5	11.14931	$5,240	12%
Class 8 Low Roof Day Cab	80.5	7.90766	$5,228	12%
Class 8 Mid Roof Day Cab	85.4	8.38900	$5,228	12%
Class 8 High Roof Day Cab	85.6	8.40864	$5,317	13%
Class 8 Low Roof Sleeper Cab	72.3	7.10216	$7,181	14%
Class 8 Mid Roof Sleeper Cab	78.0	7.66208	$7,175	14%
Class 8 High Roof Sleeper Cab	75.7	7.43615	$7,276	14%
Class 8 Heavy-Haul	52.4	5.14735	$5,063	8%
Trailers				
Long Dry Box Trailer	78.9	7.75049	$1,081	5%
Short Dry Box Trailer	123.7	12.15128	$772	2%
Long Refrigerated Box Trailer	80.6	7.91749	$1,081	5%
Short Refrigerated Box Trailer	127.5	12.52456	$772	2%
Vocational Diesel				
LHD Urban	424	41.6503	$1,106	12%
LHD Multi-Purpose	373	36.6405	$1,164	11%
LHD Regional	311	30.5501	$873	7%
MHD Urban	296	29.0766	$1,116	11%
MHD Multi-Purpose	265	26.0314	$1,146	10%
MHD Regional	234	22.9862	$851	6%
HHD Urban	308	30.2554	$1,334	9%
HHD Multi-Purpose	261	25.6385	$1,625	9%
HHD Regional	205	20.1375	$2,562	7%
Vocational Gasoline				
LHD Urban	461	51.8735	$1,106	8%
LHD Multi-Purpose	407	45.7972	$1,164	8%
LHD Regional	335	37.6955	$873	6%
MHD Urban	328	36.9078	$1,116	7%
MHD Multi-Purpose	293	32.9695	$1,146	7%
MHD Regional	261	29.3687	$851	5%

Note:

[a] Engine costs are included in average vehicle costs. These costs are based on our projected market adoption rates of various technologies and these costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the RIA (see RIA 2.11).

Table 4 Summary of Final 2024 Standards Including Average Per Vehicle Costs and Projected Improvement

REGULATORY SUBCATEGORY	CO_2 GRAMS PER TON-MILE	FUEL CONSUMPTION GALLON PER 1,000 TON-MILE	AVERAGE INCREMENTAL COST PER VEHICLE RELATIVE TO PHASE 1 COSTS IN MODEL YEAR 2024 [A]	AVERAGE PERCENT FUEL CONSUMPTION AND CO_2 IMPROVEMENT IN MY 2024 RELATIVE TO MY 2017
Tractors				
Class 7 Low Roof Day Cab	99.8	9.80354	$8,037	16%
Class 7 Mid Roof Day Cab	107.1	10.52063	$8,037	16%
Class 7 High Roof Day Cab	106.6	10.47151	$8,210	18%
Class 8 Low Roof Day Cab	76.2	7.48527	$8,201	17%
Class 8 Mid Roof Day Cab	80.9	7.94695	$8,201	16%
Class 8 High Roof Day Cab	80.4	7.89784	$8,358	18%
Class 8 Low Roof Sleeper Cab	68.0	6.67976	$11,100	19%
Class 8 Mid Roof Sleeper Cab	73.5	7.22004	$11,100	19%
Class 8 High Roof Sleeper Cab	70.7	6.94499	$11,306	19%
Class 8 Heavy-Haul	50.2	4.93124	$7,937	12%
Trailers				
Long Dry Box Trailer	77.2	7.58350	$1,204	7%
Short Dry Box Trailer	120.9	11.87623	$1,171	4%
Long Refrigerated Box Trailer	78.9	7.75049	$1,204	7%
Short Refrigerated Box Trailer	124.7	12.24951	$1,171	4%
Vocational Diesel				
LHD Urban	385	37.8193	$1,959	20%
LHD Multi-Purpose	344	33.7917	$2,018	18%
LHD Regional	296	29.0766	$1,272	11%
MHD Urban	271	26.6208	$2,082	18%
MHD Multi-Purpose	246	24.1650	$2,110	16%
MHD Regional	221	21.7092	$1,274	11%
HHD Urban	283	27.7996	$2,932	16%
HHD Multi-Purpose	242	23.7721	$3,813	16%
HHD Regional	194	19.0570	$4,009	12%
Vocational Gasoline				
LHD Urban	432	48.6103	$1,959	13%
LHD Multi-Purpose	385	43.3217	$2,018	9%
LHD Regional	324	36.4577	$1,272	12%
MHD Urban	310	34.8824	$2,082	11%
MHD Multi-Purpose	279	31.3942	$2,110	9%
MHD Regional	251	28.2435	$1,274	13%

Note:

[a] Engine costs are included in average vehicle costs. These costs are based on our projected market adoption rates of various technologies and these costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the RIA (see RIA 2.11).

Table 5 Summary of Final 2027 Standards Including Average Per Vehicle Costs and Projected Improvement

REGULATORY SUBCATEGORY	CO_2 GRAMS PER TON-MILE (FOR HD PUV, GRAMS PER MILE)	FUEL CONSUMPTION GALLON PER 1,000 TON-MILE (FOR HD PUV, GALLONS PER 100 MILES)	AVERAGE INCREMENTAL COST PER VEHICLE RELATIVE TO PHASE 1 COSTS IN MODEL YEAR 2027 [A]	AVERAGE PERCENT FUEL CONSUMPTION AND CO_2 IMPROVEMENT IN MY 2027 RELATIVE TO MY 2017
Tractors				
Class 7 Low Roof Day Cab	96.2	9.44990	$10,235	19%
Class 7 Mid Roof Day Cab	103.4	10.15717	$10,235	19%
Class 7 High Roof Day Cab	100.0	9.82318	$10,298	21%
Class 8 Low Roof Day Cab	73.4	7.21022	$10,439	20%
Class 8 Mid Roof Day Cab	78.0	7.66208	$10,439	19%
Class 8 High Roof Day Cab	75.7	7.43615	$10,483	22%
Class 8 Low Roof Sleeper Cab	64.1	6.29666	$13,535	24%
Class 8 Mid Roof Sleeper Cab	69.6	6.83694	$13,574	23%
Class 8 High Roof Sleeper Cab	64.3	6.31631	$13,749	25%
Class 8 Heavy-Haul	48.3	4.74460	$9,986	15%
Trailers				
Long Dry Box Trailer	75.7	7.43615	$1,370	9%
Short Dry Box Trailer	119.4	11.72888	$1,204	6%
Long Refrigerated Box Trailer	77.4	7.60314	$1,370	9%
Short Refrigerated Box Trailer	123.2	12.10216	$1,204	5%
Vocational Diesel				
LHD Urban	367	36.0511	$2,533	24%
LHD Multi-Purpose	330	32.4165	$2,571	21%
LHD Regional	291	28.5855	$1,486	13%
MHD Urban	258	25.3438	$2,727	22%
MHD Multi-Purpose	235	23.0845	$2,771	20%
MHD Regional	218	21.4145	$1,500	12%
HHD Urban	269	26.4244	$4,151	20%
HHD Multi-Purpose	230	22.5933	$5,025	20%
HHD Regional	189	18.5658	$5,670	14%
Vocational Gasoline				
LHD Urban	413	46.4724	$2,533	18%
LHD Multi-Purpose	372	41.8589	$2,571	16%
LHD Regional	319	35.8951	$1,486	11%
MHD Urban	297	33.4196	$2,727	16%
MHD Multi-Purpose	268	30.1564	$2,771	15%
MHD Regional	247	27.7934	$1,500	10%
Class 2b and 3 HD Pickups and Vans[b]				
HD Pickup and Van	460	4.88	$1,486	17%

Notes:

[a] Engine costs are included in average vehicle costs. These costs are based on our projected market adoption rates of various technologies and these costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the RIA (see RIA 2.11).

[b] For HD pickups and vans, Table 5 shows results for MY2029, assuming continuation of MY2027 standard.

Table 6 Summary of Final 2021 and 2024 Custom Chassis Vocational Standards Including Average Per Vehicle Costs and Projected Improvement

REGULATORY SUBCATEGORY	CO_2 GRAMS PER TON-MILE	FUEL CONSUMPTION GALLON PER 1,000 TON-MILE	AVERAGE INCREMENTAL COST PER VEHICLE RELATIVE TO PHASE 1 COSTS IN MODEL YEAR 2021 [A]	AVERAGE PERCENT FUEL CONSUMPTION AND CO_2 IMPROVEMENT IN MY 2021 RELATIVE TO MY 2017
Vocational Custom Chassis				
Coach Bus	210	20.6287	900	7%
Motor Home	228	22.3969	600	6%
School Bus	291	28.5855	800	10%
Transit	300	29.4695	1000	7%
Refuse	313	30.7466	700	4%
Mixer	319	31.3360	300	3%
Emergency	324	31.8271	400	1%

Note:

[a] Engine costs are included in average vehicle costs. These costs are based on our projected market adoption rates of various technologies and these costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the RIA (see RIA 2.11).

Table 7 Summary of Final 2027 Custom Chassis Vocational Standards Including Average Per Vehicle Costs and Projected Improvement

REGULATORY SUBCATEGORY	CO_2 GRAMS PER TON-MILE	FUEL CONSUMPTION GALLON PER 1,000 TON-MILE	AVERAGE INCREMENTAL COST PER VEHICLE RELATIVE TO PHASE 1 COSTS IN MODEL YEAR 2027 [A]	AVERAGE PERCENT FUEL CONSUMPTION AND CO_2 IMPROVEMENT IN MY 2027 RELATIVE TO MY 2017
Vocational Custom Chassis				
Coach Bus	205	20.1375	1400	11%
Motor Home	226	22.2004	900	9%
School Bus	271	26.6208	1300	18%
Transit	286	28.0943	1800	14%
Refuse	298	29.2731	1300	12%
Mixer	316	31.0413	600	7%
Emergency	319	31.3360	600	6%

Note:

[a] Engine costs are included in average vehicle costs. These costs are based on our projected market adoption rates of various technologies and these costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the RIA (see RIA 2.11).

This Regulatory Impact Analysis (RIA) provides detailed supporting documentation to EPA and NHTSA joint rules under each of their respective statutory authorities. Because there are slightly different requirements and flexibilities in the two authorizing statutes, this RIA provides documentation for the primary joint provisions as well as for provisions specific to each agency.

This RIA is generally organized to provide overall background information, methodologies, and data inputs, followed by results of the various technical and economic analyses. A summary of each chapter of the RIA follows.

Chapter 1: Industry Characterization. In order to assess the impacts of greenhouse gas (GHG) and fuel consumption regulations upon the affected industries, it is important to understand the nature of the industries impacted by the regulations. This chapter provides market information for the trailer industry, as well as the variety of ownership patterns, for background purposes. It also provides information on the vocational vehicle industry.

Chapter 2: Technology and Cost. This chapter presents details of the vehicle and engine technologies and technology packages for reducing greenhouse gas emissions and fuel consumption. These technologies and technology packages represent potential ways that the industry could meet the CO_2 and fuel consumption stringency levels, and they provide the basis for the technology costs and effectiveness analyses.

Chapter 3: Test Procedures. Laboratory procedures to physically test engines, vehicles, and components are a crucial aspect of the heavy-duty vehicle GHG and fuel consumption program. The rulemaking will establish some new test procedures for both engine and vehicle compliance and will revise existing procedures. This chapter describes the relevant test procedures, including methodologies for assessing engine emission performance, the effects of aerodynamics and tire rolling resistance, as well as procedures for chassis dynamometer testing and their associated drive cycles.

Chapter 4: Vehicle Simulation Model. An important aspect of a regulatory program is its ability to accurately estimate the potential environmental benefits of heavy-duty truck technologies through testing and analysis. Most large truck manufacturers employ various computer simulation methods to estimate truck efficiency for purposes of developing and refining their products. Each method has advantages and disadvantages. This section will focus on the use of a type truck simulation modeling that the agencies have developed specifically for assessing tailpipe GHG emissions and fuel consumption for purposes of this rulemaking. The agencies will revise the existing simulation model -- the "Greenhouse gas Emissions Model (GEM)" -- as the primary tool to certify vocational vehicles, combination tractor, and combination trailers, Class 2b through Class 8 heavy-duty vehicles that are not heavy-duty pickups or vans) and discuss the model in this chapter.

Chapter 5: Impacts on Emissions and Fuel Consumption. This program estimates anticipated impacts from the CO_2 emission and fuel efficiency standards. The agencies quantify fuel use and emissions from the GHGs carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and hydrofluorocarbons (HFCs). In addition to reducing the emissions of greenhouse gases and fuel consumption, this program will also influence the emissions of "criteria" air pollutants, including carbon monoxide (CO), fine particulate matter ($PM_{2.5}$) and sulfur dioxide (SO_X) and the ozone precursors hydrocarbons (VOC) and oxides of nitrogen (NO_X); and several air toxics (including benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein), as described further in Chapter 5.

The agencies used EPA's Motor Vehicle Emission Simulator (MOVES2014a) to estimate downstream (tailpipe) emission impacts for combination tractors and vocational vehicles, and a spreadsheet model based on emission factors the "GREET" model to estimate upstream (fuel production and distribution) emission changes resulting from the decreased fuel. For HD pickups and vans, the agencies used DOT's CAFE model to estimate manufacturer responses to these standards. NHTSA used the CAFE model to estimate emission impacts, and EPA used the MOVES model to calculate emission impacts using CAFE model technology penetration outputs as an input. Based on these analyses, the agencies estimate that this program will lead to 199.2 million metric tons (MMT) of CO_2 equivalent (CO_2EQ) of annual GHG reduction and 14.9 billion gallons of fuel savings in the year 2050, as discussed in more detail in Chapter 5.

Chapter 6: Health and Environmental Impacts. This chapter discusses the health effects associated with non-GHG pollutants, specifically: particulate matter, ozone, nitrogen oxides (NO_X), sulfur oxides (SO_X), carbon monoxide and air toxics. These pollutants will not be directly regulated by the standards, but the standards will affect emissions of these pollutants and precursors. Reductions in these pollutants are the co-benefits of the rulemaking (that is, benefits in addition to the benefits of reduced GHGs). This section discusses current and projected concentrations of non-GHG pollutants as well as the air quality modeling methodology and modeled projected impacts of this rule. This chapter also discusses GHG-related impacts, such as changes in atmospheric CO_2 concentrations, global mean temperature, sea level rise, and ocean pH associated with the program's GHG emissions reductions.

Chapter 7: Vehicle-Related Costs of the Program. In this chapter, the agencies present our estimate of the costs associated with the program. The presentation summarizes the costs associated with new technology expected to be added to meet the GHG and fuel consumption standards, including hardware costs to comply with the air conditioning (A/C) leakage program. The analysis discussed in Chapter 7 provides our best estimates of incremental costs on a per truck basis and on an annual total basis. We also present the fuel savings and maintenance costs in this chapter, along with a detailed payback analysis for various vehicle segments.

Chapter 8: EPA's Economic and Other Impacts Analysis. This chapter provides EPA's description of the net benefits of the HD National Program. To reach these conclusions, the chapter discusses each of the following aspects of the analyses of benefits:

Rebound Effect: The VMT rebound effect refers to the fraction of fuel savings expected to result from an increase in fuel efficiency that is offset by additional vehicle use.

Energy Security Impacts: A reduction of U.S. petroleum imports reduces both financial and strategic risks associated with a potential disruption in supply or a spike in cost of a particular energy source. This reduction in risk is a measure of improved U.S. energy security.

Monetized GHG Impacts: The agencies estimate the monetized benefits of GHG reductions by assigning a dollar value to reductions in GHG emissions using recent estimates of the social cost of greenhouse gasses (SC-GHG). The SC-GHG is an estimate of the monetized damages associated with an incremental increase in greenhouse gas emissions in a given year.

Other Impacts: There are other impacts associated with the GHG emissions and fuel efficiency standards. Lower fuel consumption will, presumably, result in fewer gallons being refilled and, thus, less time spent refueling. The increase in vehicle-miles driven due to a positive rebound effect may also increase the societal costs associated with traffic congestion, crashes, and noise. However, if drivers drive those additional rebound miles, there must be a value to them which we estimate as the value of increased travel. The agencies also discuss the impacts of safety standards and voluntary safety improvements on vehicle weight.

Chapter 8 also presents a summary of the total costs, total benefits, and net benefits expected under the program.

Chapter 9: NHTSA and EPA considered the potential safety impact of technologies that improve HD vehicle fuel efficiency and GHG emissions as part of the assessment of regulatory alternatives. This chapter discusses the literature and research considered by the agencies, which included two National Academies of Science reports, an analysis of safety effects of HD pickups and vans using estimates from the DOT report on the effect of mass reduction and vehicle size on safety, and agency-sponsored safety testing and research.

Chapter 10: NHTSA CAFE Model. This chapter describes NHTSA's CAFE modeling system. The agencies used DOT's CAFE model to estimate manufacturer responses to these standards for HD pickups and vans, and NHTSA also used the CAFE model to estimate emission impacts for this sector.

Chapter 11: Results of Preferred and Alternative Standards. The heavy-duty truck segment is very complex. The sector consists of a diverse group of impacted parties, including engine manufacturers, chassis manufacturers, truck manufacturers, trailer manufacturers, truck fleet owners and the public. The agencies have largely designed this program to maximize the environmental and fuel savings benefits, taking into account the unique and varied nature of the regulated industries. In developing this program, we considered a number of alternatives that could have resulted in fewer or potentially greater GHG and fuel consumption reductions. Chapter 9 Section summarizes the alternatives we considered.

Chapter 12: Small Business Flexibility Analysis. This chapter describes the agencies' analysis of the small business impacts due to the joint program.

Chapter 13: Natural Gas Vehicles and Engines. This chapter describes EPA's lifecycle analysis for natural gas used by the heavy-duty truck sector.

Chapter 1: Industry Characterization

1.1 Introduction

The fuel consumption and CO_2 emissions standards described in the Preamble of this FRM will be applicable to three currently-regulated categories of heavy-duty vehicles: (1) Combination Tractors; (2) Heavy-duty Pickup Trucks and Vans; and (3) Vocational Vehicles, as well as spark-ignition and compression-ignition heavy-duty engines. The industry characterization for these sectors can be found in the RIA for the HD Phase 1 rulemaking.[1] With this rulemaking, the agencies will be setting standards for combination trailers for the first time. Also with this rulemaking, the agencies are setting standards that apply for small businesses for the first time, as well as offering separate standards for vocational custom chassis. The characterization laid out in this chapter focuses on trailers and vocational custom chassis, whereas Chapter 12 of this RIA highlights impacts related to small businesses.

1.2 Trailers

A trailer is a vehicle designed to haul cargo while being pulled by another powered motor vehicle. The most common configuration of large freight trucks consists of a Class 7 or 8 tractor hauling one or more trailers. Vehicles in these configurations are called "combination tractor-trailers" or simply "tractor-trailers." A trailer may be constructed to rest upon the tractor that tows it, or be constructed so part of its weight rests on an auxiliary front axle called a "converter dolly" between two or more trailers. Trailers are attached to tractors by a *coupling pin* (or *king pin*) on the front of the trailer and a horseshoe-shaped coupling device called a *fifth wheel* on the rear of the towing vehicle or on the converter dolly. A tractor can also pull international shipping or domestic *containers* mounted on open-frame chassis, which when driven together on the road function as trailers.

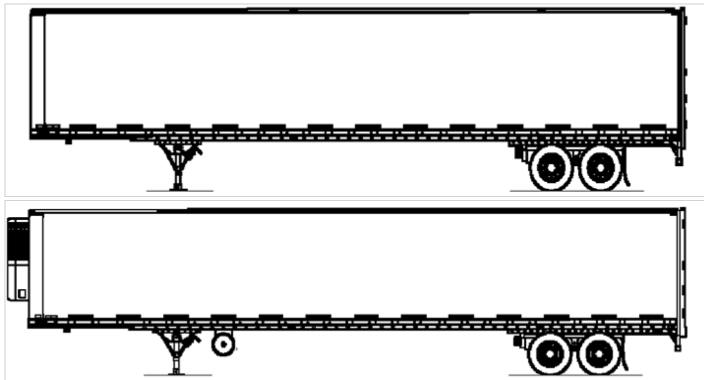
The Truck Trailer Manufacturers Association, an industry trade group primarily for manufacturers of Class 7 and 8 truck trailers, offers publications of recommended practices, technical bulletins and manuals that cover many aspects of trailer manufacture, and serves as a liaison between the industry and government agencies.[2] To date, federal regulations for the trailer industry are limited to those issued by the Department of Transportation (See 49 CFR). These regulations govern trailer dimensions and weight, as well as trailer safety requirements (e.g., lights, reflective materials, bumpers, etc.). In addition, DOT requires that each trailer, like other on-road vehicles, must have a Vehicle Identification Number (VIN).[3] The VIN is displayed on a label that is permanently-affixed to the trailer. It is required to contain the manufacturer identification, make and type of vehicle, model year, type of trailer, body type, length, and axle configuration. Trailer manufactures are responsible for reporting each trailer's VIN information to NHTSA prior to the sale of the trailer.

1.2.1 Trailer Types

Class 7 and 8 tractors haul a diverse range of trailer types. The most common trailer type is the box trailer, which is enclosed and can haul most types of mixed freight. The general rectangular shape of these trailers allows operators to maximize freight volume within the regulated dimensional limits, since the majority of freight shipped by truck cubes-out (is volume-limited) before it grosses-out (is weight-limited). Despite considerable improvements in suspension, material, safety, durability, and other advancements, the basic shape of the box trailer has not changed much over the past decades, although its dimensions have increased incrementally from what used to be the industry's standard length of 40' to today's standard 53' long van trailer. Today, box vans are commonly found in lengths of 28', 48', and 53'and widths of 102" or 96." The 28' vans ("pups") are often driven in tandem and connected by a dolly. Current length restrictions for the total combination tractor-trailer vehicle limit tandem operation to 28' trailers. However, some members of the trucking industry are pushing to increase the length limits to allow trailers as long as 33' to be pulled in tandem, and arguing that these "less than truckload" (LTL) operations could increase capacity per truckload, reduce the number of trucks on the road, reduce the fuel consumption and emissions of these tractor-trailers, and remain within the current weight limits.[4,5]

Trailers are often highly customized for each order. The general structure of the box trailer type is common and consists of vertical support posts in the interior of the trailer covered by a smooth exterior surface. However the exterior of the trailer may be constructed of aluminum or a range of composite materials. Historically, floors were constructed of wood, however many trailer customers are requesting aluminum floors to reduce weight. Semi-trailer axles are commonly a dual tandem configuration, but can also be single, spread tandem (i.e., two axles separated to maximize axle loads), tridem (i.e., three axles equally spaced), tri axles (i.e., three axles consisting of a tandem and a third axle that may be liftable), or multi-axles to distribute very heavy loads. Axles can be fixed in place, or allowed to slide to adjust weight distribution. Doors are commonly located at the rear of the trailer. The most common door is the side-by-side configuration, in which each door opens outward. Roll-up doors, which are more costly, allow truck drivers to pull up to loading docks without first stopping to open the doors. Roll-up doors are common on trailers with temperature-sensitive freight. Additional variations in trailers include side-access doors, or use the underside of the trailer for belly boxes or to store on-demand items such as ladders or spare tires.

The most common box trailer is the standard dry van, which transports cargo that does not require special environmental conditions. In addition to the standard rectangular shape, dry vans come in several specialty variants, such as drop floor, expandable, and curtain-side. Another type of specialty box trailer is the refrigerated van trailer (reefer). This is an enclosed, insulated trailer that hauls temperature sensitive freight, with a transportation refrigeration unit (TRU) or heating unit mounted in the front of the trailer powered by a small (9-36 hp) diesel engine. Figure 1-1 shows an example of the standard dry and refrigerated van.



Adapted from http://www.wbmcguire.com/links/Guides/TruckTrailerGuide.pdf

Figure 1-1 Example of Dry and Refrigerated Van

Many other trailer types are uniquely designed to transport a specific type of freight. Platform trailers carry cargo that may not be easily contained within or loaded and unloaded into a box trailer, such as large, non-uniform equipment or machine components. Platforms come in different configurations including standard flatbed, gooseneck, and drop deck. Tank trailers are pressure-tight enclosures designed to carry liquids, gases or bulk, dry solids and semi-solids. Tank trailers are generally constructed of steel or aluminum. The plumbing for intake and discharge of the contents could be located below the tank or at the rear. There are also a number of other specialized trailers such as grain (with and without hoppers), dump (frameless, framed, bottom dump, demolition), automobile hauler (open or enclosed), livestock trailers (belly or straight), construction and heavy-hauling trailers (tilt bed, hydraulic).

A sizable fraction of U.S. freight is transported in large, steel containers both internationally via ocean-going vessels and domestically via rail cars. Containers are constructed with steel sidewalls and external support beams, which results in a corrugated exterior. These containers haul mixed freight and are designed with similar dimensions to box trailers. Ocean-going international shipping containers are typically 20-feet or 40-feet in length. Domestic containers, which often travel by rail, are 53-feet in length. Transport of these containers from ports or rail to their final destination requires the container to be loaded on a specialty piece of equipment called a chassis. The chassis, which is attached to the fifth wheel of a Class 7 or 8 tractor, consists of a frame, axles, suspension, brakes and wheel assemblies, as well as lamps, bumpers and other required safety components. Fixed chassis vary in length according to the type of container that will be attached, though some chassis adjust to accommodate different sizes. When the chassis and container are assembled the unit serves the same function as a road trailer.[6] However, under customs regulations, the container itself is not considered part of a road vehicle.[7]

ACT Research compiles factory shipment information from a Trailer Industry Control Group that represents 80 percent of the U.S. trailer industry. Figure 1-2 shows the distribution of trailers sold in the U.S. based on ACT Research's 2013 factory shipment data. The most common type of trailer in use today is the dry van trailer, followed by the refrigerated van. Together, these box vans make up greater than 70 percent of the industry. Trailer Body

Builders' annual trailer output report estimates there were over 240,000 trailers sold in North America 2013.

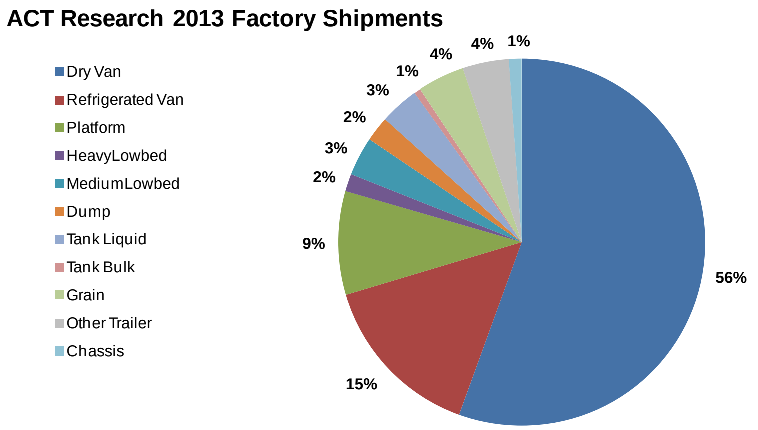


Figure 1-2 ACT Research's 2013 U.S. factory shipments

1.2.2 Trailer Manufacturers

The diverse van, platform, tank and specialty trailers are produced by a large number of trailer manufacturers. EPA estimates there are 178 trailer manufacturers. Trailers are far less mechanically complex than the tractors that haul them, and much of trailer manufacturing is done by hand. This relatively low barrier to entry for trailer manufacturing accounts, in part, for the large number of trailer manufacturers. Figure 1-3 shows the production distribution of the industry for the top 28 companies.[8] While the percentages and ranking vary slightly year-to-year, the top five manufacturers consistently produce over 70 percent of the manufacturing output of the industry.

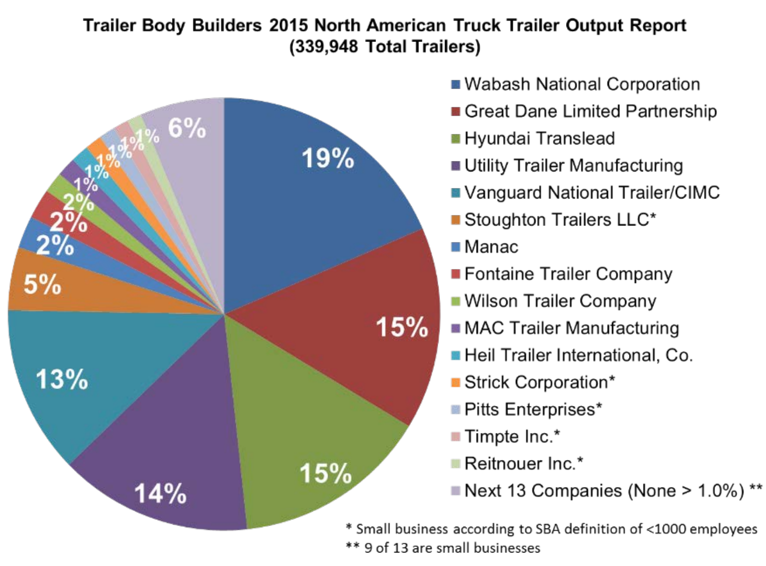


Figure 1-3 2015 Trailer Output Report from Trailer Body Builders

Table 1-1 illustrates the varying revenue among trailer manufacturers and further distinguishes the very different roles in that market played by small and large manufacturers. The revenue numbers were obtained from Hoovers online company database.[9] Over 80 percent of trailer manufacturers meet the Small Business Administration's (SBA) definition of a small business (i.e., less than 1,000 employees), yet these manufacturers make up less than 25 percent of the overall revenue from the industry. In fact, a majority of the small business trailer manufacturers make less than $10 million in revenue per year.

Table 1-1 Summary of 2014 Trailer Industry Revenue by Business Size

REVENUE RANGE	BUSINESS SIZE		
	All Sizes	Large	Small[a]
> 1000M	3	3	0
$500M - $999M	2	2	0
$400M - $499M	1	1	0
$300M - $399M	3	3	0
$200M - $299M	5	4	1
$100M - $199M	3	1	2
$50M - $99M	14	6	8
$40M - $49M	22	2	20
$15M - $19M	8	0	8
$10M - $14M	17	3	14
$5M - $9M	35	4	31
< $5M	65	2	63
Total Companies	178	31	147
Total Revenue ($M)	10841	8543	2298
Average Revenue ($M)	61	276	16
Box Trailer Mfrs	13	8	5
Non-Box Trailer Mfrs	173	29	144

Note:
[a] The Small Business Administration (SBA) defines a trailer manufacturer as a "small business" if it has fewer than 1,000 employees

The trailer industry was particularly hard hit by the recent recession. Trailer manufacturers saw deep declines in new trailer sales of 46 percent in 2009; some trailer manufacturers saw sales drop as much as 71 percent. This followed overall trailer industry declines of over 30 percent in 2008. The 30 largest trailer manufacturers saw sales decline 72 percent from 282,750 in 2006, to only 78,526 in 2009. Several trailer manufacturers shut down entire production facilities and a few went out of business altogether. Trailer production has steadily grown across the industry since 2010 and, although historic production peaks have not been repeated to date, it has now returned to levels close to those seen in the mid-2000s. Figure 1-4 shows the ACT Research's annual factory shipments, which illustrates the unsteady production over the past 17 years. Trailer Body Builders' annual trailer output report estimates there were over 240,000 trailers sold in North America in 2013. Output increased to 292,000 in 2014 and to nearly 340,000 in 2015 (very close to the current record from 1999).

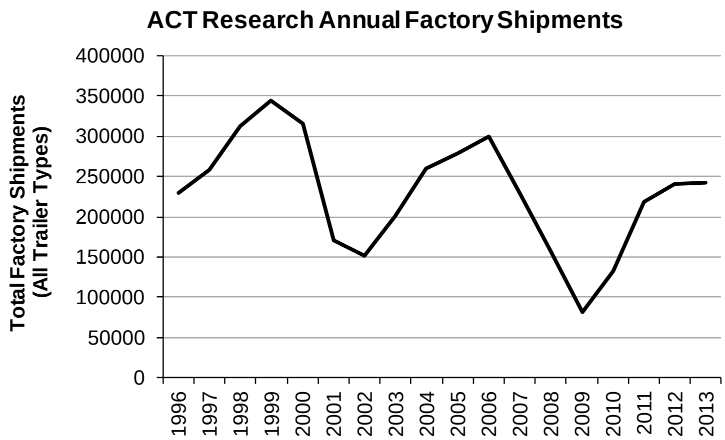


Figure 1-4 Annual Factory Shipments Tracked by ACT Research

1.2.3 Trailer Use

In order to determine the appropriate tractor type for each trailer, the agencies investigated "primary trip length" results from the Vehicle Inventory and Use Survey database to determine the distribution of trailers in short- and long-haul applications.[10] Using a primary trip length of 500 miles or less to represent short-haul use, the agencies found that, of the reported vehicles, over 50 percent of the 53-feet and longer dry vans were used in long-haul and over 80 percent of the shorter vans were used in short-haul applications. Over 70 percent of the reported 53-feet and longer refrigerated vans were long-haul trailers, with 65 percent of the shorter refrigerated vans used in short-haul applications. The survey found that non-box trailers are most frequently used for short-haul. Figure 1-5 summarizes these findings.

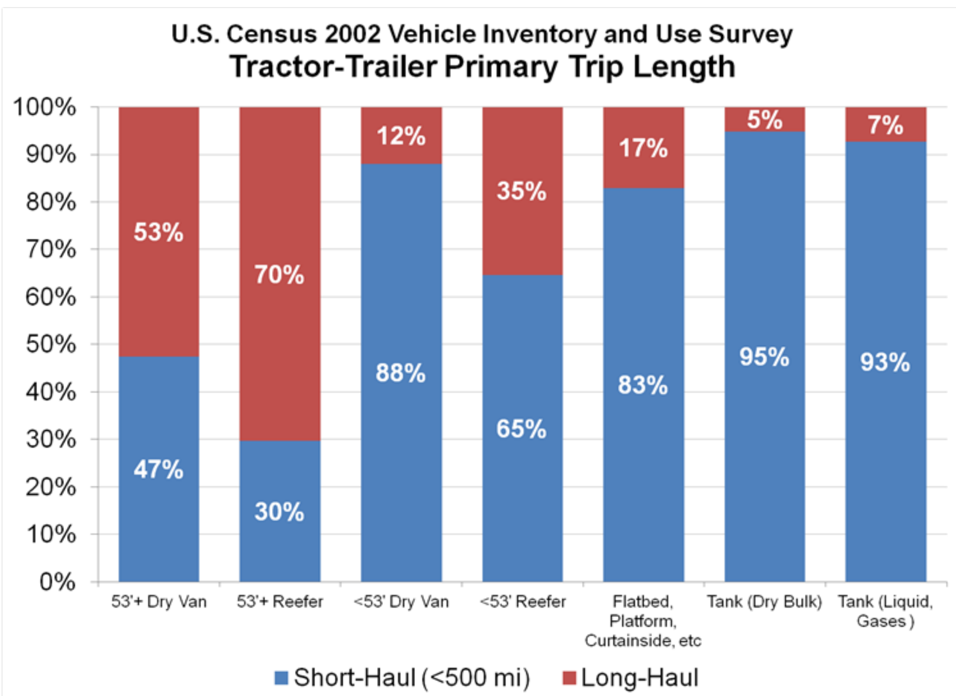


Figure 1-5 2002 Vehicle Inventory and Use Survey Considering Primary Trip Length for Tractor-Trailers

Truck drivers and trucking fleets frequently do not control all or even any of the trailers that they haul. Trailers can be owned by freight customers, large equipment leasing companies, third party logistics companies, and even other trucking companies. Containers on chassis, which function as trailers, are rarely owned by truck operators. Rather, they are owned or leased by ocean-going shipping companies, port authorities or others. This distinction between who hauls the freight and who owns the equipment in which it is hauled means that truck owners and operators have limited ability to be selective about the trailers they carry, and very little incentive or ability to take steps to reduce the fuel use of trailers that they neither own or control.

For refrigerated trailers, the story is slightly different. These trailers are used more intensely and accumulate more annual miles than other trailers. Over time, refrigerated trailers can also develop problems that interfere with their ability to keep freight temperature-controlled. For example, the insulating material inside a refrigerated trailer's walls can gradually lose its thermal capabilities due to aging or damage from forklift punctures. The door seals on a refrigerated trailer can also become damaged or loose with age, which greatly affects the insulation characteristics of the trailer, similar to how the door seal on a home refrigerator can reduce the efficiency of that appliance. As a result of age-related problems and more intense usage, refrigerated trailers tend to have shorter procurement cycles than dry van trailers, which means a faster turnover rate, although still not nearly as fast as for trucks in their first use.

Tractor-trailers are often used in conjunction with other modes of transportation (e.g., shipping and rail) to move goods across the country, known as intermodal shipping. Intermodal traffic typically begins with containers carried on ships, and then they are loaded onto railcars, and finally transported to their end destination via truck. Trucks that are used in intermodal applications are of two primary types. Trailer-on-flatcar (TOFC) involves lifting the entire trailer or the container attached to its chassis onto the railcar. In container-on-flatcar (COFC) applications, the container is removed from the chassis and placed directly on the railcar. The use of TOFCs allows for faster transition from rail to truck, but is more difficult to stack on a vessel; therefore the use of COFCs has been increasing steadily. Both applications are used throughout the U.S. with the largest usage found on routes between West Coast ports and Chicago, and between Chicago and New York.

1.2.4 Trailer Fleet Size Relative to the Tractor Fleet

In 2013, over 800,000 trailers were owned by for-hire fleets and almost 300,000 were owned by private fleets. Trailers that are purchased by fleets are typically kept much longer than are the tractors, so trucks and trailers have different purchasing cycles. Also, many trailers are owned by shippers or by leasing companies, not by the trucking fleets. Because of the disconnect between owners and operators, the trailer owners may not benefit directly from fuel consumption and GHG emission reductions.

The industry generally recognizes that the ratio of the number of dry van trailers in the fleet relative to the number of tractors is typically three-to-one.[11] Typically at any one time, two trailers are parked while one is being transported. Certain private fleets may have ratios as high as six-to-one and owner-operators may have a single trailer for their tractor. The ratio of refrigerated vans to tractors is closer to two-to-one. This is partly due to the fact that it is more expensive to purchase and operate refrigerated vans compared to dry vans. Specialty trailers, such as tanks and flatbeds are often attached to a single trailer throughout much of their life. This characteristic of the trailer fleet impacts the cost effectiveness of trailer technologies. The annual savings achieved due to these technologies are proportional to the number of miles traveled in a year and the analysis for many of the trailers must account for some amount of inactivity, which will reduce the benefits.

1.3 Vocational Vehicles: Custom Chassis

Based on public comments, information on entities who have certified, and stakeholder outreach, we have deepened our understanding of the vocational vehicle market, including the nature of specialization vs diversification among vocational vehicle manufacturers. We have identified seven vocations as shown in Table 1-2, for which there are manufacturers who are not diversified in their products competing for sales with diversified manufacturers. We are calling these custom chassis in this rulemaking.

Table 1-2 Diversification of Vocational Chassis Manufacturers[a]

Vehicle Type	Number of Single-type Chassis Manufacturers	Number of Multiple-type Chassis Manufacturers
Coach (Intercity) Bus	2	3
Motor Home	3	8
School Bus	1	2
Transit Bus	4	4
Refuse Truck	1	6
Cement Mixer	2	7
Emergency Vehicle	6	7

Note:
[a] Includes U.S.-made vehicles and those imported for sale in the U.S.

The diversity of vocational vehicles also includes applications such as terminal tractors, street sweepers, concrete pumpers, asphalt blasters, aircraft deicers, sewer cleaners, mobile medical clinics, bookmobiles, and mobile command centers. Most of these are produced by manufacturers of the vehicles listed in Table 1-2, while some are produced by small, specialized companies.

In terms of total production volume, Table 1-3 summarizes what we know about the sales of the seven custom chassis vehicle types. Of the other miscellaneous vehicles, the ones produced in the highest volume are the terminal tractors, at about 6,000 per year (including those certified with nonroad engines), with typical annual miles of less than 10,000 miles per year.[12]

Table 1-3 Custom Chassis Population Estimates

APPLICATION TYPE	PERCENT OF NEW MY 2018 VOCATIONAL POPULATION	AVERAGE VMT IN FIRST YEAR
Coach (Intercity) Bus	1%	85,000
Motor Home	13%	2,000
School Bus	10%	14,000
Transit Bus	1%	64,000
Refuse Truck	3%	34,000
Cement Mixer [b]	1%	20,000
Emergency Vehicle [c]	1%	6,000

Notes:
[a] Source: MOVES 2014 for all except mixer and emergency.[A]
[b] Source for cement mixer is UCS[13]
[c] Source for emergency is ICCT (2009)[14] and FAMA (2004)[15]

[A] Vehicle populations are estimated using MOVES2014. More information on projecting populations in MOVES is available in the following report: USEPA (2015). "Population and Activity of On-road Vehicles in MOVES2014 – Draft Report" Docket No. EPA-HQ-OAR-2014-0827.

References

[1] U.S. EPA and NHTSA, 2011. Regulatory Impact Analysis for the Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium and Heavy-Duty Engines and Vehicles. EPA-420-R-11-901. Available at: http://www3.epa.gov/otaq/climate/documents/420r11901.pdf.
[2] http://www.ttmanet.org.
[3] 49 CFR 565.
[4] "Both Sides of Truck Weight, Size Gear Up for Next Battle." Szakonyi, Mark. February 25, 2014. Available at: http://www.joc.com/regulation-policy/transportation-policy/us-transportation-policy. Accessed: August 18, 2014.
[5] "Wabash Shows What a 33-Foot Pup Would Look Like." Berg, Tom. Heavy-Duty Trucking TruckingInfo.com. March 31, 2014. Available at: www.truckinginfo.com/blog/trailer-talk/story/2014/03/wabash-shows-what-a-33-foot-pup-would-look-like.aspx. Accessed: September 23, 2014.
[6] Per 46 CFR § 340.2.
[7] 19 CFR 115.3.
[8] Trailer-BodyBuliders. North American Trailer Output Report, 2015 Trailer Production Figures Table. Available online at: http://trailer-bodybuilders.com/trailer-output/2015-trailer-production-figures-table.
[9] Dun & Bradstreet. Hoover's Inc. Online Company Database. Available at: http://www.hoovers.com.
[10] U.S. Census Bureau. 2002 Economic Census – Vehicle Inventory and Use Survey. 2002. Available at: https://www.census.gov/prod/ec02/ec02tv-us.pdf.
[11] TIAX. LLC. "Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles," Final Report to the National Academy of Sciences, November 19, 2009. Page 4-49.
[12] See Charged Magazine, 2012 article, https://chargedevs.com/features/find-your-ninche-balqon-corporation-targets-short-haul-drayage-tractors/, accessed April 2016.
[13] National Ready Mixed Association Fleet Benchmarking and Costs Survey, http://www.nxtbook.com/naylor/NRCQ/NRCQ0315/index.php#/22, from UCS Custom Chassis Recommendations, May 2016.
[14] ICCT, May 2009, "Heavy-Duty Vehicle Market Analysis: Vehicle Characteristics & Fuel Use, Manufacturer Market Shares."
[15] Fire Apparatus Manufacturer's Association, Fire Apparatus Duty Cycle White Paper, August 2004, available at http://www.deepriverct.us/firehousestudy/reports/Apparatus-Duty-Cycle.pdf.

Chapter 2: Technology and Cost

2.1 Overview of Technologies

In discussing the potential for CO_2 emission and fuel consumption reductions, it can be helpful to think of the work flow through the system. The initial work input is fuel. Each gallon of fuel has the potential to produce some amount of work and will produce a set amount of CO_2 (about 22 pounds (10 kg) of CO_2 per gallon of diesel fuel). The engine converts the chemical energy in the fuel to useable work to move the truck. Any reductions in work demanded of the engine by the vehicle or improvements in engine fuel conversion efficiency will lead directly to CO_2 emission and fuel consumption reductions.

Current diesel engines are around 40 percent efficient over a range of operating conditions depending on engine sizes and applications, while gasoline engine efficiency is much lower than that of diesel engines. This means that approximately one-third of the fuel's chemical energy is converted to useful work and roughly two-thirds is lost to friction, gas exchange, and waste heat in the coolant and exhaust. In turn, the truck uses this work delivered by the engine to overcome overall vehicle-related losses such as aerodynamic drag, tire rolling resistance, friction in the vehicle driveline, and to provide auxiliary power for components such as air conditioning and lights. Lastly, the vehicle's operation, such as vehicle speed and idle time, affects the amount of total energy required to complete its activity. While it may be intuitive to look first to the engine for CO_2 emission and fuel consumption reductions given that only about one-third of the fuel is converted to useable work, it is important to realize that any improvement in vehicle efficiency proportionally reduces both the work demanded and the energy wasted.

Technology is one pathway to improve heavy-duty truck GHG emissions and fuel consumption. Near-term solutions exist, such as those being deployed by SmartWay partners in heavy-duty truck long haul applications. Other solutions are currently under development and being implemented in the light-duty vehicle segment, especially in the large pickup sector where some of the technologies apply to the heavy-duty pickup trucks covered under this rulemaking. Long-term solutions are currently under development to improve efficiencies and cost-effectiveness. While there is not a "silver bullet" that will significantly eliminate GHG emissions from heavy-duty trucks like the catalytic converter has for criteria pollutant emissions, significant GHG and fuel consumption reductions can be achieved through a combination of engine, vehicle system, and operational technologies.

The following sections will discuss technologies in relation to each of the regulatory categories – Heavy-Duty Pickup Trucks and Vans, Heavy-Duty Engines, Class 7 and 8 Combination Tractors, Trailers, and Class 2b-8 Vocational Vehicles. In each of these sections, information on technological approaches, costs, and percent improvements is provided. Depending on the segment, the vehicle-level technologies available for consideration may include idle reduction, improved tire rolling resistance, improved transmissions, improved axles, weight reduction, improved accessories, and aerodynamic technologies. Depending on the segment, the engine-level technologies available for consideration may include friction reduction, variable valve timing, cylinder deactivation, turbocharging, downsizing, combustion optimization, aftertreatment optimization, and waste heat recovery. The agencies are not projecting that all of the technologies discussed in these sections would be used for compliance with the engine and vehicle standards, for reasons that are also discussed in each section. Nevertheless, the *potential* for there to be technologies other than those which form the basis for the compliance pathway set forth by the agencies, or which can be used in different combinations or penetration rates than that projected compliance pathway, is an important consideration in assessing the feasibility of the standards. Summaries of all of the technologies, along with the corresponding costs, fuel consumption and GHG emissions improvement percentages are provided in this chapter. This chapter also describes the agencies' basis for determining penetration rates for the various technologies for each of the respective regulatory subcategories. Summaries of engine technologies, effectiveness, and costs are provided in Chapters 2.2, 2.3, 2.6, and 2.7. A summary of engine and vehicle technologies, effectiveness, and costs for HD pickup trucks and vans is provided in Chapter 2.5. A summary of technologies, effectiveness, and costs for tractors is provided in Chapter 2.8. A summary of technologies, effectiveness, and costs for vocational vehicles is provided in Chapter 2.9. A summary of technologies, effectiveness, and costs for trailers is provided in Chapter 2.10. A detailed analysis of technology costs is found in Chapters, 2.11 and 2.12.

EPA and NHTSA collected information on the cost and effectiveness of fuel consumption and CO_2 emission reducing technologies from several sources. The primary sources of information were the 2010 National Academy of Sciences report on Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles (NAS)[1], TIAX's assessment of technologies to support the NAS panel report (TIAX)[2], EPA's Heavy-Duty Lumped Parameter Model[3], the analysis conducted by NESCCAF, ICCT, Southwest Research Institute and TIAX for reducing fuel consumption of heavy-duty long haul combination tractors (NESCCAF/ICCT)[4], and the technology cost analysis conducted by ICF for EPA (ICF).[5] In addition, the agencies relied on NHTSA's technology assessment report under contract with SwRI and Tetra Tech.[6,7,8] We also held many meetings with engine and vehicle OEMs and received information from comment to the notice of proposed rulemaking that further informed our decision making process. In addition, the agencies used the vehicle simulation model (the Greenhouse gas Emissions Model or GEM) to quantify the effectiveness of various technologies on CO_2 emission and fuel consumption reductions in terms of vehicle performance. These values were used, in turn, to calculate standard stringency of all standards where GEM is used in determining ultimate compliance. Thus, in all instances where GEM is used for compliance, it was also used in determining standard stringency. The simulation tool is described in RIA Chapter 4 in more detail.

2.2 Technology Principles – SI Engines

The engine technology principles described in this chapter for SI and CI engines are typically described as applying for gasoline and diesel-fueled engines, respectively. Even so, these technology principles generally also apply for engines powered by other fuels, including natural gas. In Section II of the Preamble to these rules, the agencies describe regulatory provisions that differ between SI and CI engines. Technologies related to closed crankcases for natural gas engines are described below in Chapter 2.11 and in the Preamble Section XI.B.2.d. The agencies describe technologies and test procedures related to minimizing evaporative emissions from natural gas fuel systems in Chapter 2.11 as well as in Section XI.B.2.f of the Preamble to these rules. The agencies' approach in this document is to first describe the principles of how technologies can work for an engine, without specifying the type of vehicle into which it will be installed, or the test cycle over which it will be certified. Later, in Chapter 2.5, the agencies describe a subset of these technologies as they apply specifically to complete HD pickup trucks and vans over their applicable operation and test cycles. In Chapter 2.6, the agencies describe a subset of these technologies as they apply to SI engines intended for vocational vehicles. The effectiveness values described in this section are ranges that cover SI and CI engines in general and will differ between vocational vehicles which are engine certified and HD pickup trucks and vans which are chassis certified. The effectiveness ranges represent expected levels of effectiveness with appropriate implementation of the technology but actual effectiveness levels will vary with manufacturer specific design and specifications for the technologies. These may include considerations for durability or other related constraints. The agencies did not receive comments disputing the expected technology effectiveness values reported in the NPRM.

2.2.1 Engine Friction Reduction

In addition to low friction lubricants, manufacturers can reduce friction and improve fuel consumption by improving the design of engine components and subsystems. Examples include improvements in low-tension piston rings, piston skirt design, roller cam followers, improved crankshaft design and bearings, material coatings, material substitution, more optimal thermal management, and piston and cylinder surface treatments. The 2010 NAS Report, NESCCAF[9] and EEA[10] reports as well as confidential manufacturer data used in the both the light-duty and this heavy-duty vehicle rulemaking suggest a range of effectiveness for engine friction reduction to be between 1 to 3 percent. Reduced friction in bearings, valve trains, and the piston-to-liner interface would improve efficiency. Any friction reduction must be carefully developed to avoid issues with durability or performance capability.

2.2.2 Variable Valve Timing

Variable valve timing (VVT) classifies a family of valve-train designs that alter the timing of the intake valve, exhaust valve, or both, primarily to reduce pumping losses, increase specific power, and control the level of residual gases in the cylinder. VVT reduces pumping losses when the engine is lightly loaded by controlling valve timing closer to the optimum needed to sustain horsepower and torque. VVT can also improve volumetric efficiency at higher engine speeds and loads. Additionally, VVT can be used to alter (and optimize) the effective compression ratio where it is advantageous for certain engine operating modes (*e.g.*, in the Atkinson Cycle).

VVT has now become a widely adopted technology in the light duty fleet and this technology is readily adaptable to the heavy-duty fleet: in MY 2014, most of all new cars and light trucks had engines with some method of variable valve timing.[11] There are currently many different types of variable valve timing being utilized by Manufacturers, which have a variety of different names and methods. The three major types of VVT are listed below.

Each implementation of VVT uses a cam phaser to adjust the camshaft angular position relative to the crankshaft position, referred to as "camshaft phasing." This phase adjustment results in changes to the pumping work required by the engine to accomplish the gas exchange process. The majority of current cam phaser applications use hydraulically-actuated units, powered by engine oil pressure and managed by a solenoid that controls the oil pressure supplied to the phaser.

2.2.2.1 Coupled Cam Phasing for Overhead Valve (OHV) and Single Overhead Camshaft (SOHC) Engines

Valvetrains with coupled (or coordinated) cam phasing (CCP) can modify the timing of both the inlet valves and the exhaust valves an equal amount by varying the phasing of the camshaft across an engine's range of operating speeds; also known as VVT. For engines configured as an overhead valve (OHV) or as a single overhead camshaft (SOHC) only one cam phaser is required per camshaft to achieve CCP.

Based on the heavy-duty Phase 1 vehicle rulemaking, 2015 NHTSA Technology Study, and previously-received confidential manufacturer data, the agencies estimate the fuel consumption reduction effectiveness of this technology to be between 1 and 3 percent for heavy-duty applications across the different test cycles and operational opportunities.

2.2.2.2 Intake Cam Phasing (ICP) for Dual Overhead Camshaft Engines (DOHC)

Valvetrains with ICP, which is the simplest of the cam phasing technologies, can modify the timing of the inlet valves by phasing the intake camshaft while the exhaust valve timing remains fixed. This requires the addition of a cam phaser on each bank of intake valves on the engine. An in-line 4-cylinder engine has one bank of intake valves, while V-configured engines have two banks of intake valves.

Some newer Class 2b and 3 market entries are offering dual overhead camshaft (DOHC) engine designs where two camshafts are used to operate the intake and exhaust valves independently. Consistent with the heavy-duty 2014-2018 MY vehicle rulemaking and the SwRI report, the agencies agree with the effectiveness values of 1 to 2 percent reduction in fuel consumption for heavy-duty applications across the different test cycles and operational opportunities, for this technology.

2.2.2.3 Dual Cam Phasing (DCP) for Dual Overhead Camshaft Engines (DOHC)

The most flexible VVT design is dual (independent) cam phasing, where the intake and exhaust valve opening and closing events are controlled independently. This option allows the option of controlling valve overlap, which can be used as an internal EGR strategy. At low engine loads, DCP creates a reduction in pumping losses, resulting in improved fuel consumption. Increased internal EGR also results in lower engine-out NO_X emissions. The amount by which fuel consumption is improved depends on the residual tolerance of the combustion system. Additional improvements are observed at idle, where low valve overlap may result in improved combustion stability, potentially reducing idle fuel consumption. DCP requires two cam phasers on each bank of the engine.

Some newer Class 2b and 3 market entries are offering dual overhead camshaft (DOHC) engine designs where two camshafts are used to operate the intake and exhaust valves independently. Consistent with the light-duty 2012-2016 MY vehicle rulemaking and the SwRI report, the agencies agree with the effectiveness values of 1 to 3 percent reduction in fuel consumption for heavy-duty applications across the different test cycles and operational opportunities for this technology.

2.2.2.4 Variable Valve Lift (VVL)

Controlling the lift of the valves provides a potential for further efficiency improvements. By optimizing the valve-lift profile for specific engine operating regions, the pumping losses can be reduced by reducing the amount of throttling required to produce the desired engine power output. By moving the throttling losses further downstream of the throttle valve, the heat transfer losses that occur from the throttling process are directed into the fresh charge-air mixture just prior to compression, delaying the onset of knock-limited combustion processes. Variable valve lift control can also be used to induce in-cylinder mixture motion, which improves fuel-air mixing and can result in improved thermodynamic efficiency. Variable valve lift control can also potentially reduce overall valvetrain friction. At the same time, such systems may also incur increased parasitic losses associated with their actuation mechanisms. A number of manufacturers have already implemented VVL into their fleets (Toyota, Honda, and BMW), but overall this technology is still available for most of the fleet. There are two major classifications of variable valve lift, described below:

2.2.2.5 Discrete Variable Valve Lift (DVVL)

Discrete variable valve lift (DVVL) systems allow the selection between two or three discrete cam profiles by means of a hydraulically-actuated mechanical system. By optimizing the cam profile for specific engine operating regions, the pumping losses can be reduced by reducing the amount of throttling required to produce the desired engine power output. This increases the efficiency of the engine. These cam profiles consist of a low and a high-lift lobe, and may include an inert or blank lobe to incorporate cylinder deactivation (in the case of a 3-step DVVL system). DVVL is normally applied together with VVT control. DVVL is also known as Cam Profile Switching (CPS). DVVL is a mature technology in LD applications with low technical risk.

Based on the light-duty MY 2017-2025 final rule, previously-received confidential manufacturer data, 2015 NHTSA Technology Study, and report from the Northeast States Center for a Clean Air Future (NESCCAF), the agencies estimate the fuel consumption reduction effectiveness of this technology to be between 1 and 3 percent for heavy-duty applications across the different test cycles and operational opportunities.

2.2.3 Cylinder Deactivation

In conventional spark-ignited engines throttling the airflow controls engine torque output. At partial loads, efficiency can be improved by using cylinder deactivation instead of throttling. Cylinder deactivation can improve engine efficiency by disabling or deactivating (usually) half of the cylinders when the load is less than half of the engine's total torque capability – the valves are kept closed, and no fuel is injected – as a result, the trapped air within the deactivated cylinders is simply compressed and expanded as an air spring, with reduced friction and heat losses. The active cylinders combust at almost double the load required if all of the cylinders were operating. Pumping losses are significantly reduced as long as the engine is operated in this “part cylinder” mode. Effectiveness improvements scale roughly with engine displacement-to-vehicle weight ratio: the higher displacement-to-weight vehicles, operating at lower relative loads for normal driving, have the potential to operate in part-cylinder mode more frequently. Cylinder deactivation is less effective on heavily-loaded vehicles because they require more power and spend less time in areas of operation where only partial power is required. The technology also requires proper integration into the vehicles which is difficult in the vocational vehicle segment where often the engine is sold to a chassis manufacturer or body builder without knowing the type of transmission or axle used in the vehicle or the precise duty cycle of the vehicle. The cylinder deactivation requires fine tuning of the calibration as the engine moves into and out of deactivation mode to achieve acceptable NVH. Additionally, cylinder deactivation would be difficult to apply to vehicles with a manual transmission because it requires careful gear change control. NHTSA and EPA adjusted the 2017-2025 MY light-duty rule estimates using updated power to weight ratings of heavy-duty trucks and confidential business information and downwardly adjusted the effectiveness to 0 to 3 percent over average driving patterns for these vehicles to reflect the differences in drive cycle and operational opportunities compared to light-duty vehicles.

2.2.4 Stoichiometric Gasoline Direct Injection (SGDI)

Stoichiometric gasoline direct injection (SGDI) engines inject fuel at high pressure directly into the combustion chamber (rather than into the intake port in port fuel injection). SGDI requires changes to the injector design, an additional high pressure fuel pump, new fuel rails to handle the higher fuel pressures, and changes to the cylinder head and piston crown design. Direct injection of the fuel into the cylinder improves cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency without the onset of combustion knock. Recent injector design advances, improved electronic engine management systems and the introduction of multiple injection events per cylinder firing cycle promote better mixing of the air and fuel, enhance combustion rates, increase residual exhaust gas tolerance, and improve cold start emissions. SGDI engines achieve higher power density and match well with other technologies, such as boosting and variable valvetrain designs.

Several manufacturers have recently introduced vehicles with SGDI engines, including GM and Ford, who have announced their plans to increase dramatically the number of SGDI engines in their vehicle portfolios.

Based on the heavy-duty 2014-2018 MY vehicle rulemaking, the 2015 NHTSA Technology Study, and previously-received confidential manufacturer data, the agencies estimate the fuel consumption reduction effectiveness of SGDI to be between 1 and 2 percent for heavy-duty applications across the different test cycles and operational opportunities.

2.2.5 Turbocharging and Downsizing (TRBDS)

The specific power of a naturally aspirated engine is primarily limited by the rate at which the engine is able to draw air into the combustion chambers. Turbocharging and supercharging (grouped together here as boosting) are two methods to increase the intake manifold pressure and cylinder charge-air mass above naturally aspirated levels. Boosting increases the airflow into the engine, thus increasing the specific power level, and with it the ability to reduce engine displacement while maintaining performance. This effectively reduces the pumping losses at lighter loads in comparison to a larger, naturally aspirated engine.

Almost every major manufacturer offering both light-duty and heavy-duty vehicles, including 2b/3s, currently markets vehicles in their light-duty offerings with some form of boosting. Only one manufacturer, Ford, has allowed the light-duty derived boosted engine to migrate into its 2b/3 van offering. The ability to use a smaller boosted engine is currently limited to applications where operational duty cycles are more consistent with light-duty vehicles of similar utility like full size pick-ups and MDPVs. The Ford 2b/3 van has similar capability as the light-duty pick-up from which the boosted engine is borrowed. In applications that require high payload or towing capacity that substantially exceeds the light-duty ranges of towing capacity, manufacturers have chosen to maintain the larger displacement non-boosted engines because of the boosted engine's loss of effectiveness when performing towing. In their comments, AAPC illustrated this issue showing that downsized and boosted engines actually perform worse from a brake specific fuel consumption perspective when encountering high loads, such as towing, than a traditional non-boosted engine of more historical displacements. Class 4 and higher vocational vehicles have not employed any form of boosted and downsized engines because of this penalty. In our projected compliance pathways for pickups and vans, the agencies are projecting use of a smaller boosted engine only where suited to a 2b/3 vehicle's duty cycles – reflecting current industry practice. This approach properly targets GHG and fuel consumption reductions to the expected vehicle duty cycles and provides a balance based on the consumer's requirements of their work vehicle.

While boosting has been a common practice for increasing performance for several decades in light-duty vehicles, turbocharging has considerable potential to improve fuel economy and reduce CO_2 emissions when the engine displacement is also reduced. Specific power levels for a boosted engine often exceed 100 hp/L, compared to average naturally aspirated engine power densities of roughly 70 hp/L. As a result, engines can be downsized roughly 30 percent or higher while maintaining similar peak output levels. However, as just discussed above, the effectiveness of boosted and downsized engines is a function of duty cycle and may not be appropriate for some applications encountering regular high loads such as towing. In the last decade, improvements to turbocharger turbine and compressor design have improved their reliability and performance across the entire heavy-duty engine operating range. New variable geometry turbines and ball-bearing center cartridges allow faster turbocharger spool-up (virtually eliminating the once-common "turbo lag") while maintaining high flow rates for increased boost at high engine speeds. Low speed torque output has been dramatically improved for modern turbocharged engines. However, even with turbocharger improvements, maximum engine torque at very low engine speed conditions, for example launch from standstill, is increased less than at mid and high engine speed conditions. The potential to downsize engines may be less on vehicles with low displacement to vehicle mass ratios, for example, a very small displacement engine in a vehicle with significant curb weight, cargo weight or towing, in order to provide adequate acceleration from standstill, particularly up grades or at high altitudes.

Use of gasoline direct injection (GDI) systems with turbocharged engines and charge air cooling also reduces the fuel octane requirements for knock limited combustion and allows the use of higher compression ratios. Ford's "EcoBoost" downsized, turbocharged GDI engines introduced on MY 2010 light-duty vehicles allow the replacement of V8 engines with V6 engines with improved 0-60 mph acceleration and with fuel economy improvements of up to 12 percent as documented in their technical paper.[12]

Recently published data with advanced spray-guided injection systems and more aggressive engine downsizing targeted towards reduced fuel consumption and CO_2 emissions reductions indicate that the potential for reducing CO_2 emissions for turbocharged, downsized GDI engines may be as much as 15 to 30 percent relative to port-fuel-injected engines. Confidential manufacturer data suggest an incremental range of fuel consumption and CO_2 emission reduction of 4.8 to 7.5 percent for turbocharging and downsizing. Other publicly-available sources suggest a fuel consumption and CO_2 emission reduction of 8 to 13 percent compared to current-production naturally-aspirated engines without friction reduction or other fuel economy technologies: a joint technical paper by Bosch and Ricardo suggesting fuel economy gain of 8 to 10 percent for downsizing from a 5.7 liter port injection V8 to a 3.6 liter V6 with direct injection using a wall-guided direct injection system;[13] a Renault report suggesting a 11.9 percent NEDC fuel consumption gain for downsizing from a 1.4 liter port injection in-line 4-cylinder engine to a 1.0 liter in-line 4-cylinder engine, also with wall-guided direct injection;[14] and a Robert Bosch paper suggesting a 13 percent NEDC gain for downsizing to a turbocharged DI engine, again with wall-guided injection.[15] These reported fuel economy benefits show a wide range depending on the SGDI technology employed and the use of these technologies are directly applicable to heavy-duty SI engines.

The agencies reviewed estimates from the 2017-2025 final light-duty rule, the TSD, and existing public literature. The previous estimate from the MYs 2017-2025 suggested a 12 to 14 percent effectiveness improvement, which included low friction lubricant (level one), engine friction reduction (level one), DCP, DVVL and SGDI, over baseline fixed-valve engines, similar to the estimate for Ford's EcoBoost engine, which is already in production in light-duty and . Additionally, the agencies analyzed Ricardo vehicle simulation data and the 2015 NHTSA Technology Study for various turbocharged engine packages.

2.2.6 Engine Down Speeding

In general, engine down speeding has been determined to reduce frictional losses and also reduce the need for component temperature protection in SI engines. Component protection occurs at higher engine speeds and loads where components such as exhaust valves, exhaust manifolds, catalysts and other components in the exhaust system reach temperatures where materials may require cooling to prevent damage or reduced durability and accelerated deterioration. The SI engine has various methods of accomplishing this protection requirement including using additional fuel enrichment to act as a coolant in the exhaust. Other methods to reduce exhaust component temperatures include reducing engine output such as torque governing through variable valve timing, limiting boost in boosted engines or simply reducing air flow into the engine by commanding the electronic throttle to a smaller percentage opening thereby reducing available air volume.

In the case of chassis certified pick-ups and vans, down speeding is generally achieved by managing the transmission gear selection in electronically controlled automatic transmissions. It is largely contained in the transmission technology description in Chapter 2.5 below. There is typically no incentive to implement additional strategies for limiting engine speed as described above as they are not quantified in the test cycles and may require a reduction in advertised rated engine power which can become a competitive disadvantage.

Vocational vehicles which use SI engines certified to GHG and criteria emissions over the FTP engine dyno cycle can capture the benefits of down speeding more favorably. Since FTP engine certification is based on a test method that first quantifies the total available engine power from idle to the electronically governed engine top speed or rev limiter, the opportunity exists to shift the entire engine operation down to lower engine speeds where frictional losses are lower and need for temperature protection is reduced. This strategy will generally require the engine manufacturer to reduce peak power and engine speed rating of the engine. This strategy has not been used in past SI engine certifications so little information exists about its effectiveness but the expected range of effectiveness is 0 to 4 percent depending on the aggressiveness of the down speeding.

2.3 Technology Principles – CI Engines

In this section, technology principles for CI engines will be discussed. Although most technologies discussed here, with the exception of engine downsizing, down speeding, and WHR with Rankine cycle technology were considered by the agencies as potentially available for compliance with the Phase 1 engine standards, the level of improvement and complexity are different for Phase 2. It should be mentioned that the technologies discussed here are for compression ignition diesel engines and are not interchangeable with technologies used for spark ignition engines. See the spark ignition engine discussion in Chapter 2.2 Technology Principles – SI Engines.

2.3.1 Low Temperature Exhaust Gas Recirculation

Most LHDD, MHDD, and HHDD engines sold in the U.S. market today use cooled EGR, in which part of the exhaust gas is routed through a cooler (rejecting energy to the engine coolant) before being returned to the engine intake manifold. EGR is a technology employed to reduce peak combustion temperatures and thus NO_X. Low-temperature EGR uses a larger or secondary EGR cooler to achieve lower intake charge temperatures, which tend to further reduce NO_X formation. For a given NO_X requirement, low-temperature EGR can allow changes such as more advanced injection timing that would increase engine efficiency slightly more than one percent. Because low-temperature EGR reduces the engine’s exhaust temperature, it has not been considered as part of a technology package that also includes exhaust energy recovery systems such as turbocompounding or a bottoming cycle.

2.3.2 Combustion System Optimization

Improvements in the fuel injection system allow more flexible fuel injection capability with higher injection pressure and can improve engine fuel efficiency, while maintaining the same emission level. Combustion system optimization, featuring piston bowl, injector tip and the number of holes, in conjunction with the advanced fuel injection system, is able to further improve engine performance and fuel efficiency. Manufacturers have been working to improve engines in these areas for some time. At this point, all engine manufacturers have substantial development efforts underway that we project will be translated into production in the near future. Some examples include the combustion development programs conducted by Cummins[16], Detroit Diesel[17], and Navistar[18] funded by Department of Energy as part of the SuperTruck program. These manufacturers found that improvement due to combustion alone during this program was 1 to 2 percent. While their findings are still more focused on the research end of development, specifically targeting one optimal operating point, the results of these research programs do support the possibility that some of the technologies they are developing could be applied to production engines in the 2027 time frame. The agencies have determined that it is feasible that fuel consumption and CO_2 emissions could be reduced by as much as 1.0 percent in the agencies' certification cycles in the 2027 time frame through the use of these technologies.

Some technologies were evaluated but not included in the agencies' technical feasibility analysis for the Phase 2 regulation since the agencies do not anticipate these technologies will be commercially available by 2027. For example, alternative combustion processes such as homogeneous charge compression ignition (HCCI), premixed charge compression ignition (PCCI), low-temperature combustion (LTI), and reactivity controlled compression ignition (RCCI) technologies were not included in the agencies' feasibility analysis for Phase 2. While these technologies show good indicated thermal efficiency, fuel savings over the entire range of engine operation is still a major challenge. At the current level of development it is not clear that the technologies will be in commercial production by 2027. This, however, does not preclude the use of these technologies for compliance should manufacturers develop and commercialize these alternative combustion or other approaches.

2.3.3 Model Based Control

Another important area of potential improvement is advanced engine control incorporating model based calibration to reduce losses of control during transient operation. Improvements in computing power and speed would make it possible to use much more sophisticated algorithms that are more predictive than today's controls. Because such controls are only beneficial during transient operation, they would reduce emissions over the Federal Test Procedure (FTP) cycle, but not over the Supplemental Emission Test (SET) cycle. Detroit Diesel introduced the next generation model based control concept, achieving 4 percent thermal efficiency improvement while simultaneously reducing emissions in transient operations in their earlier report.[19] More recently, this model based control technology was put into their one of vehicles for final demonstration under DOE's SuperTruck program.[20] Their model based concept features a series of real time optimizers with multiple inputs and multiple outputs. This controller contains many physical based models for engine and aftertreatment. It produces fully transient engine performance and emissions predictions in a real-time manner. Although we do not project that this control concept would be in MY 2017 production, real time model control could be in production during the Phase 2 time frame, thus significantly improving engine fuel economy.

2.3.4 Turbocharging System

Many advanced turbocharger technologies can be added into production in the time frame between MYs 2021 and 2027 and some of them are already in production, such as mechanical or electric turbocompound, more efficiency variable geometry turbine, and Detroit Diesel's patented asymmetric turbocharger. A turbocompound system extracts energy from the exhaust to provide additional power. Mechanical turbocompounding includes a power turbine located downstream of the turbine which in turn is connected to the crankshaft to supply additional power. On-highway demonstrations of this technology began in the early 1980s. It has been first used in heavy duty production by Detroit Diesel for their DD15 and DD16 engines. That company claims a 3 to 5 percent fuel consumption reduction due to the system.[21] Results are duty cycle dependent, and require significant time at high load to see a fuel efficiency improvement. Light load factor vehicles can expect little or no benefit. Volvo reports two to four percent fuel consumption improvement in line haul applications, which would be likely in production even before 2020.[22]

Electric turbo-compound is another potential technology that can improve engine brake efficiency. Efficiencies are attained through better vehicle integration and lower backpressure impacts. Since the electric power turbine speed is no longer linked to crankshaft speed, this allows more efficient operation of the turbine. Navistar reports on the order of a 1 to 1.6 percent efficiency improvement over mechanical turbocompound systems at 0.5 to 0.7 gm/hp-hr engine-out NO_X levels.[23,24] This concept, however, does not work well with lower engine out NO_X as indicated in the report, as zero benefit is reported at 0.3 to 0.4 gm/hp-hr engine-out NO_X, due to lower exhaust gas temperatures. Navistar reports a 1.6 percent fuel efficiency improvement, again as compared to a mechanical turbocompound system.

Two-stage turbocharger technology has been used in production by Navistar and other manufacturers. Ford's new developed 6.7L diesel engine features a twin-compressor turbocharger. Higher boost with wider range of operations and higher efficiency can further enhance engine performance, thus fuel economy. It is expected that this type of technology will continue to be improved by better matching with system and developing higher compressor and turbine efficiency.

Furthermore, improved turbocharger efficiency when combined with turbocompounding was shown in the SwRI study to reduce fuel consumption while maintaining criteria emissions limits. Findings show that there is limited scope for improved turbocharger efficiency on engines which do not use turbocompound, because an increase in turbocharger efficiency would result in reduced or eliminated EGR flow which in turn would cause the engine to exceed NO_x emissions requirements.

2.3.5 Engine Breathing System

Various high efficiency air handling (air and exhaust transport) processes could be produced for heavy duty applications in the Phase 2 time frame. To maximize the efficiency of such processes, induction systems may be improved by manufacturing more efficiently designed flow paths (including those associated with air cleaners, chambers, conduit, mass air flow sensors and intake manifolds) and by designing such systems for improved thermal control. Improved turbocharging and air handling systems must include higher efficiency EGR systems and intercoolers that reduce frictional pressure loss while maximizing the ability to thermally control induction air and EGR. EGR systems that often rely upon an adverse pressure gradient (exhaust manifold pressures greater than intake manifold pressures) must be reconsidered and their adverse pressure gradients minimized. "Hybrid" EGR strategies which rely upon pressure gradients and EGR pumps may provide pathways for improvement. Other components that offer opportunities for improved flow efficiency include cylinder heads, ports and exhaust manifolds to further reduce pumping losses. Cummins reports 1.4 percent through optimization.[25] Detroit Diesel projects a 2 percent fuel efficiency improvement through air handling system development.[26] Navistar predicts almost 4 percent through a combination of variable intake valve closing timing (IVC), turbocharger efficiency and match improvements. A few plots in this reference show another 4 percent, but these are not explained.

Variable air breathing systems such as variable valve actuation may provide additional gains at different loads and speeds. The primary gain in diesel engines is achieved by varying the EVO event versus engine speed and load, in conjunction with turbocharger optimization to minimize blowdown losses. Navistar reports a 1.25 percent fuel consumption improvement.[23] Again, all these reference points are referred to a single optimal point from the DOE SuperTruck program.

2.3.6 Engine Parasitic and Friction Reduction

Engine parasitic and friction reduction is another key technical area that can be further improved in the 2020 to 2027 time frame. Reduced friction in bearings, valve trains, and the piston-to-liner interface can improve efficiency. Friction reduction opportunities in the engine valve train and at its roller/tappet interfaces exist for several production engines. The piston at its skirt/cylinder wall interface, wrist pin and oil ring/cylinder wall interface offers opportunities for friction reduction. Use of more advanced lubricating oil that will be available in the future will also play a key role in reducing friction. Any friction reduction must be carefully developed to avoid issues with durability or performance capability. Lube oil and water pumps as well are another area where efficiency improvements will occur. Navistar identifies a combined improvement of up to 2 percent through reduced bearing friction, reduced piston and ring friction, and unspecified lube oil pump improvements.[27] In their 2012 paper they report 5.5 percent improvement through a combination of friction reduction and both lube and cooling system improvements.[23] In this same presentation they specified 0.45 percent demonstrated through water pump improvements and 0.3 percent through lube pump improvements. The total number of 5.5 percent remains optimistic, even for a single optimal test point. Cummins reports a combined number of 3 percent.[25]. Detroit Diesel reports a combined number of 2 percent, with 0.5 percent coming from improved water pump efficiency.[26] Navistar shows a 0.9 percent benefit for a variable speed water pump and variable displacement oil pump; 0.5 percent for piston/ring/liner friction reduction; and 0.6 percent for bearing friction reduction[23]. In addition, Federal-Mogul recently announced new piston ring coatings that can lead to a 20 percent reduction in engine friction, and, in looking to the future, sees an opportunity to reduce friction by an additional 30 percent, which is equivalent to a 1.2 percent reduction in brake specific fuel consumption at road load conditions.[28] It should be noted that water pump improvements include both pump efficiency improvement and variable speed or on/off controls. Lube pump improvements are primarily achieved using variable displacement pumps and may also include efficiency improvement. All of the results shown in this paragraph are demonstrated through DOE's SuperTruck program under a single optimal operating point, which has not been changed since the proposal.

In addition, SwRI's reports show that if the exact certification cycles, weighting and vehicle weights are used, the friction reduction in the Phase 2 timeframe is in the range of 1.47 percent compared to a 2018 baseline engine.[7]

2.3.7 Integrated Aftertreatment System

All manufacturers now use diesel particulate filters (DPF) to reduce particulate matter (PM) and SCR to reduce NO_X emissions, and these types of technologies are likely to be used for compliance with criteria pollutant standards for many years to come. There are three areas considered to improve integrated aftertreament systems, which result in a reduction of fuel consumption. The first is better combustion system optimization through increased aftertreatment efficiency. The second is reduced backpressure through further development of the devices themselves. The third is reduced ammonia slip out of SCR during transient operation, thus reducing net urea consumption. Navistar reports a 7 to 8 percent improvement in efficiency projected through a combination of higher cylinder pressure, injection optimization, and engine/aftertreatment optimization.[23] Cummins reports a 0.5 percent improvement through improved aftertreatment flow (catalyst size optimization and improved NO_X surface utilization).[25] Detroit Diesel projects a 2 percent fuel efficiency improvement through reduced use of EGR, thinner wall DPF, improved SCR cell density, and catalyst material optimization.[26]

2.3.8 Engine Downsizing and Down Speeding

Engine downsizing can be more effective if it is combined with down speeding which leads to increased vehicle efficiency through lower power demand. This lower power demand shifts the vehicle operating points to lower load zones, which moves the engine away from some of the optimum operation points. In order to compensate for this loss, down speeding allows the engine to move back into the optimum operating points resulting in reduced fuel consumption. Increasing power density by reducing the engine size allows the vehicle operating points to move back to the optimum operating points, thus further improving fuel economy. Both Detroit Diesel and Volvo demonstrate the same methodology for proper implementation of downsizing [29,30] Detroit Diesel also shows that engine downsizing can result in friction reduction due to a reduction in engine surface area when compared to a bigger bore engine.[26]

Engine down speeding can also be an effective fuel efficiency technology even when used alone (i.e. not in combination with engine downsizing), especially when a vehicle uses a fast axle ratio. Down speeding, in this situation, can allow the engine to operate in a lower speed zone that is closer to or just in the middle of engine sweet spot, which is typically in the speed range of 1100-1200 rpm for a heavy duty engine. In order to take advantage of a fast or low axle ratio, the engine must be optimized toward the low speed zone by either generating higher peak torque in the lower speed zone or shifting the entire rating speed into a lower rating, or a combination thereof. The engine air handling and combustion system, as a result of these changes, must be re-optimized to accommodate a typical higher peak cylinder pressure rise. Depending on how the engine system is optimized, the overall engine fuel consumption can be improved. However, from an engine certification standard point, such as the 13-mode SET cycle, down speeding is always accompanied by moving mode speeds to a lower speed zone, which usually take advantage of the sweet spot, thus making the engine more efficient in terms of the certification cycle. On the other hand, from a vehicle operating standard point, the benefit of down speeding is primarily realized through the use of a lower axle ratio, allowing the engine to operate in an optimal zone.

2.3.9 Waste Heat Recovery

Organic Rankine Cycle waste heat recovery (WHR) systems have been studied for many years. The agencies' overall assessment of WHR as a fuel saving technology is that it offers great promise in the long term. However, it would take several years to develop, and initially, it would be viable primarily in line-haul applications. The agencies recognize the many challenges that would need to be overcome, but believe with enough time and development effort, this can be done. We have received a large number of comments from the both the NPRM and NODA that yield two differing opinions. Most vehicle and engine manufacturers, with one exception, objected to the purportedly aggressive technology penetration rate reflected in the proposed engine standards. They argued that the WHR systems in the literature and utilized in the DOE SuperTruck program are still in the research and development stage, and these systems are still a long way off with respect to reaching production. Their voiced concern is that bringing this technology to market before it is ready could lead to high warranty costs and reliability issues, leading to significant down time for vehicles or fleets, possibly even beyond 2027. One engine manufacturer, however, indicated that WHR systems could be used in a production setting as early as the MY 2021 to 2027 time frame because their WHR system is approaching the prototype stage of development, with projected small market penetration starting in 2021.

The basic approach of a WHR system is to use engine exhaust waste heat from multiple sources to evaporate a working fluid in a heat exchanger. This evaporated fluid is then passed through a turbine or equivalent expander to create mechanical or electrical power. The working fluid is then condensed back to the fluid in the fluid reservoir tank and returned back to the flow circuit via a pump to restart the cycle. With support of the Department of Energy, three major engine and vehicle manufacturers have developed WHR systems under the SuperTruck program. Cummins' WHR system is based on an organic Rankine cycle using refrigerant as the working fluid.[31,32] Their system recovers heat from the EGR cooler, as well as from the exhaust gas downstream of the aftertreatment system. It converts that heat to power through a mechanical gear train coupled to the engine's output shaft. Some iterations of their system also sought gains from low-temperature coolant and lubricant heat rejection via a parallel loop. The system includes a recuperator that transfers post-turbine energy back into the working fluid loop prior to the condenser. This recuperator reduces condenser heat rejection requirements and improves overall system efficiency. Volvo has developed a similar system to Cummins' with variations in terms of hardware components, including the use of ethanol as the working fluid instead of a refrigerant.[33] Daimler, on the other hand, has developed a different type of ethanol based system to recover heat from the exhaust gas using an electrical generator to provide power to charge a high-voltage battery that is primarily used to drive a hybrid system.

Pre-prototype WHR systems have been shown to be very efficient under optimized conditions. In demonstrations where operation occurred at a single optimal engine operating point, Cummins reported potential efficiency gains from WHR on the order of 2.8 percent from the baseline engine without WHR[31], Volvo reported around 2.5 percent[33], and Daimler reported 2.3 percent.[29] It is important to note that all of these WHR systems are still in the pre-prototype stage of research and development. Despite the promising performance of pre-prototype WHR systems, the cost and complexity of these packages from Cummins, Volvo and Daimler remain high. The agencies believe that manufacturers will continue to make improvements to these systems over time, just as they have for other advanced technologies that initially had high cost and complexity at a comparable stage of development.

WHR technology also poses issues with respect to package size and transient response. The agencies believe that WHR will be less effective in urban traffic and will most likely be applied to line haul vehicles. Our projected technology paths for compliance, and projected technology penetration rates, reflect this assumption.

WHR may offer the benefit of replacing the EGR cooler and decrease cooling system heat rejection requirements by converting some heat into work. To the extent that WHR systems use exhaust heat, they may increase the overall cooling system heat rejection requirement, thus increasing radiator size, which can have a negative impact on cooling fan power needs, as well as on vehicle aerodynamics. Significant challenges could arise if the space under a vehicle's hood happens to be tight, leaving little or no room for a larger radiator, thus necessitating a redesign of the vehicle's front face, sacrificing potential aerodynamic improvements. This issue becomes more challenging for truck cooling systems that are currently at cooling capacity design limits.

Current WHR systems are heavy, estimated to be on the order of 300-500 lbs depending on system design. Without time to optimize designs, any attempt to reduce weight by simply reducing the size of the key components, such as boilers and condensers, would likely have an adverse impact on the system efficiency. Given enough lead time, the agencies believe manufacturers might be able to improve materials and designs to reduce overall system weight without compromising efficiency.

Manufacturers have not yet arrived at a consensus on which working fluid(s) will be used in WHR systems to balance concerns regarding performance, global warming potential (GWP), and safety. Current working fluids have a high GWP (conventional refrigerant), are expensive (low GWP refrigerant), are hazardous (ammonia, etc.), are flammable (ethanol/methanol), or can freeze (water). One of the challenges is determining how to seal the working fluid properly under vacuum conditions with high temperature to avoid safety issues for flammable/hazardous working fluids. Addressing leaks would also be an important issue with respect to greenhouse gas emission for a high GWP working fluid. Because of these challenges, choice of working fluid will be an important factor for system safety, efficiency, and overall production viability.

Other key challenges facing WHR systems are their reliability, durability, and market acceptance. Durability concerns that have been raised include: boiler fouling and cracking associated with high thermal gradients, thermal shock, condenser fouling, as well as sensor and actuator durability under harsh temperature and pressure conditions. It can be reasonably estimated that the current WHR systems under development by major engine manufacturers consist of at least two hundred parts including expanders, boilers, condensers, and fluid pumps, together with many fasteners, wiring cables, sensors, actuators, and piping. Determining overall system efficacy and reliability involves rigorous testing in support of comprehensive Failure Modes and Effects Analysis (FEMA). These parts, as well as the entire WHR system as a whole, must undergo severe winter and summer tests. Multiple trucks equipped with the same WHR system must be run on the road, accumulating millions of miles. During these tests, all failures must be recorded, associated with specific failure modes or error codes, and the root cause of the failure must be determined. Warranty costs for each failure mode based on component cost and labor must be assigned. Due to the large number of components, some of the failure modes might not be identified during the road tests even with multiple occurrences. It would be a high risk for any manufacturer to put their new technology into the market without careful system validation via on-the-road tests. Similarly, owners and operators might be unlikely to risk early adoption of such a complex technology if premature deployment leads to potential down time, along with its associated cost.

Based on the literature and preceding discussion, WHR technology can be characterized as being in the technology demonstration stage for purposes such as the DOE SuperTruck program. It should be clear that the demonstration defined by DOE SuperTruck program means that the demonstrated truck with the technologies developed under the DOE program can be successfully run through a pre-specific routes, and it doesn't mean that technologies used in the truck reach any matured stage or prototype stage, regardless of cost. Although a few trucks with WHR technology have been tested on the road,[33,34,35] many of the components used in the trucks and product-acceptable packaging are still years away from production. Figure 2-1 shows a generic form of the product process flow. As can be seen from this figure, it could take 5-15 years from the applied research/development stage to arrive at the prototype stage depending on the complexity of the technology. WHR is now in that prototype stage. During the prototype stage, all prototype components must be available and extensive engine and vehicle tests with WHR must be conducted. The production start-up phase would follow. After that, significant efforts must be made to advance the system from a prototype to a commercial product, which typically takes about five years for complex systems like WHR. During this approximate five-year period, multiple vehicles will go through weather condition tests, long lead-time parts and tools will be identified, and market launch and initial results on operating stability will be completed. Production designs will be released, all product components should be made available, production parts on customer fleets and weather road testing will be verified before finally launching production, and distribution of parts to the vehicle service network for maintenance and repair will be readied.

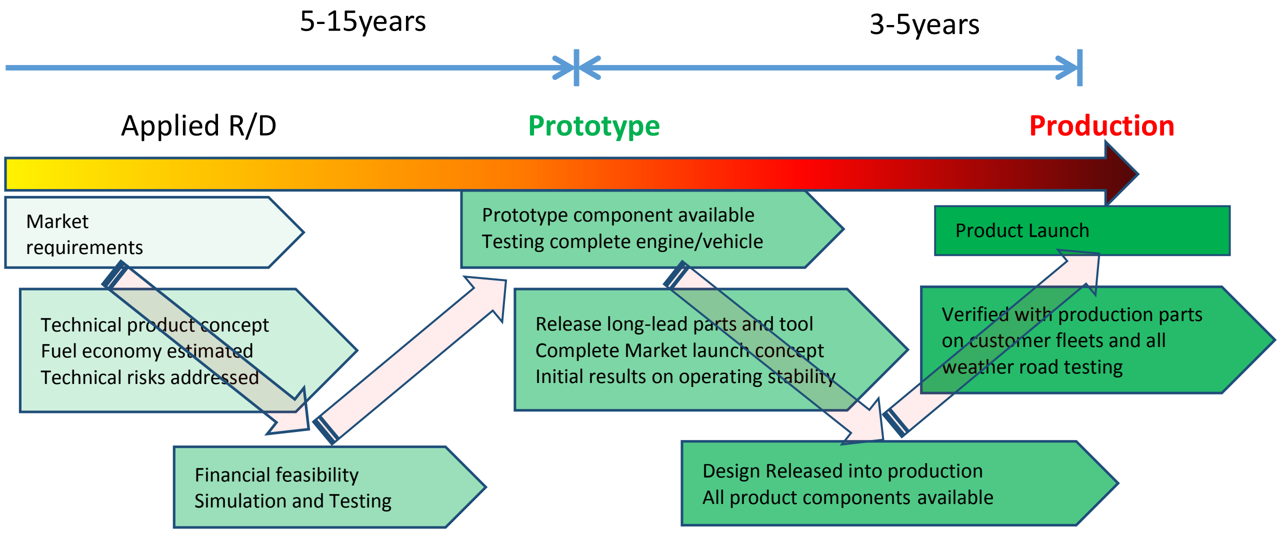


Figure 2-1 Product Process Flow

The GHG standards themselves can provide an effective incentive for manufacturers to reach the commercial product stage earlier than would otherwise occur. They can motivate manufacturers to shorten the period for advancing from a complicated prototype system to a commercial product and can also help to ensure market penetration after launching a product. Nevertheless, in order for WHR to be produced commercially, several things are needed. First, it is critical to optimize the WHR package volume, cooling capability, and aero drag at typical cruise speeds on highway since the most significant benefits of WHR technology would be in line-haul applications. Removal of the exhaust heat exchangers located in the exhaust system would reduce the total system volume and weight. Working fluids need to be selected with a reasonably low GWP and high performance potential. In addition, the engine with a WHR system needs to be continuously tested in a very well equipped engine dynamometer. This allows to continue optimization in a system level as well as identification of issues associated with reliability. On top of that, the component bench tests, such as individual components like heat exchangers, condenser, and expander need to be extensively conducted through a series of durability and performance test protocols for accumulated thousands of hours, thus identifying any potential issues associated with reliability. In the meantime, one of the most effective approaches should be to put a few hundred trucks into fleets for trial in the next several years, so that a comprehensive FEMA can be thoroughly identified and warranty cost analyses be more precisely conducted before launching into full volume production. The fleet testing results can also provide valuable feedback to the engine dynamometer tests, thus continuing optimization of the component size, weight and performance including working fluid. Manufacturers have shown in the past that a robust FEMA process can address most problems before a technology is more widely introduced. Therefore, the lead time appears to be one of the most noticeable constraints.

We believe that all the issues and hurdles discussed above can be resolved with adequate lead time. However, it would be challenging to predict high rates of initial market penetration because of the many uncertainties as stated above. The NACFE report [36]analyzes a wide range of HD fuel efficiency technology adoption rates versus time, and we considered these recent historic trends as we developed our market adoption rate projections. While more mature technologies such as electronic fuel injection and turbocharging are not presented in this report, the trends for a number of emerging fuel efficiency technologies are depicted. We note that a number of charts which are relevant here are presented at the end of this report. Many of these technologies are those that we are projecting to continue to increase in market adoption during the Phase 2 timeframe. While there are a number of exceptions, many of the technology adoption rate curves follow an S-shape: slow initial adoption as shown in Figure 2 of this report[36], then more rapid adoption, and then a leveling off as the market saturates (not always at 100 percent).

This characteristic S-curve is further annotated and expanded in the figure below. There are two curves in this figure. “Simple” typically means that the technology can be relatively quickly adopted by the market because of the technology complexity. The example includes the use of aero fairings on the vehicle side, and turbocharger and fuel injection technologies on the engine side. “Complex” means that the technology is so complicated that the market will take a much longer time to adopt. WHR with the Rankine cycle is one of these types (but certainly not the sole example). The agencies thus view it legitimate to apply this type of S-curve to WHR. This figure also shows the four typical steps to reach high market penetration, but either technology needs to go through an S-shape curve because of factors indicated on the left side of this figure, which would make it difficult to quickly bring the technology into the market with high market penetration. Taking “fleet consideration” of this figure as an example, the payback time would be the most sensitive. Reliability, down time, limited credible data, resale values, and capital investment are many of the other concerns. We believe that WHR adoption behavior can very well follow the S-shape curve, where we project a steeper rise in market adoption in and around the 2027 timeframe. We have worked closely with one of the engine manufacturers who are leading WHR development. With reliable and credible CBI information, we now believe that our initial estimate for 15 percent market penetration of WHR in MY 2027 was conservative. Given our averaging, banking and trading program flexibilities and that manufacturers may choose from a range of other technologies, we believe that manufacturers will be able to meet the 2027 standards, which we based on 25 percent WHR adoption in heavy duty tractor engines. Again, this illustration is consistent with the findings reported by NACFE.[36] For example, the tire pressure inflation used for trailers follows this type of S-curve took four years from 1 percent market penetration to 16 percent, and then to 31 percent in another year. One of the key lessons learned from this report is that if a technology is pushed too hard and too quickly, the market penetration could be rolled back because of reliability and warranty issues. See 80 FR 40236 noting similar concerns in a general context. Taking idle reduction with diesel APU engine technology as an example, it quickly reached 15 percent market penetration from 3 percent in one year, and then reached 32 percent in four years, but it quickly dropped back to 13 percent in 3-4 years. This type of behavior could happen to WHR with Rankine cycle technology if pushed too hard.

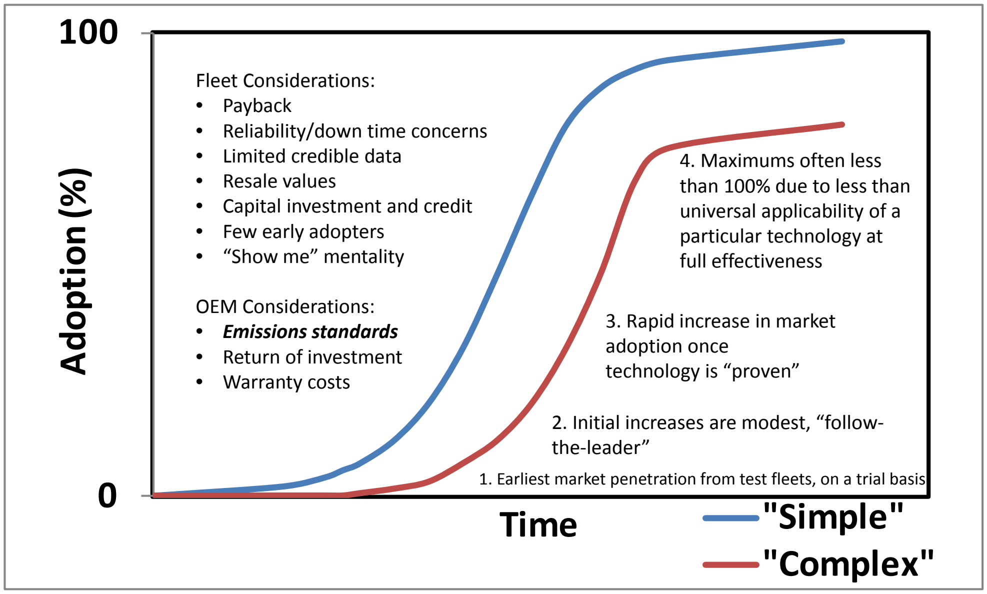


Figure 2-2 S-shape Market Penetration

2.4 Technology Principles – Class 4 to 8 Vehicles

2.4.1 Aerodynamics

The aerodynamic efficiency of heavy-duty vehicles has gained increasing interest in recent years as fuel prices, competitive freight markets, and overall environmental awareness has focused owners and operators on getting as much useful work out of every gallon of diesel fuel as possible. Up to 25 percent of the fuel consumed by a line-haul tractor traveling at highway speeds is used to overcome aerodynamic drag forces, making aerodynamic drag a significant contributor to a Class 7 or 8 tractor's GHG emissions and fuel consumption.[37] Because aerodynamic drag varies by the square of the vehicle speed, small changes in the tractor aerodynamics can have significant impacts on GHG emissions and fuel efficiency of that vehicle. With much of their driving at highway speed, the benefits of reduced aerodynamic drag for Class 7 or 8 tractors can be significant.[38]

The common measure of aerodynamic efficiency is the coefficient of drag (C_d) or drag area (C_dA). The aerodynamic drag force (*i.e.*, the force the vehicle must overcome due to air) is a function of C_d, the area presented to the wind (*i.e.*, the projected area perpendicular to the direction of travel or frontal area), and the square of the vehicle speed. C_d values for today's line-haul fleet typically range from greater than 0.80 for a classic body tractor to approximately 0.58 for tractors that incorporate a full package of widely, commercially available aerodynamic features on both the tractor and trailer.

While designers of heavy-duty vehicles and aftermarket products try to aerodynamically streamline heavy-duty vehicles, there are some challenges. Aerodynamic design must meet practical and safety needs such as providing for physical access and visual inspections of vehicle equipment. Since weight added to the vehicle can impact its overall fuel efficiency, GHG emissions and, in limited cases, the amount of freight the vehicle can carry, aerodynamic design and devices must balance the aerodynamic benefit with the contribution to the vehicle weight. In addition, aerodynamic designs and devices must balance being as light and streamlined as possible with in-use application durability to withstand the rigors a working freight vehicle encounters while traveling or loading and unloading.

However, there are some macro and micro scale techniques that can be employed to reduce vehicle drag such as reducing vehicle size, especially, the frontal area; smoothing the shape to make it more aerodynamically efficient, thus reducing the C_d; and/or re-directing air to prevent entry into areas of high drag (e.g., wheel wells) or to maintain smooth air flow in certain areas of the vehicle. Reducing the size of the vehicle can reduce the frontal area; which reduces the pressure building up on the lateral surface area exposed to the airflow. Improving the vehicle shape may include revising the fore components of the vehicle such as rearward canting/raking or smoothing/rounding the edges of the front end components (e.g., bumper, headlights, windshield, hood, cab, mirrors) or integrating the components at key interfaces (e.g., windshield/glass to sheet metal) to alleviate fore vehicle drag. Finally, redirecting the air to prevent areas of low pressure and slow moving air; thus eliminating areas where air builds creating turbulent vortices and increasing drag. Techniques such as blocking gaps in the sheet metal, ducting of components, shaping or extending sheet metal to reduce flow separation and turbulence are methods being considered to direct air from areas of high drag (e.g., underbody, tractor-trailer gap, underbody and/or rear of trailer).

The issue for heavy-duty vehicles is that the cab and/or passenger compartment is designed for a specific purpose such as accommodating an inline cylinder engine or allowing for clear visibility given the size of the vehicle. Consequently, a reduction in vehicle size and/or frontal area may not be realistic for some applications. This also may necessitate an expensive, ground-up vehicle redesign and, with a tractor model lifecycle of up to 20 years, may mean that a mid-cycle tractor design is not feasible. In addition, the frontal area is defined by the shape behind the cab so reducing just the cab frontal area/size reduction may not be effective. Thus, this approach is something that may occur in a long-term timeframe of 10-20 years from today.

Instead, most heavy-duty tractor manufacturers have explored, or are exploring, the latter two techniques in the short-term. Compared to previous generation tractors, every high roof tractor today has a roof fairing directing air over the top of the cab, fuel tank/chassis fairings that prevent side air from flowing underneath the vehicle, and cab side extenders that prevent flow from being trapped in the tractor-trailer gap. As a compliance strategy for HD Phase 1, many manufacturers refined the aerodynamic shape of their front end components and other components (e.g., curving or further extending side extenders) resulting in efficiency difference between pre- and post-HD Phase 1, model year tractor aerodynamic performance. Further, manufacturers have developed new tractor designs that are taking advantage of sealing gaps in sheet metal to redirect the flow and introducing some hard edges to induce turbulent flow on certain surfaces to prevent premature flow separation and downstream turbulent flow. For HD Phase 2, we anticipate manufacturers would continue to apply these techniques across their models and continue to explore refinements and re-designs in other areas of the tractor.

In addition to tractor improvements, there has been growth in the market for trailer aerodynamic devices encouraged by our successful SmartWay Partnership and Technology Verification Program. These devices function similar to components on the tractor by preventing air intrusion into areas of the trailer prone to high aerodynamic drag including the tractor-trailer gap, the trailer underbody, and the rear of the trailer as shown in Figure 2-3 and Figure 2-4 below.

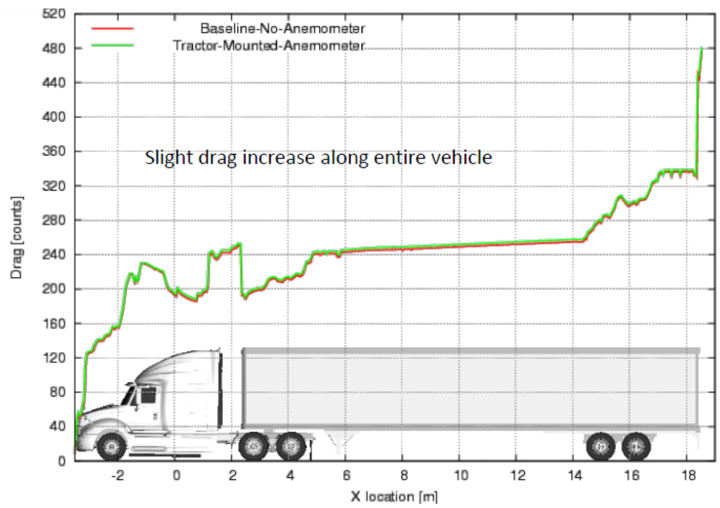


Figure 2-3 Progression of Total Drag along a Typical Line-Haul Tractor-Trailer Vehicle

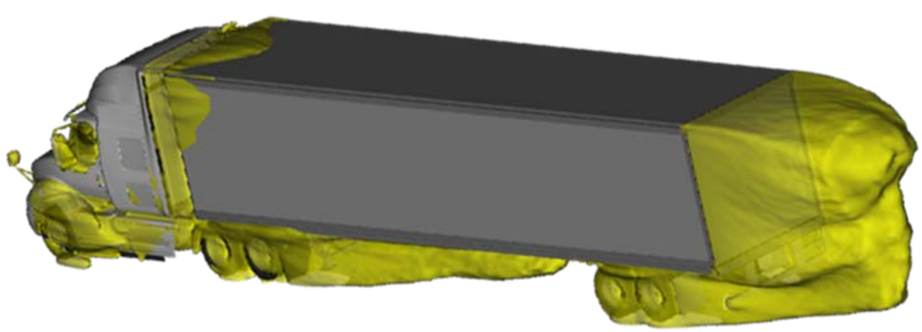


Figure 2-4 Low Pressure Regions Contributing To Aerodynamic Drag Along A Typical Line-Haul Tractor-Trailer Vehicle

To address this, trailer front/nose devices are being used to round the front end and edges of the trailer while also reducing the tractor-trailer gap; skirts on the side of the trailer prevent air entering the underside of the trailer and becoming turbulent on the various underbody structure components; and trailer aft/rear treatments reduce separation of air flow of the rear edge of the trailer to reduce the large wake of turbulent air behind the trailer. Based on current SmartWay Technology Verification, these devices can reduce fuel consumption from 1 to 9 percent, depending on the technology, and if it is employed individually or in combination.

As a result, we believe there is an opportunity within HD Phase 2 to promote continual improvement of tractor aerodynamics and capitalize on the potential improvement that aerodynamic trailer devices can provide for trailers, and for overall combination tractor-trailer efficiency.

2.4.2 Advanced Aerodynamic Concepts

The HD Phase 2 standards will be fully phased in by the 2027 model year. This represents a significant amount of time from today's action. As such, it is possible that by the time the Phase 2 standards are implemented, the state of heavy-duty aerodynamic technology and performance may have advanced significantly. Thus, there may be a need to have standards to adequately address future tractor-trailer aerodynamic advances.

Accordingly, we are considering aerodynamic concepts that can achieve aerodynamic performance beyond that of the aerodynamic-attributed improvements in the HD Phase 2 standards. There are many approaches applicable to today's tractors and trailers that are not considered in the HD Phase 2 standards and there is also ongoing advanced research aimed at creating a completely new design paradigm for tractor-trailer combinations.

The advanced aerodynamic standards would not be required but would rather serve as a marker for future aerodynamic concepts and/or as a metric for HD Phase 2 advanced/innovative aerodynamic technologies.

2.4.2.1 Aerodynamic Improvements to Current Tractor-Trailer Combinations Based on Existing Technology

2.4.2.1.1 Manufacturer Commercial Initiatives

In order to anticipate technology advancement, it is important to benchmark current technology improvements based on today's tractors and trailers. A number of Class 8 tractor OEM's have incorporated the technologies requested by their customers to improve fuel economy and to meet the HD Phase 1 standards. These technologies include side skirts, boat tails and roof fairings as well as some driver monitoring tools. Recently, Jack Roberts released an article on the internet titled: "Photo, video: Western Star introduces re-designed on-highway tractor." [39]

Figure 2-5 Pictures of the Western Star Class 8 Tractors

In addition to providing photos and videos of Western Star's redesigned on-highway tractor, the article describes a multitude of new features that define the new tractor. These features include:

- A new sweptback four piece bumper with an under bumper valance that contributes to aerodynamic efficiency.
- New halogen headlights that are optimized for aerodynamic performance and excellent visibility.
- A state-of-the-art visor specifically engineered to work with the impressive slope in the hood's rear air ramp to direct airflow over the cab without an aerodynamic penalty.
- Roof and cab fairings that sweep back for tighter trailer gap and help direct air flow over and around the trailer.
- Optional chassis side fairings that reduce drag by up to 6 percent while still providing easy access to batteries and DEF tank.
- The Western Star Twin Force dual air intake, which feeds a massive centrally mounted air filter to improve efficiency.

This example demonstrates that manufacturers are continuing to find ways to improve tractors and are continually exploring concepts, such as those in used in the SuperTruck initiative, to improve commercially-available products.

2.4.2.1.2 Supplier Research: SABIC Roof Fairing Technology and Manufacturing

Developments in aerodynamics have long been assumed to yield advances in vehicle fuel efficiency. SABIC Innovative Plastics US LLC (SABIC) evaluated a variety of injection moldable thermoplastic roof fairing designs for a heavy tractor day cab to quantify efficiencies that could be obtained through advanced aerodynamics. Computational Fluid Dynamic (CFD) modeling was performed by Exa Corporation, an industry recognized leader in CFD. Multiple designs exhibited significant reductions in drag compared to a baseline roof fairing (Figure 1 of Figure 2-6). The baseline represented a top performing roof fairing on the market today. The best performing SABIC concept (Figure 2-7) achieved a 5.8 percent reduction in drag and fuel use compared to the baseline. Under the well-established 2:1 relationship between delta drag and fuel use, the fuel efficiency improved by nearly 3 percent from the baseline design.

The design concept optimized the shape to manage the airflow over the vehicle and enable reduced drag and increased fuel economy. Air channels – developed for injection molding processes – limit the air stagnation on the front of the trailer as well as accelerate and control the direction of the air flow. This innovative concept has been validated using state of the art CFD methods. On vehicle tests are suggested to validate findings from these studies. (from Matthew D. Marks, Senior Business Manager, Regulatory Automotive and Mass Transportation, November 14, 2014).

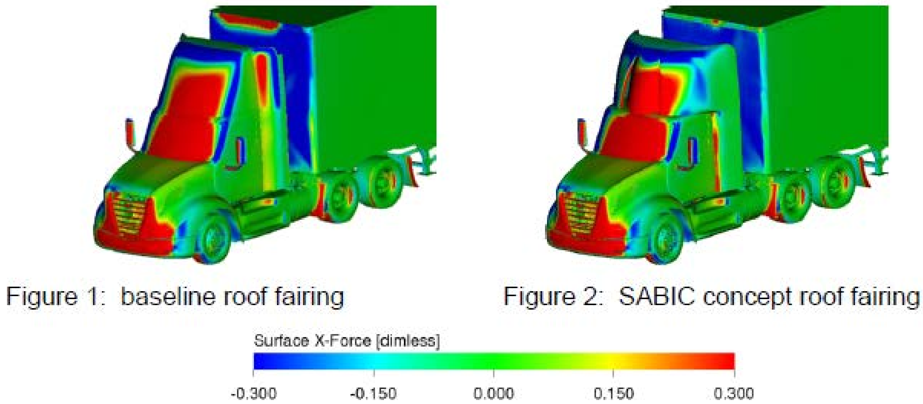


Figure 2-6 Surface X-Force (dimensionless) on Baseline and SABIC Concept Roof Fairing

Aerodynamic (surface) force is the force exerted on a body whenever there is a relative velocity between the body and the air. These plots represent this force in the direction of the vehicle travel at highway speeds. Red indicates a 'pushing' of the vehicle rearward, while blue indicates a 'pulling' of the vehicle forward.

Figure 2-7 SABIC Concept Roof Fairing Operation

2.4.2.1.3 HD Phase 1 Research: External Active Grille Shutter Potential on Heavy-Duty Tractors

During HD Phase 1 aerodynamic assessment, we looked at several trends to understand some of the aerodynamic trends such as removal of tractor chassis fairings and side extenders, different tractor-trailer gap widths, and different trailer leading edge radii. However, one trend of particular relevance to advanced aerodynamic improvements for current tractors is the case of open versus closed grille.

We evaluated the open vs. closed grille trend in the full and reduced scale wind tunnel. Below in Figure 2-8 is a picture of a 1/8th scale tractor model in the reduced scale wind tunnel with the grille covered with aluminum tape to simulate a fully closed grille.

Figure 2-8 Photo of 1/8th Scale Model of a Tractor with the Front, External Grille Covered With Aluminum Tape to Simulate A Closed Grill Configuration

Below in Table 2-1 and Table 2-2 are the results of our open versus closed grille evaluations in the full and reduced scale wind tunnel separately. The tables provide the deltas for an open grille C_dA minus the closed grille C_dA; where the C_dAs have been corrected for blockage, in the case of the full scale wind tunnel, and normalized for differences in measured frontal area between the full and reduced scale wind tunnels using a nominal frontal area of 10.4 m^2 (111.95 in^2). For the full scale wind tunnel, only one tractor OEM was tested. In contrast, for the reduced scale wind tunnel, three tractor OEMs were tested.

Table 2-1 Full Scale Wind Tunnel Results for Open verses Close Grille Configurations

TRACTOR MODEL	DELTA WAC_DA @55MPH	% DELTA C_DA VS. OPEN GRILLE C_DA
1	0.03	0.60%

Table 2-2 Reduced Scale Wind Tunnel Results for Open versus Close Grille Configurations

TRACTOR MODEL	DELTA WAC_DA @55MPH	% DELTA C_DA VS. OPEN GRILLE C_DA
A	0.10	1.69%
B	0.12	1.89%
C	0.09	1.45%

Based on the data in these tables, there is a potential wind-average drag improvement of 0.6 percent to 1.45 percent from closing off the external, front grille of the tractor. This indicates the potential of active grille shutter systems on heavy-duty tractors. These systems are currently being applied on light duty vehicles behind the external grille to improve aerodynamics. However, a recent SAE paper determined that the optimal position for active grille shutter systems was the external grille flush with the vehicle sheet metal.[40] This technique could be implemented on the external grille designs for current-design, heavy-duty tractors as well.

2.4.2.1.4 National Research Council of Canada Historical Research on Improving Heavy-Duty Tractors

The National Research Council of Canada (NRC-Can) performed an assessment of the drag effect of various tractor components[41] and found the following in Table 2-3.

Table 2-3 Reduced Scale Wind Tunnel Results for Open versus Close Grille Configurations

COMPONENT	DELTA WAC_DA
OEM Side Mirrors	-0.156
OEM Fender Mirrors	-0.098
Wheel Covers (Tractor and Trailer)	0.020
Tractor Drive Axle Wrap-Around Splash Guards	0.049
Roof Fairing Rear-Edge Filler	0.137

Based on this table, there is the potential to improve tractor aerodynamics by 0.206 WAC_dA) with the addition of wheel covers, drive axle wrap around splash guards, and roof fairing rear edge filler, and up to 0.460 if the OEM side and fender mirrors are replaced with a camera system, as suggested by the study, and combined with the wheel covers, drive axle wrap around splash guards, and roof fairing rear edge filler. Therefore, considering the current wind-average drag performance of current heavy-duty tractors, this study demonstrates the possibility to improve tractors an additional ~1 percent with some simple changes.

2.4.2.2 Aerodynamic Improvements to Current Tractor-Trailer Combinations Based on Complete Vehicle Redesign

This section contains summaries of ongoing work from various DOE efforts as well as individual efforts such as Airflow Truck Company to develop improved aerodynamic Class 8 vehicles. In addition to aerodynamics, there are other technologies such as driver awareness and ability to drive for maximum fuel economy with increased aerodynamics. Overall it is expected that the research being performed over the next year or two will reveal drastic improvements in C_dA and fuel economy. DOE's Lawrence Livermore National Laboratory is also looking at the aerodynamics of tankers.

2.4.2.2.1 Collaborative, Government-Industry Advanced Aerodynamic Research: SuperTruck Program

DOE's SuperTruck project is one of several initiatives which is a public-private initiative to stimulate innovation in the trucking industry through sponsorship from government agencies, companies, national laboratories and universities. DOE's Vehicle Technologies Program provided matching funds to the program. Four programs basically involved all major vehicle and engine manufacturers were awarded by DOE under SuperTruck program. They are Cummins, Daimler, Navistar, and Volvo. Cummins was teamed up with Peterbilt on the vehicle side of the program.

The goal of the SuperTruck Initiative was to achieve 50 percent freight efficiency improvement with 30 percent from vehicle and 20 percent from engine compared to a 2009 vehicle. This means that it require development of a tractor that could meet or exceed 10 mpg – where tractors at this point are averaging between 5.5 and 6.5 mpg. Advances in engines, aerodynamics and more helped the tractor project increase its fuel economy. The SuperTruck objectives included development and demonstration of a highly efficient and clean diesel engine, an advanced waste heat recovery system, an aerodynamic tractor and trailer combination and a lithium ion battery auxiliary power unit, to reduce engine idling.

Significant progress has been made since the initiation of this program in 2010. Two programs are particularly worth noting. They are the Cummins-Peterbilt and Daimler programs. The Cummins-Peterbilt SuperTruck project team was the first to report and demonstrate a SuperTruck vehicle with10.7mpg. Details of the SuperTruck are given in four videos on the todaystrucking.com website.[42] Aerodynamic features of the tractor include the following: airflow into the engine compartment (through the front bumper, through the radiator and under the vehicle), less clearance between the road and the bottom of the tractor (rubber skirt under steps), close gaps on tractor/trailer (between hood and bumper, etc.), minimized gap between the trailer and tractor with a ball and socket design, full trailer skirt, roof fairing, smaller mirrors, minimized gap between wheels and wheel wells, wheel covers, boat tail, air foil on rear bumper design, single wide tires, and perforated mud flaps that allow air to bypass through them and reduce drag. A picture of this truck based on a Peterbilt tractor is shown in Figure 2-9 below. Eaton Corp, also part of the Cummins-Peterbilt SuperTruck project team, contributed technologies including the design, development and prototyping of an advanced automated transmission that facilitated reduced engine-operating speeds. Cummins and Eaton jointly designed shift schedules and other features to yield further improved fuel efficiency.

Even with the addition of these aerodynamic features, overall the tractor mass was reduced by over 1,300 lbs. The article states that the CFD analysis of the tractor showed a 50 percent reduction in drag and with a 2:1 drag reduction the aero improvements resulted in a 25 percent improvement in fuel economy. In the 300 mile test course shown on the video, it was stated that the tractor achieved 10.7-11.1 mpg.

Figure 2-9 Peterbilt SuperTruck Concept (Picture from: http://www.peterbilt.com/about/media/2014/396/)

This effort represents the first step in the evolution of improving the aerodynamic efficiency of tractor-trailer by radically redesigning today's tractor-trailer combination, as a wholly integrated system rather each component, tractor and trailer, independently.

Just one year later after Cummins' demonstration, Daimler demonstrated their own SuperTruck vehicle with 12.2 mpg as showed in Figure 2-10.

Figure 2-10 Daimler SuperTruck Vehicle (picture from: http://freightlinersupertruck.com/#main)

The key enabling technology on the aero side in this vehicle includes, but is not limited to, full tractor aero with cab/sleeper, underbody, drive wheel fairing, mirror cam, steer wheel, and full side extender. In addition, this vehicle also includes a 50 percent BTE DD11 Engine with WHR, predictive hybrid controller, predictive engine controller, new final drive active oil management with high efficiency gear oil, lightweight aluminum frame and cross members, ultra-light weight air suspension, advanced load shift with 6x2 axle, solar reflective paint, and enhanced Trailer aerodynamics. More detailed features on this Daimler truck can be seen in their DOE report[34].

2.4.2.2.2 Government Sponsored Advanced Aerodynamic Research: Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory's (LLNL) Kambiz Salari presented information at the 2014 DOE Annual Merit Review on "DOE's Effort to Improve Heavy Duty Vehicle Fuel Efficiency through Improved Aerodynamics." A joint project with Wabash, Navistar, Michelin, Safeway, Frito Lay, Praxair, Freight Wing Inc., ATDynamics, Kentucky Trailer and Spirit was funded in 2013 and 2014. The objective was to develop a new integrated tractor-trailer design from ground up by first, designing the first generation of an integrated tractor-trailer geometry called Generic Speed Form one (GSF1) and second, performing wind tunnel tests of selected aero devices for tractor-trailers and tankers to improve fuel efficiency. The goal was to reduce aerodynamic drag of Class 8 tractor-trailers by approximately 25 percent leading to a 10-15 percent increase in fuel efficiency at 65 mph. In addition, the group developed an aerodynamic tractor-trailer prototype designed to achieve 50 percent reduced aerodynamic drag as shown in Figure 2-11. This effort represents the next generation of tractors and trailers: a completely redesigned, fully integrated, optimized shape for the tractor-trailer combination.

Figure 2-11 Pictures Showing Future Heavy-Duty Tractor Trailer Concept to Achieve >50 percent Aerodynamic Improvement for Class 8 Line Haul Heavy-Duty Vehicles

2.4.2.2.3 Independent Advanced Aerodynamic Research: Airflow Truck Company Bullet Truck Concept

In addition to the work being performed by the OEMs and consortiums mentioned above, there are also independent commercial initiatives underway to radically redesign the tractor-trailer combination similar to the concept by Lawrence Livermore National Laboratories discussed above.

The Class 8 tractor and trailer modifications in Figure 2-12 were designed, built, and tested in 2012 by Mr. Robert Sliwa of the Airflow Truck Company. Mr. Sliwa built his first aerodynamic tractor in the 1983 when he was an owner-operator. After that, Mr. Sliwa became interested in computers and used his computer background along with his truck driver and race car driver experience to create the Bullet Truck. His current design is described at www.airflowtruck.com and his tractor design modifications are similar in appearance to the bullet looking trains used in Europe. The tractor uses a 1999 engine and the test was conducted in a manner in which the tractor was driven at 55 mph by an experienced driver throughout its test while loaded at 65,000 lbs from Newington, Connecticut to Tracy, California.

The website shows that the vehicle achieved 13.4 mpg during this trip that included traveling through the Rocky Mountains. CFD analyses of the design after the vehicle was built found a modest decrease in C_dA, thus giving credence to the design work under the hood (most of which are outlined at airflowtruck.com) and driving techniques. Several new technologies were developed during this work which included retractable tractor steps, all electric air conditioning, crankshaft mounted cooling fan, computer-controlled fan hub, waterless engine coolant, reduced engine parasitic losses, full tractor and trailer side skirts, 4 axle ATIS, and an engine feedback information display.

Figure 2-12 Figure of the Bullet Truck by Airflow Truck Company[9]

AirFlow has designed and is currently building the third prototype (Proof of Concept) of a "Hyper Fuel Mileage, Ultra Low GHG Emissions, and roadable Class 8 heavy duty truck" called the StarShip. The StarShip is a Class 8 heavy duty truck tractor that will be mated with a new 2016 Strick 53' dry van trailer, which is typical of an over-the-road freight hauling trailer. AirFlow has further modified the stock trailer to be much more aerodynamic than when it left the Strick factory. There is also a full array of solar panels on the trailer roof. This solar array will charge batteries mounted on the tractor during the day to enable to provide electric Heat, Ventilation, and Air Conditioning (HVAC) to the cab for driver comfort while traveling down the roadway, and when the driver is engaged in federally mandated rest and safety breaks. Utilizing a proprietary all-electric HVAC system will allow the StarShip to reduce GHG emissions and increase fuel efficiency by completely removing the diesel engine-driven air conditioning compressor, and its associated engine parasitic efficiency losses. It will also allow the StarShip to automatically and periodically turn off its diesel engine belt-driven 300 amp alternator, further saving fuel and further reducing GHG emissions. These aerodynamic, solar, and hybridized component improvements will further reduce GHG vehicle emissions and vastly increase fuel efficiency.

The latest proof of concept vehicle, the StarShip, is due to be completed in Q3 2016 and will begin its local and regional road testing then. The design of the StarShip continues to be refined. The StarShip utilizes an experimental 2017 EPA low-emissions certified, six cylinder, 400 horsepower diesel-fueled Cummins engine to power the vehicle. The engine is certified to produce air pollutants and GHG emissions in an amount significantly below the current 2013 standard. Future versions of the StarShip model may include a hybrid (diesel engine/electric motor) and/or a purely electric propulsion unit, powered only with an onboard battery bank, similar to a Tesla automobile.

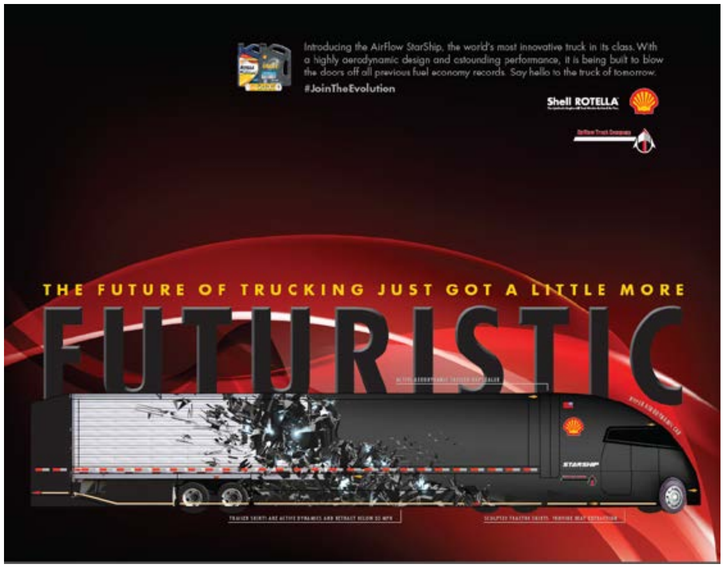


Figure 2-13 StarShip Advertisement by Shell Rotella and Airflow Truck Company

2.4.3 Tires

2.4.3.1 Improved Rolling Resistance

Research indicates that a tire's contribution to overall vehicle fuel efficiency is approximately proportional to the vehicle weight on it.[43] Energy loss associated with tires is mainly due to deformation of the tires under the load of the vehicle, known as hysteresis, but smaller losses result from aerodynamic drag, and other friction forces between the tire and road surface and the tire and wheel rim. Collectively the forces that result in energy loss from the tires are referred to as rolling resistance. Tires with higher rolling resistance lose more energy, thus using more fuel and producing more CO_2 emissions in operation, while tires with lower rolling resistance lose less energy, and use less fuel, producing less CO_2 emissions in operation.

A tire's rolling resistance is a factor considered in the design of the tire, and is affected by the tread and casing compound materials, the architecture of the casing, tread design, and the tire manufacturing process. It is estimated that 35 to 50 percent of a tire's rolling resistance is from the tread and the other 50 to 65 percent is from the casing.[43] Tire inflation can also impact rolling resistance in that under-inflated tires can result in increased deformation and contact with the road surface. In addition to the effect on CO_2 emissions and fuel consumption, these design and use characteristics of tires also influence durability, traction (both wet and dry grip), vehicle handling, ride comfort, and noise. Tires that have higher rolling resistance are likely designed to address one or more of these other tire attributes.

EPA's SmartWay program identified test methods and established criteria to designate certain tires as having lower rolling resistance (LRR) for use in the program's emissions tracking system, verification program, and SmartWay vehicle specifications. To measure a tire's efficiency, the vertical load supported by the tire must be considered, because rolling resistance is a function of the load on a tire. EPA uses a tire's rolling resistance coefficient (CRR) to characterize LRR tires. CRR is measured using the ISO 28850 test method (see 40 CFR

1037.520(c),) and reported as the rolling resistance force over vertical load (kg/metric ton). Differences in rolling resistance of up to 50 percent have been identified for tires designed to equip the same vehicle.[44]

LRR tires are commercially available from most tire manufacturers and can be applied to vehicles in all MD/HD classes. According to an energy audit conducted by Argonne National Lab, tires were shown to be the second largest contributor to energy losses for a Class 6 delivery truck at 50 percent load and speeds up to 35 mph (a typical average speed of urban delivery vehicles).[45] For Class 8 tractor-trailers, the share of vehicle energy required to overcome rolling resistance is estimated at nearly 13 percent.[46]

NHTSA, EPA, and ARB met with stakeholders from the tire industry (Bridgestone, Continental, Cooper, Goodyear, and Michelin) in 2014 to discuss the next generation of LRR tires for the Phase 2 timeframe for all segments of Class 2b-8 vehicles, including trailers. Manufacturers discussed forecasts for rolling resistance levels and production availability in the Phase 2 timeframe, as well as their plans for improving rolling resistance performance while maintaining other performance parameters such as traction, handling, wear, mass reduction, retreadability, and structural durability.

The meetings included specific discussions of the impacts of the current generation of LRR tires on vehicle stopping distance and handling. Manufacturers indicated no known safety disbenefit in the current on-road fleet from use of LRR tires. While the next generation of tires may require some tradeoffs in wear performance and costs over the next 10 years to achieve better tire rolling resistance performance, manufacturers said they will not trade off safety for performance. They also emphasized that keeping tires inflated (through proper maintenance or automatic systems) was the best way to assure long term fuel efficiency and safety during vehicle operation.

2.4.3.2 Wide Base Singles

Low rolling resistance tires can be offered for dual assembly tires and as wide base singles (WBS). Wide base singles are primarily intended for combination tractor-trailers, but some vocational vehicles are able to accommodate them. In the early years of this technology, some states and local governments restricted use of WBS, but many of these restrictions have since been lifted. As of December 2010, NACFE reports that there is virtual acceptance in North America with only a few provinces in Canada that disallow or require special permitting for the use of wide base tires.[47] A wide base single is a larger tire with a lower profile. The common wide base single sizes include 385/65R22.5, 425/65R22.5, 445/65R22.5, 435/50R22.5 and 445/50R22.5. Generally, a wide base single tire has less sidewall flexing compared to a dual assembly and therefore less hysteresis occurs. Compared to a dual tire assembly, wide base singles also produce less aerodynamic resistance or drag. Wide base singles can contribute to improving a vehicle’s fuel efficiency through design as a low rolling resistance tire and/or through vehicle weight reduction.

According to one study, the use of fuel efficient wide base singles can reduce rolling resistance by 3.7 to 4.9 percent compared to the most equivalent dual tire.[48] An EPA study with a tractor-trailer demonstrated an improvement in fuel consumption of 6 percent at 55 mph on the highway, 13 percent at 65 mph on the highway and 10 percent on a suburban loop[49] using wide base singles on the drive and trailer axles. EPA attributed the fuel consumption improvement to the reduction in rolling resistance and vehicle weight reduction from using wide base singles. In 2008 the Department of Energy (DOE) compared the effect of different combinations of tires on the fuel efficiency of Class 8 tractors. The data collected based on field testing indicates that tractors equipped with wide base singles on the drive axle experience better fuel efficiency than tractors equipped with dual tires, independent of the type of tire on the trailer.[50] This study in particular indicated a 6.2 percent improvement in fuel efficiency from wide base singles.

There is also a weight savings associated with wide base singles compared to dual tires. Wide base singles can reduce a tractor and trailer's weight by as much as 1,000 lbs. when combined with aluminum wheels. Bulk haulers of gasoline and other liquids recognize the immediate advantage in carrying capacity provided by the reduction in the weight of tires and have led the transportation industry in retrofitting their tractors and trailers.[51]

New generation wide base singles, which were first introduced in 2000, are designed to replace a set of dual tires on the drive and/or trailer positions. They are designed to be interchangeable with the dual tires without any change to the vehicle[52]. If the vehicle does not have hub-piloted wheels, there may be a need to retrofit axle components.[51, 53] In addition to consideration of hub/bearing/axle, other axle-end components may be affected by use of wide base singles. To assure successful operation, suitable components should be fitted as recommended by the vehicle manufacturer.[54]

Current wide base singles are wider than earlier models and legal in all 50 states for a 5-axle, 80,000 GVWR truck.[48] Wide base singles meet the "inch-width" requirements nationwide, but are restricted in certain states up to 17,500 lbs. on a single axle at 500 lbs/inch width limit, and are not allowed on single axle positions on certain double and triple combination vehicles[52]. An inch-width law regulates the maximum load that a tire can carry as a function of the tire width. Typically wide base singles are optimized for highway operation and not for city or on/off highway operation. However, newer wide base singles are being designed for better scrub resistance, which would allow an expansion of their use. The current market share of wide base singles in combination tractor applications is 5 percent and the potential market is all combination tractors.[48] New generation wide base singles represent an estimated 0.5 percent of the 17.5 million tires sold each year in the U.S.[52]

2.4.3.3 Tire Pressure Systems

Proper tire inflation is critical to maintaining proper stress distribution in the tire, which reduces heat loss and rolling resistance. Tires with reduced inflation pressure exhibit more sidewall flexing and tread shearing, resulting in greater rolling resistance than a tire operating at its optimal inflation pressure. Bridgestone tested the effect of inflation pressure and found a 2 percent variation in fuel consumption over a 40 psi range.[43] Tractor-trailers operating with all tires under-inflated by 10 psi have been shown to increase fuel consumed by up to 1 percent.[55] Tires can gradually lose pressure from small punctures, leaky valves or simply diffusion through the tire casing. Changes in ambient temperature can also have an effect on tire pressure. Trailers that remain unused for long periods of time between hauls may experience any of these conditions. To achieve the intended fuel efficiency benefits of low rolling resistance tires, it is critical that tires are maintained at the proper inflation pressure.

Although most truck fleets understand the importance of keeping tires properly inflated, it is likely that a substantial proportion of trucks on the road have one or more underinflated tires. An industry survey conducted in 2002 at two truck stops found that fewer than half of the tires checked were within 5 pounds per square inch (psi) of their recommended inflation pressure. Twenty-two percent of the vehicles checked had at least one tire underinflated by at least 20 psi, and 4 percent of the vehicles were running with at least one flat tire, defined as a tire underinflated by 50 psi or more. The survey also found mismatches in tire pressure exceeding 5 percent for dual tires on axle ends.[56]

A commercial vehicle tire condition study conducted by the Federal Motor Carrier Safety Administration (FMCSA) in 2003 found similar indicators of poor tire inflation pressure maintenance in commercial fleets. The FMCSA concluded that only 44 percent of all tires on commercial vehicles were inflated within 5 psi of the recommended pressure, while over 7 percent of all tires in operation on commercial vehicles were underinflated by at least 20 psi. It was also determined that the rates of tires used in dual assemblies that differed in pressure by more than 5 psi was approximately 20 percent for tractor duals and 25 percent for trailer duals. Finally, the FMCSA concluded that there were significant differences in tire inflation maintenance practices between private and for-hire fleets, smaller and larger fleets, and local bus and motor coach fleets.[57]

If drivers or fleets are not diligent about checking and attending to under-inflated tires, the trailer may have much higher rolling resistance and much higher CO_2 emissions and fuel consumption. Proper tire inflation pressure can be maintained with a rigorous tire inspection and maintenance program and EPA provides information on proper tire inflation pressure through its SmartWay program.[58] Tire pressure monitoring (TPM) and automatic tire inflation (ATI) systems are designed to address under-inflated tires. Both systems alert drivers if a tire's pressure drops below its set point. TPM systems monitor the tires and require user-interaction to reinflate to the appropriate pressure. Yet unless the vehicle experiences a catastrophic tire failure, simply alerting the driver that a tire's pressure is low may not necessarily result in action to correct the problem. A driver may continue driving to their final destination before addressing the tires, resulting in many miles of driving with improperly inflated tires. Current ATI systems take advantage of trailers' air brake systems to supply air back into the tires (continuously or on demand) until a selected pressure is achieved. In the event of a slow leak, ATI systems have the added benefit of maintaining enough pressure to allow the driver to get to a safe stopping area.[59]

Estimates of the benefits of ATI systems vary depending on the base level of maintenance already performed by the driver or fleet, as well as the number of miles the trailer travels. Vehicles that are well maintained or that travel fewer miles would experience less benefits from ATI systems compared to vehicles that log many miles or have a history of driving with poorly inflated tires. The agencies believe ATI systems can provide a CO_2 and fuel consumption benefit to most tractors and trailers. Drivers and fleets that diligently maintain their tires will spend less time and money to inspect each tire knowing that they are properly inflated. Vehicles that have lower annual VMT due to long periods between uses would be less susceptible to low tire pressures when they resume activity. Vehicles with high annual VMT would experience the fuel savings associated with consistent tire pressures.

2.4.3.4 Retreaded Tires

The tread life of a tire is a measure of durability and some tires are designed specifically for greater durability. Commercial vehicle tires are designed to be retreaded, a process in which a new tread is bonded to the tire casing. The original tread of a tire will last anywhere from 100,000 miles to over 300,000 miles, depending on vehicle operation, original tread depth, tire axle position, and proper tire maintenance. Retreading can extend the tire's useful life by 100,000 miles or more.[60] In 2005, the Tire Industry Association estimated that approximately 17.6 million retreaded truck tires were sold in North America[61].

All of the top commercial vehicle tire manufacturers are involved in tire retread manufacturing. Bridgestone Bandag Tire Solutions accounts for 42 percent of the domestic retreaded vehicle tire market with its Bandag retread products; Goodyear Tire and Rubber Company accounts for 28 percent, mostly through its Wingfoot Commercial Tire Systems; Michelin Retread Technologies Incorporated, with Megamile, Oliver, and Michelin retread products, accounts for 23 percent. Other tire companies like Continental and independent retread suppliers like Marangoni Tread North America (which also produces the Continental "ContiTread" retread product) make up the remaining 7 percent.[62] The retreading industry itself consists of hundreds of retreaders who sell and service retreaded tires, often (but not always) using machinery and practices identified with one of the major retread producers. There are about 800 retread plants in North America.[63] The top 100 retreaders in the U.S. retread 47,473 truck tires per day.

To maintain the quality of the casing and increase the likelihood of retreading, a tire should be retreaded before the tread depth is reduced to its legal limit. At any time, steer tires must have a tread depth of at least 4/32 of an inch and other tires, including drive tires and trailer tires, must have a tread depth of at least 2/32 of an inch (49 CFR 393.75). Trucking fleets often retread tires before tire treads reach this minimum depth in order to preserve the integrity of the tire casing for retreading. If the casing remains in good condition, a truck tire can be safely retreaded multiple times. Heavy truck tires in line haul operation can be retread 2 to 3 times and medium-duty truck tires in urban use can be retread 5 or more times.[64] To accommodate this practice, many commercial vehicle tire manufacturers warranty their casings for up to five years, excluding damage from road hazards or improper maintenance.

To protect the casing, a steer tire is generally retreaded once the tread is worn down to 6/32 of an inch and a drive tire is retreaded once the tread is worn down to 8/32 of an inch.[65] Tires used on Class 8 vehicles are retreaded as many as three times.

Both the casing and the tread contribute to a tire's rolling resistance. It is estimated that 35 to 50 percent of a tire's rolling resistance is the result of the tread. Differences in drive tire rolling resistance of up to 50 percent for the same casing with various tread compounds have been demonstrated. For example, a fuel efficient tread (as defined by the manufacturer) was added to two different casings resulting in an average increase in rolling resistance of 48 percent. When a nonfuel efficient tread (also defined by the manufacturer) was added to the same casings, the rolling resistance increased by 125 percent on average. This characterizes the effect of the tread on the rolling resistance of a tire.

Because tires can be retreaded multiple times, changes in the casing due to wear, damage and material aging may impact rolling resistance to a greater degree than would occur in an original tire. Additionally, as evidenced above, if a tread compound different than the original tread is used, a retreaded tire can have higher or lower rolling resistance than the original tire. Since the agencies have no way of knowing whether the rolling resistance of retreaded tires will be higher or lower than the rolling resistance of the original tires, we similarly have no way of knowing whether low rolling resistance tire benefits will continue to accrue for a vehicle's entire lifetime.

2.4.4 Transmissions

Transmissions are a significant vehicle component. They are part of the drivetrain, which also includes axles and tires. Ways to improve transmissions include electronic controls, shift strategy, gear efficiency, and gear ratios. The relative importance of having an efficient transmission increases when vehicles operate in conditions with a higher shift density. Each shift represents an opportunity to lose speed or power that would have to be regained after the shift is completed. Further, each shift engages gears that have their own inherent inefficiencies.

Optimization of vehicle gearing to engine performance through selection of transmission gear ratios, final drive gear ratios and tire size can play a significant role in reducing fuel consumption and GHGs. Optimization of gear selection versus vehicle and engine speed accomplished through driver training or automated transmission gear selection can provide additional reductions. The 2010 NAS report found that the opportunities to reduce fuel consumption in heavy-duty vehicles due to transmission and driveline technologies in the 2015 time frame ranged between 2 and 8 percent.[66]

The design goal is for the transmission to deliver the needed power to the vehicle while maintaining engine operation within the engine's "sweet spot" for most efficient operation. Truck and chassis manufacturers today offer a wide range of tire sizes, final gear ratios and transmission choices so that owners can work with application engineers to specify an optimal combination given the intended vehicle service class and other performance needs.

2.4.4.1 Optimizing Number of Gears and Gear Ratios

Manufacturers of light and medium heavy-duty vehicles can choose to replace 6-speed transmissions with 8-speed or more automatic transmissions. Additional ratios allow for further optimization of engine operation over a wider range of conditions, but this is subject to diminishing returns as the number of speeds increases. As additional planetary gear sets are added (which may be necessary in some cases to achieve the higher number of ratios), additional weight and friction are introduced. Also, the additional shifting of such a transmission can be perceived as bothersome to some consumers, so manufacturers need to develop strategies for smooth shifts.

The Phase 1 rulemaking projected that 8-speed transmissions could incrementally reduce fuel consumption by 1 to 3 percent from a baseline 6-speed automatic transmission over some test cycles. The SwRI report uses 2 to 3 percent fuel consumption reduction when replacing 6-speed baseline automatic transmissions with improved 8-speed automatic transmissions. Chapter 2.9 of the RIA outlines the agencies' updated analysis that takes into account public comments on the proposal.

2.4.4.2 Gear Efficiencies

As described elsewhere for axles and engines, the efficiency of gears can be improved by reducing friction and minimizing mechanical losses. This can be done by reducing the friction between the two gears in contact. This friction is reduced mainly by improving the surface finish of the gears. The other way of doing is by reducing the amount of distance the gear faces are sliding against each other.

2.4.4.3 Shift Strategies

Calibrating the transmission shift schedule to upshift earlier and quicker, and to lock up or partially lock up the torque converter under a broader range of operating conditions can reduce fuel consumption and CO_2 emissions. However, this operation can result in a perceptible degradation in noise, vibration, and harshness. The degree to which NVH can be degraded before it becomes noticeable to the driver is strongly influenced by characteristics of the vehicle, and although it is somewhat subjective, it always places a limit on how much fuel consumption can be improved by transmission control changes.

During operation, an automatic transmission's controller manages the operation of the transmission by scheduling the upshift or downshift, and locking or allowing the torque converter to slip based on a preprogrammed shift schedule. The shift schedule contains a number of lookup table functions, which define the shift points and torque converter lockup based on vehicle speed and throttle position, and other parameters such as temperature. Aggressive shift logic can be employed in such a way as to maximize fuel efficiency by modifying the shift schedule to upshift earlier and inhibit downshifts under some conditions, which reduces engine pumping losses and engine friction. The application of this technology does require a manufacturer to confirm that drivability, durability, and NVH are not significantly degraded.

A torque converter is a fluid coupling located between the engine and transmission in vehicles with automatic transmissions and continuously-variable transmissions (CVT). This fluid coupling allows for slip so the engine can run while the vehicle is idling in gear (as at a stop light), provides for smoothness of the powertrain, and also provides for torque multiplication during acceleration, and especially launch. During light acceleration and cruising, the inherent slip in a torque converter causes increased fuel consumption, so modern automatic transmissions utilize a clutch in the torque converter to lock it and prevent this slippage. Fuel consumption can be further reduced by locking up the torque converter at lower vehicle speeds, provided there is sufficient power to propel the vehicle, and noise and vibration are not excessive. If the torque converter cannot be fully locked up for maximum efficiency, a partial lockup strategy can be employed to reduce slippage. Early torque converter lockup is applicable to all vehicle types with automatic transmissions. Some torque converters would require upgraded clutch materials to withstand additional loading and the slipping conditions during partial lock-up. As with aggressive shift logic, confirmation of acceptable drivability, performance, durability and NVH characteristics would be required to successfully implement this technology.

2.4.4.4 Architectures

The manual transmission architecture has traditionally been considered the most efficient architecture since it did not experience the losses inherent in a torque converter required on a traditional automatic transmission (a traditional automatic transmission being a transmission with fully automated shifting and using a hydraulic lock-up torque converter for smooth vehicle launching from a stop). However, this traditional understanding has been called into question as advances in electronics and computer processing power allow for more efficiency from a manual transmission architecture with fully automated shifting. The two primary manual transmission architectures employing automated shifting are the automated manual transmission (AMT) and the dual-clutch transmission (DCT). When implemented well, these mechanically more efficient designs could inherently provide better fuel efficiency and lower greenhouse gas emissions than conventional torque converter automatic transmission designs and, potentially, even fully manual transmissions. These transmissions offer the inherently lower losses of a manual transmission with the efficiency and shift quality advantages of electronic controls. The lower losses stem from the elimination of the conventional lock-up torque converter, and a greatly reduced need for high pressure hydraulic circuits to hold clutches to maintain gear ratios (in automatic transmissions).

2.4.4.4.1 AMT

An AMT is mechanically similar to a conventional manual transmission, but shifting and launch functions are automatically controlled by electronics. The term AMT generally refers to a single clutch design (differentiating it from a dual-clutch transmission, or dual-clutch AMT, described below) which is essentially a manual transmission with automated clutch and shifting. Because of shift quality issues with single-clutch designs, dual-clutch designs are more common in light-duty applications where driver acceptance is of primary importance. In the HD sector, shift quality remains important but is less so when compared to light-duty. As a result, the single-clutch AMT architecture can be an attractive technology for HD vehicles.

2.4.4.4.2 DCT

A DCT uses separate clutches (and separate gear shafts) for the even-numbered and the odd-numbered gears. In this way, the next expected gear is pre-selected thereby allowing for faster and smoother shifting. For example, in a 6 speed DCT, if the vehicle is accelerating in third gear, the shaft with gears one, three and five has gear three engaged and is transmitting power to the wheels. The shaft with gears two, four, and six is idle but has gear four engaged. When a shift is required, the controller disengages the odd-gear clutch while simultaneously engaging the even-gear clutch, thus making a smooth shift. If, on the other hand, the driver slows the vehicle instead of continuing to accelerate, the transmission would have to change to second gear on the idling shaft to anticipate a downshift. This shift can be made quickly on the idling shaft since there is no torque being transferred on it.

There are variations of the DCT design, with some having wet clutches and some dry clutches, and more recent versions that incorporate a torque converter similar to but smaller than the torque converter of a traditional automatic transmission. The wet clutch designs offer a higher torque capacity that comes from the use of a hydraulic system that cools the clutches. Wet clutch systems are also less efficient than dry clutch systems due to the losses associated with the hydraulic pumping. They also are more costly due to the hydraulics.

2.4.4.5 Hybrid Powertrain Systems

The industry is currently developing many variations of hybrid powertrain systems. The fully integrated hybrids developed to date have seen fuel consumption and CO_2 emissions reductions between 20 and 50 percent in the field where they are used in high kinetic intensity applications. However, there are still some key issues that are restricting the penetration of hybrids, including overall system cost, battery technology, and lack of cost-effective electrified accessories.

A hybrid vehicle is a vehicle that combines two significant sources of propulsion energy, where one uses a consumable fuel (like diesel), and one is rechargeable (during operation, or by another energy source). Hybrid technology is well established in the U.S. light-duty market, some manufacturers have been producing heavy-duty hybrid models for many years, and others are looking to develop hybrid models in future years.

Hybrids reduce fuel consumption through three major mechanisms:

- The internal combustion engine can be optimized (through downsizing, modifying the operating cycle, or other control techniques) to operate at or near its most efficient point more of the time. Power loss from engine downsizing can be mitigated by employing power assist from the secondary power source.
- Some of the energy normally lost as heat while braking can be captured and stored in the energy storage system for later use.
- The engine is turned off when it is not needed, such as when the vehicle is coasting or when stopped.

Hybrid vehicles utilize some combination of these three mechanisms to reduce fuel consumption and CO_2 emissions. The effectiveness of fuel consumption and CO_2 reduction depends on the utilization of the above mechanisms and how aggressively they are pursued. One area where this variation is particularly prevalent is in the choice of engine size and its effect on balancing fuel economy and performance. Some manufacturers choose not to downsize the engine when applying hybrid technologies. In these cases, performance is vastly improved, while fuel efficiency improves significantly less than if the engine were downsized to maintain the same performance as the conventional version. The non-downsizing approach is used for vehicles where towing and/or hauling are an integral part of their performance requirements. In these cases, if the engine is downsized, the battery can be quickly drained during a long hill climb with a heavy load, leaving only a downsized engine to carry the entire load. Because towing capability is currently a heavily-marketed HD pickup truck attribute, manufacturers are hesitant to offer a truck with a downsized engine that can lead to a significantly diminished towing performance when the battery state of charge level is low, and therefore engines are traditionally not downsized for these vehicles. In assessing the cost of hybrid technology for heavy duty vehicles, the agencies have assumed that engines will not be downsized.

Strong hybrid technology utilizes an axial electric motor connected to the transmission input shaft and connected to the engine crankshaft through a clutch. The axial motor is a motor/generator that can provide sufficient torque for launch assist, all electric operation, and the ability to recover significant levels of braking energy.

A hybrid drive unit is complex and consists of discrete components such as the electric traction motor, transmission, generator, inverter, controller and cooling devices. Certain types of drive units may work better than others for specific vehicle applications or performance requirements. Several types of motors and generators have been developed for hybrid-electric drive systems, many of which merit further evaluation and development on specific applications. Series HEVs typically have larger motors with higher power ratings because the motor alone propels the vehicle, which may be applicable to Class 3-5 applications. In parallel hybrids, the power plant and the motor combine to propel the vehicle. Motor and engine torque are usually blended through couplings, planetary gear sets and clutch/brake units. The same mechanical components that make parallel heavy-duty hybrid drive units possible can be designed into series hybrid drive units to decrease the size of the electric motor(s) and power electronics.

An electrical energy storage system is needed to capture energy from the generator, to store energy captured during vehicle braking events, and to return energy when the driver demands power. This technology has seen a tremendous amount of improvement over the last decade and recent years. Advanced battery technologies and other types of energy storage are emerging to give the vehicle its needed performance and efficiency gains while still providing a product with long life. The focus on the more promising energy storage technologies such as nickel metal-hydride (NiMH) and lithium technology batteries along with ultra-capacitors for the heavy-duty fleet should yield interesting results after further research and applications in the light-duty fleet.

Heavy-duty hybrid vehicles also use regenerative braking for improved fuel economy, emissions, brake heat, and wear. A conventional heavy vehicle relies on friction brakes at the wheels, sometimes combined with an optional engine retarder or driveline retarder to reduce vehicle speed. During normal braking, the vehicle's kinetic energy is wasted when it is converted to heat by the friction brakes. The conventional brake configuration has large components, heavy brake heat sinks, and high temperatures at the wheels during braking, audible brake squeal, and consumable components requiring maintenance and replacement. Hybrid electric systems recover some of the vehicle's kinetic energy through regenerative braking, where kinetic energy is captured and directed to the energy storage system. The remaining kinetic energy is dissipated through conventional wheel brakes or in a driveline or transmission retarder. Regenerative braking in a hybrid electric vehicle can require integration with the vehicle's foundation (friction) braking system to maximize performance and safety.

Today's systems function by simultaneously using the regenerative features and the friction braking system, allowing only some of the kinetic energy to be saved for later use.

Optimizing the integration of the regenerative braking system with the foundation brakes would increase the benefits and is a focus for continued work. This type of hybrid regenerative braking system improves fuel economy, GHG emissions, brake heat, and wear.

In a hydraulic hybrid system, deceleration energy is taken from the drivetrain by an inline hydraulic pump/motor unit by pumping hydraulic fluid into high pressure cylinders. The fluid, while not compressible, pushes against a membrane in the cylinder that compresses an inert gas to 5,000 PSI or more when fully charged. Upon acceleration, the energy stored in the pressurized tank pushes hydraulic fluid back into the drivetrain pump/motor unit, allowing it to motor into the drivetrain and assist the vehicle's engine with the acceleration event. This heavy-duty vehicle hybrid approach has been demonstrated successfully, producing good results on a number of commercial and military trucks.

Despite the significant future potential for hybrids discussed above, there are no simple solutions applicable for each heavy-duty hybrid application due to the large vocational vehicle fleet variation. A choice must be made relative to the requirements and priorities for the application. Challenges in motor subsystems such as gear reductions and cooling systems must be considered when comparing the specific power, power density, and cost of the motor assemblies. High speed motors can significantly reduce weight and size, but they require speed reduction gear sets that can offset some of the weight savings, reduce reliability and add cost and complexity. Air-cooled motors are simpler and generally less expensive than liquid cooled motors, but they are larger and heavier, and they require access to ambient air, which can carry dirt, water, and other contaminants. Liquid-cooled motors are generally smaller and lighter for a given power rating, but they may require more complex cooling systems that can be avoided with air-cooled versions. Various coolant options, including water, water-glycol, and oil, are available for liquid-cooled motors but must be further researched for long term durability. Electric motors, power electronics, electrical safety, regenerative braking, and power-plant control optimization have been identified as the most critical technologies requiring further research to enable the development of higher efficiency hybrid electric propulsion systems.

2.4.5 Axles

2.4.5.1 Axle Efficiency

Axle efficiency is improved by reducing generally two categories of losses; mechanical losses and spin losses.

Mechanical losses can be reduced by reducing the friction between the two gears in contact. This friction is reduced mainly by improving the surface finish of the gears. The other way of doing this by reducing the amount of distance the gear faces are sliding against each other. Generally speaking frictional losses are proportional to the torque on the axle not a function of rotational speed of the axle.

Spin losses on the other hand are a function of speed and not torque. One of the main ways to reduce the spin losses of the axle is by using a lower viscosity lubricant. Some high-performance lower viscosity formulations have been designed to have superior performance at high operating temperatures, and may have extended change intervals.

A study conducted by researchers at Shell Global Solutions on a Mercedes Benz OM 460LA heavy-duty diesel engine run under the World Harmonized Transient Cycle (WHTC) and World Harmonized Stationary Cycle (WHSC), used a combination of a SAE 5W-30 engine oil, SAE 75W-80 gearbox oil and SAE 75W-90 axle oil. The combination yielded average fuel economy improvements of 1.8 percent over the WHTC and 1.1 percent over the WHSC, relative to a SAE 15W-40 engine oil, SAE 80W gearbox and SAE 90 axle oil [VT-27]. The baseline lubricants represent current mainstream products, and the new lubricants were top-tier formulations focusing on modified viscometric effects. Using the WHSC cycle, significant variations in the individual lubricant contribution under different speed and load conditions within the cycle were identified. Additionally, an average fuel economy improvement of 1.8 percent was observed using medium-duty trucks under a range of typical European driving conditions in a controlled field trial.[67]

Spin losses can also be reduced by lowering the volume of lubricant in the sump. This reduces the surface area of the gears that are churning through the lubricant. One of the main challenges of doing this is making sure that there is still adequate coverage of lubricant on the gears and bearings as well as adequate circulation so that the lubricant temperature does not rise too high and accelerate the aging of the lubricant.

If a manufacturer wishes to demonstrate a benefit specific to any technology that improves axle efficiency, an axle efficiency test can be performed and input into GEM. See RIA Chapter 3 for a description of the test procedure for axle efficiency.

2.4.5.2 Gear Ratio

Combining with transmission ratio, selection of the axle ratio can play a significant role in vehicle performance. For an on-highway tractor, the axle ratio must be selected in such a way that the engine can constantly run inside the sweet spot, where the engine efficiency is optimal for a typical constant cruise speed like 65 miles per hour. Although many vehicles on the road already use a fast axle ratio as low as 2.64:1 with the direct drive of transmission, which moves the engine speed in the range of 1200 rpm or even lower, most vehicles still use higher or slower axle ratio, which puts the engine speed in the range of 1300-1400 rpm. In order to take advantage of optimal engine speed, which is typically in the range of 1100-1150 rpm for HHD diesel vehicles, it is expected that a faster axle ratio lower than 2.64:1 would be widely used in 2018 and beyond for tractors. Furthermore, in order to enhance vehicle performance, many axle manufacturers are developing dual speed axles, allowing vehicles to switch to a higher axle ratio during transient driving conditions, such as city traffic. On the vocational side, the ability to start a heavy vehicle, climb hills, and operate smoothly at low speed is strongly influenced by axle ratio, and therefore, one can see a large variation of axle ratios depending on the application.

2.4.5.3 Tandem Drive Axle Improvements

Manufacturers are developing technologies to enable heavy trucks with two rear drive axles to be driven solely by the lead rear axle either permanently or on a part time basis.

2.4.5.3.1 6 x 2

Most tractors and heavy heavy-duty vocational vehicles today have three axles – a steer axle and two rear drive axles, which is commonly referred to as a 6x4 configuration. Manufacturers offer 6x2 tractors that include one rear drive axle and one rear non-driving axle. The 6x2 tractors offer three distinct benefits. First, the non-driving rear axle does not have internal friction and therefore reduces the overall parasitic losses in the drivetrain. In addition, the 6x2 configuration typically weighs approximately 300 to 400 pounds less than a 6x4 configuration.[68] Finally, the 6x2 typically costs less or is cost neutral when compared to a 6x4 tractor. Sources cite the effectiveness of 6x2 axles at between 1 and 3 percent.[69] Similarly, with the increased use of double and triple trailers, which reduce the weight on the tractor axles when compared to a single trailer, manufacturers offer 4x2 axle configurations. The 4x2 axle configuration would have as good as or better fuel efficiency performance than a 6x2.

2.4.5.3.2 Enhanced 6x2

One of the drawbacks of 6x2 axle is lack of traction, specifically during the winter condition and high grade road when the road is slippery. In order to overcome this deficiency, some axle manufacturers offer products that perform similar to the 6x4 configurations. SMARTandem offered by Meritor is just one of the examples.[70] In this system, the axle runs 6x2 for most time. Once the conditions that require more traction are experienced, the vehicle activates the system to add more loads into one the powered axle, thus instantly increasing traction. This system offers weight savings in the range of 300 to 400 lbs, as well as 2 percent fuel saving when compared to a conventional 6x4 axle.

2.4.5.3.3 Part Time 6x2 Axle

Based on confidential stakeholder discussions, the agencies anticipate that the axle market may offer, in the time frame of Phase 2, a Class 8 version of the type of axle disconnect that today allows 4x4 operators of HD pickup trucks to automatically disconnect or reconnect the front axle depending on needs for traction in varying driving conditions. The Class 8 version would likely function for the two tandem drive axles in a similar manner as the HD pickup trucks do for the front axle. The switching could be automated or user-commanded. In these cases, the axle actuator housing, sometimes called the axle disconnect housing, is part of the differential that houses the gears and shift fork required to lock two axles together. The axle actuator works together with the transfer case to send torque to all four wheel-ends. Recently, Dana Holding Corporation has developed an axle system that switches between the two modes based on driving conditions to maximize driveline efficiency.[71] When high traction is required, the system operates in 6x4 mode. When 6x4 tractive effort is not required, the system operates in 6x2 mode. It is reported that this type of system can offer a benefit of 2.5 percent.

In the 4x4 example, the transfer case connects the input from the transmission to the rear and front driveshafts. The axle actuator housing is found on the differential. In the 4x4 example, a shift fork inside the axle actuator housing slides a locking collar over two gears locking both driver and passenger side axles together. In some 4x4 vehicles, those with automatic 4WD, this process occurs automatically. In others, with selective 4WD, the driver can choose to engage 4WD or RWD with a switch. These have slightly different axle actuator housings and have actuator solenoids mounted to them.[72] These systems would not provide the weight reduction benefit of the permanent 6x2 configuration, and may offer less fuel savings, especially with operator-switchable systems.

2.4.6 Weight Reduction

Mass reduction is a technology that can be used in a manufacturer's strategy to meet the Phase 2 standards (although the agencies are not predicating the standards on use of downsizing). Vehicle mass reduction (also referred to as "light-weighting"), decreases fuel consumption and GHG emissions by reducing the energy demand needed to overcome inertia forces, and rolling resistance. Reduced mass in heavy-duty vehicles can benefit fuel efficiency and CO_2 emissions in two ways. If a truck is running at its gross vehicle weight limit with high density freight, more freight can be carried on each trip, increasing the truck's ton-miles per gallon. If the vehicle is carrying lower density freight and is below the GVWR (or GCW) limit, the total vehicle mass is decreased, reducing rolling resistance and the power required to accelerate or climb grades.

Many vehicle components are typically made of heavier material, such as traditional steel. Manufacturers have worked with mass reduction technologies for many years and a lot of these technologies have been used in production vehicles. The weight savings achieved by adopting mass reduction technologies offset weight gains due to increased vehicle size, larger powertrains, and increased feature content (sound insulation, entertainment systems, improved climate control, etc.). Generally, an empty truck contributes to about one-third of the total vehicle weight. Every 10 percent drop in vehicle weight reduces fuel use about 5 percent.[73]

Although many gains have been made to reduce vehicle mass, many of the features being added to modern tractors to benefit fuel efficiency, such as additional aerodynamic features or idle reduction systems, have the effect of increasing vehicle weight, causing mass to stay relatively constant. Material and manufacturing technologies can also play a significant role in vehicle safety by reducing vehicle weight, and in the improved performance of vehicle passive and active safety systems. Hybrid powertrains, fuel cells and auxiliary power would not only present complex packaging and weight issues, they would further increase the need for reductions in the weight of the body, chassis, and powertrain components in order to maintain vehicle functionality.

Manufacturers may employ a systematic approach to mass reduction, where the net mass reduction is the addition of a direct component or system mass reduction, also referred to as primary mass reduction, plus the additional mass reduction taken from indirect ancillary systems and components, also referred to as secondary mass reduction or mass compounding.

Mass reduction can be achieved through a number of approaches, even while maintaining other vehicle functionalities. As summarized by NAS in its 2011 light duty vehicle report, there are two key strategies for primary mass reduction: 1) substituting lighter materials for heavier materials; and 2) changing the design to use less material.[74]

2.4.6.1 Material Substitution

Substitution of a material used in an assembly or a component for one with lower density and/or higher strength includes replacing a common material such as mild steel with higher-strength and advanced steels, aluminum, magnesium, and composite materials. In practice, material substitution tends to be quite specific to the manufacturer and situation. Some materials work better than others for particular vehicle components, and unless strength is matched, some substituted components may need to be more numerous (i.e. two brackets instead of one). Further, one choices of material may lead a manufacturer to invest more heavily in adjusting its manufacturing process to its properties, thus possibly impeding its ability to consider other materials. The agencies recognize that like any type of mass reduction, material substitution has to be conducted not only with consideration to maintaining equivalent component strength, but also to maintaining all the other attributes of that component, system or vehicle, such as crashworthiness, durability, and noise, vibration and harshness (NVH).

One example that combines material substitution with component-elimination is the use of wide-based single tires and aluminum rims to replace traditional dual tires and rims, eliminating eight steel rims and eight tires from a tractor. Using aluminum, metal alloys, metal matrix composites, and other lightweight components where appropriate can reduce empty vehicle weight (known as "tare weight"), improve fuel efficiency, and reduce greenhouse gas emissions. In addition, in weight-sensitive applications, lightweight components can allow more cargo and increased productivity. A report by the National Commission on Energy Policy estimates that a fuel economy gain of 5.0 percent on certain applications could be achieved by vehicle mass reduction further illustrating the fuel economy gains possible on heavy-duty applications.[75] A report for the U.S. DOT estimated potential reductions in modal GHG emissions are 4.6 percent, though it also found that current light-weight materials are costly and are application- and vehicle-specific with need for further research and development for advanced materials.[76]

The principal barriers to overcome in reducing the weight of heavy vehicles are associated with the cost of lightweight materials, the difficulties in forming and manufacturing lightweight materials and structures, the cost of tooling for use in the manufacture of relatively low-volume vehicles (when compared to automotive production volumes), and ultimately, the extreme durability requirements of heavy vehicles. While light-duty vehicles may have a life span requirement of several hundred thousand miles, typical heavy-duty commercial vehicles must last over 1 million miles with minimum maintenance, and often are used in secondary applications for many more years. This requires high strength, lightweight materials that provide resistance to fatigue, corrosion, and can be economically repaired. Additionally, because of the limited production volumes and the high levels of customization in the heavy-duty market, tooling and manufacturing technologies that are used by the light-duty automotive industry are often uneconomical for heavy vehicle manufacturers. Lightweight materials such as aluminum, titanium and carbon fiber composites provide the opportunity for significant weight reductions, but their material cost and challenging forming and manufacturing requirements make it difficult for them to compete with low-cost steels. In addition, although mass reduction is currently occurring on both vocational vehicles and line haul tractor-trailers, the addition of other systems for fuel economy, performance or comfort increases the vehicle mass offsetting the mass reduction that has already occurred, thus it is not captured in the overall vehicle mass measurement (e.g. 500 lbs for WHR). Most vehicle manufacturers offer lightweight tractor models that are 1,000 or more pounds lighter than comparable models. Lighter-weight models combine different weight-saving options that may include:[77]

- Cast aluminum alloy wheels can save up to 40 pounds each for total savings of 400 pounds
- Aluminum axle hubs can save over 120 pounds compared to ductile iron or steel
- Centrifuge brake drums can save nearly 100 pounds compared to standard brake drums
- Aluminum clutch housing can save 50 pounds compared to iron clutch housing
- Composite front axle leaf springs can save 70 pounds compared to steel springs
- Aluminum cab frames can save hundreds of pounds compared to standard steel frames

2.4.6.2 Synergistic Effects - Reduced Power Demand

Manufacturers employ a systematic approach to mass reduction, where the net mass reduction is the addition of a direct component or system mass reduction plus the additional mass reduction that can be taken from indirect ancillary systems and components, as a result of full vehicle optimization, effectively compounding or obtaining a secondary mass reduction from a primary mass reduction. The strategy of using less material compared to the baseline component or system can be achieved by optimizing the design and structure of vehicle components, systems and vehicle structure. Vehicle manufacturers have long used these continually-improving CAE tools to optimize vehicle designs. For example, the Future Steel Vehicle (FSV) project sponsored by WorldAutoSteel used three levels of optimization: topology optimization, low fidelity 3G (Geometry, Grade, and Gauge) optimization, and subsystem optimization, to achieve 30 percent mass reduction in the body structure of a vehicle with a mild steel unibody structure.[78] Using less material can also be achieved through improving the manufacturing process, such as by using improved joining technologies and parts consolidation. This method is often used in combination with applying new materials.

If vehicle mass is reduced sufficiently through application of the two primary strategies of using less material and material substitution described above, secondary mass reduction options may become available. Secondary mass reduction is enabled when the load requirements of a component are reduced as a result of primary mass reduction. If the primary mass reduction reaches a sufficient level, a manufacturer may use a smaller, lighter, and potentially more efficient powertrain while maintaining vehicle performance. If a powertrain is downsized, a portion of the mass reduction may be attributed to the reduced torque requirement that results from the lower vehicle mass. The lower torque requirement enables a reduction in engine displacement, changes to transmission torque converter and gear ratios, and changes to the final drive gear ratio. The reduced powertrain torque may enable the downsizing and/or mass reduction of powertrain components and accompanying reduced rotating mass (e.g., for transmission, driveshafts/halfshafts, wheels, and tires) without sacrificing powertrain durability. However, there may be trade-offs, as it is possible that use of a downsized engine may require a transmission with more gears. The combined mass reductions of the engine, drivetrain, and body would reduce stresses on the suspension components, steering components, wheels, tires, and brakes, which can allow further reductions in the mass of these subsystems. Reducing the unsprung masses such as the brakes, control arms, wheels, and tires further reduce stresses in the suspension mounting points, which would allow for further optimization and potential mass reduction.

One example of a synergistic effect is rotational inertia. Reducing the weight of rotating components provides an enhanced fuel efficiency benefit over reducing the weight of static components. In theory, as components such as brake rotors, brake drums, wheels, tires, crankshafts, camshafts, and piston assemblies become lighter, the power consumption to rotate the masses would be directly proportional to the mass decrease. Using physical properties of a rotating component such as a wheel, it is relatively straightforward to calculate an equivalent mass. However, we do not have enough information to derive industry average values for equivalent mass, nor have we evaluated the best way for GEM to account for this. Using typical values for a heavy-duty steel wheel compared to a similar-sized aluminum wheel, the agencies estimate the equivalent mass ratio is in the range of 1.2 to 1.3. That means that by reducing the mass of a wheel by 20 pounds, the vehicle could theoretically perform as if 26 pounds had been reduced.

Estimates of the synergistic effects of mass reduction and the compounding effect that occurs along with it can vary significantly from one report to another. For example, in discussing its estimate, an Auto-Steel Partnership report states that “These secondary mass changes can be considerable—estimated at an additional 0.7 to 1.8 times the initial mass change.”[79] This means for each one pound reduction in a primary component, up to 1.8 pounds can be reduced from other structures in the vehicle (*i.e.*, a 180 percent factor). The report also discusses that a primary variable in the realized secondary weight reduction is whether or not the powertrain components can be included in the mass reduction effort, with the lower end estimates being applicable when powertrain elements are unavailable for mass reduction. However, another report by the Aluminum Association, which primarily focuses on the use of aluminum as an alternative material for steel, estimated a factor of 64 percent for secondary mass reduction even though some powertrain elements were considered in the analysis.[80] That report also notes that typical values for this factor vary from 50 to 100 percent. Although there is a wide variation in stated estimates, synergistic mass reductions do exist, and the effects result in tangible mass reductions. Mass reductions in a single vehicle component, for example a door side impact/intrusion system, may actually result in a significantly higher weight savings in the total vehicle, depending on how well the manufacturer integrates the modification into the overall vehicle design. Accordingly, care must be taken when reviewing reports on weight reduction methods and practices to ascertain if compounding effects have been considered or not.

2.4.7 Vehicle Speed Limiter

The power required to move a vehicle increases as the vehicle speed increases. Travelling at lower speeds provides additional efficiency to the vehicle performance. Most vehicles today have the ability to electronically control the maximum vehicle speed through the engine controller. This feature is used today by fleets and owners to provide increased safety and fuel economy. Currently, these features are designed to be able to be changed by the owner and/or dealer.

The impact of this feature is dependent on the difference between the governed speed and the speed that would have been travelled, which is dependent on road type, state speed limits, traffic congestion, and other factors. The agencies assess the benefit of a vehicle speed limiter by reducing the maximum drive cycle speed on the 65 mph Cruise mode of the cycle. The maximum speed of the drive cycle is 65 mph, therefore any vehicle speed limit with a setting greater than this would show no benefit for purposes of these regulations, but may still show benefit in the real world in states where the interstate truck speed limit is greater than the national average of 65.5 mph.

The benefits of this simple technology are widely recognized. The American Trucking Association (ATA) developed six recommendations to reduce carbon emissions from trucks in the United States. Their first recommendation is to enact a national truck speed limit of 65 mph and require that trucks manufactured after 1992 have speed governors set at not greater than 65 mph.[81] The SmartWay program includes speed management as one of their key Clean Freight Strategies and provides information to the public regarding the benefit of lower highway speeds.[82]

Some countries have enacted regulations to reduce truck speeds. For example, the United Kingdom introduced regulations in 2005 which require new trucks used for goods movement to have a vehicle speed limiter not to exceed 90 km/hr (56 mph).[83] The Canadian Provinces of Ontario and Quebec developed regulations which took effect in January 2009 that requires on-highway commercial heavy-duty trucks to have speed limiters which limit the truck's speed to 105 km/hr (65 mph).[84]

Many truck fleets consider speed limiter application a good business practice in their operations. A Canadian assessment of heavy-duty truck speed limiters estimated that 60 percent of heavy truck fleets in North America use speed limiters.[84] Con Way Freight, Con Way Truckload, and Wal-Mart currently govern the speeds of their fleets between 62 and 65 mph.[85]

A potential disbenefit of this technology is the additional time required for goods movement, or loss of productivity. The elasticity between speed reduction and productivity loss has not been well defined in industry. The Canadian assessment of speed limiters cited above found that the fuel savings due to the lower operating speeds outweigh any productivity losses. A general consensus among the OEMs is that a 1 percent decrease in speed might lower productivity by approximately 0.2 percent.[85]

In Phase 1, the agencies did not premise the tractor standards on a technology package that included VSL. Vehicle speed limiters are a technology recognized in Phase 1 GEM, but manufacturers are not opting to use the tamper-resistant VSLs as a strategy for complying with the early years of Phase 1 CO_2 emissions and fuel consumption standards.

The impact of VSL set to 55 mph of a typical high roof tractor-trailer is approximately 7 percent for day cabs and 10 percent for sleeper cabs, as shown below in Figure 2-14.

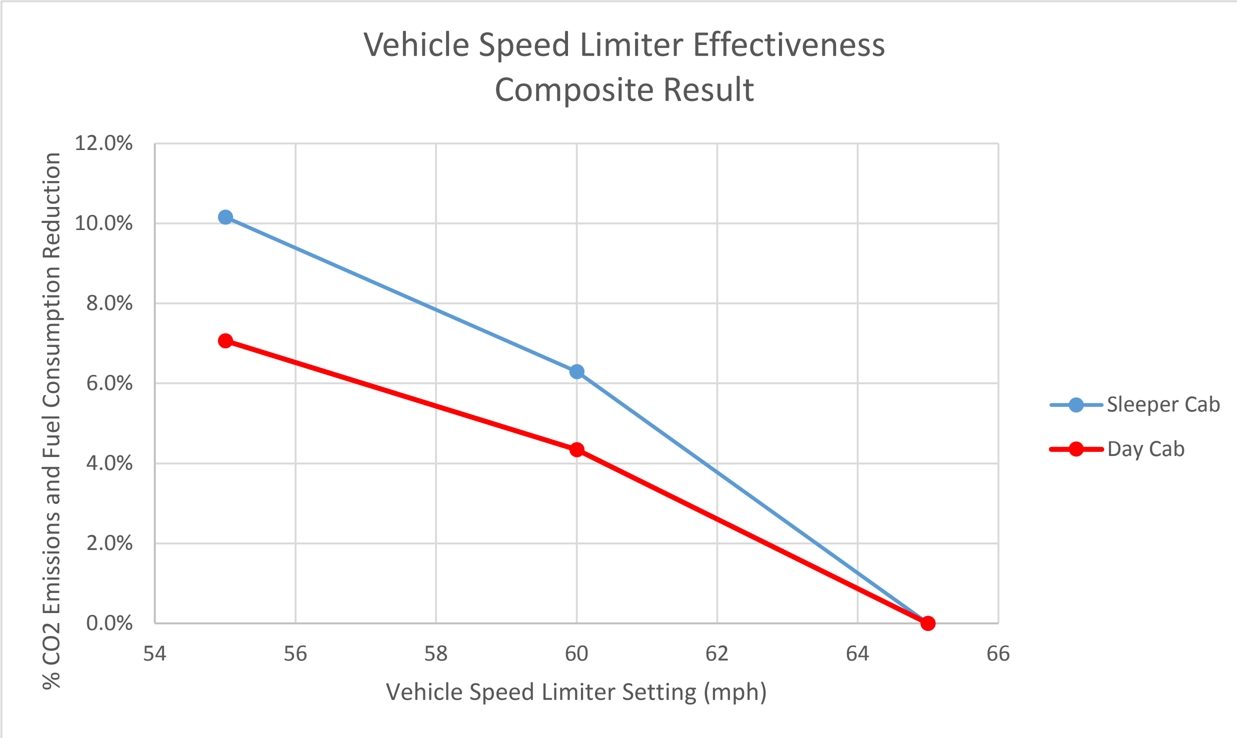


Figure 2-14 Vehicle Speed Limiter Effectiveness in Tractors

2.4.8 Reduced Idling Time

2.4.8.1 Engine Shutdown with Alternate Power Source during Hoteling

Class 8 heavy-duty diesel truck extended engine idling expends significant amounts of fuel in the United States. Department of Transportation regulations require a certain amount of rest for a corresponding period of driving hours, as discussed in Chapter 1. Extended idle occurs when Class 8 long haul drivers rest in the sleeper cab compartment during rest periods as drivers find it more convenient and economical to rest in the truck cab itself. In many cases it is the only option available. During this rest period a driver will generally idle the truck in order to provide heating or cooling or run on-board appliances. During rest periods the truck's main propulsion engine is running but not engaged in gear and it remains in a stationary position. In some cases the engine can idle in excess of 10 hours. During this period of time, fuel consumption will generally average 0.8 gallons per hour.[86] Average overnight fuel usage would exceed 8 gallons in this example. When multiplied by the number of long haul trucks without idle control technology that operate on national highways on a daily basis, the number of gallons consumed by extended idling would exceed 3 million gallons per day. Fortunately, a number of alternatives (idling reduction technologies) are available to alleviate this situation.

2.4.8.1.1 Idle Control Technologies

Idle reduction technologies in general utilize an alternative energy source in place of operating the main engine. By using these devices the truck driver can obtain needed power for services and appliances without running the engine. A number of these devices attach to the truck providing heat, air conditioning, or electrical power for microwave ovens, televisions, etc.

The idle control technologies (along with their typical hourly fuel rate) available today include the following:[87]

- Auxiliary Power Unit (APU) powers the truck's heating, cooling, and electrical system. The fuel use of an APU is typically 0.2 gallons per hour
- Fuel Operated Heater (FOH) provides heating services to the truck through small diesel fired heaters. The fuel use is typically 0.04 gallons per hour
- Battery Air Conditioning Systems (BAC) provides cooling to the truck
- Automatic Stop/Start Systems powers the truck systems through the battery and starts the engine to recharge the battery after it reaches a threshold level.
- Thermal Storage Systems provide cooling to trucks

Another alternative involves electrified parking spaces, with or without modification to the truck. An electrified parking space system operates independently of the truck's engine and allows the truck engine to be turned off while it supplies heating, cooling, and electrical power. These systems provide off-board electrical power to operate either:

1. A single system electrification which requires no on-board equipment by providing an independent heating, cooling, and electrical power system, or
2. A dual system which allows driver to plug in on-board equipment

In the first case, power is provided to stationary equipment that is temporarily attached to the truck. In the second, the truck is modified to accept power from the electrical grid to operate on-board truck equipment. The retail price of idle reduction systems varies depending on the level of sophistication. For example, on-board technologies such as APUs can retail for over $8,000 while options such as electrified parking spaces require negligible up-front costs for equipment for the tractor itself, but will accrue fees with usage.[88]

CO_2 emissions and fuel consumption during extended idling are significant contributors to emissions and fuel consumption from Class 8 sleeper cabs. The federal test procedure does evaluate idle emissions and fuel consumption as part of the drive cycle and related emissions measurement. However, long duration extended idle emissions and fuel consumption are not fully represented during the prescribed test cycle. To address the fact that real-world fuel and emissions savings can occur with idle reduction technologies that cannot be reflected on the test cycle, the agencies adopted a GEM input for manufacturers who provide for idle control using an automatic engine shutdown system (AESS) on the tractor.

The GEM input, calculated as shown in Table 2-5, recognizes the CO_2 reductions and fuel consumption savings attributed to idle control systems and allows vehicle manufacturers flexibility in product design and performance capabilities. The agencies first determined the fuel consumption of each idle reduction technology, as noted previously. Due to the range of fuel consumption of APUs and the precision of the available test information, the agencies are utilizing, as proposed, an APU fuel consumption of 0.2 gal/hr. Then the agencies determined a split between idling hours using the main engine versus the idle reduction technology. For example, the baseline idle emission rate was assumed to be determined by 100 percent main engine idling. For APU and battery APU technologies with a tamper-proof AESS, the agencies assumed that these technologies would be operating 100 percent of the idling time. For automatic start/stop systems with a tamper-proof AESS, the agencies determined that the idling power would come from the battery half of the idling time and the other half would require main engine idling. For fuel operated heaters with a tamper-proof AESS, the agencies assumed that 800 of the idling hours would involve the use of the fuel operated heater and that the main engine would idle for the other 1000 hours per year to supply cooling and other needs. For idle reduction technologies with an adjustable AESS, the agencies discounted the number of hours operated by the idle reduction technology by 20 percent to account for the fact that it is an adjustable (non tamper-proof) system. For adjustable AESS without an additional idle reduction technology, the agencies set the number of main engine operating hours at 25 percent of the total idle time to also reflect that it is adjustable and that the agencies have less certainty in the continued use of this in the real world.

MEMA commented that the agencies should assume 2,500 hours of idling per year. The agencies reviewed this and other studies to quantify idling operation. The 2010 NAS study assumes between 1,500 and 2,400 idling hours per year.[89] Gaines uses 1,800 hours per year.[90] Brodrick, et al. assumes 1,818 hours per year (6 hours per day for 303 days per year) based on an Argonne study and Freightliner fleet customers.[91] An EPA technical paper states between 1,500 and 2,400 hours per year.[92] Kahn uses 1,830 hours as the baseline extended idle case.[93] Based on the literature, the agencies are finalizing as proposed the use of 1,800 hours per year as reasonably reflecting the available range of information.

The agencies assumed the average Class 8 sleeper cab travels 125,000 miles per year (500 miles per day and 250 days per year) and carries 19 tons of payload (the standardized payload finalized for Class 8 tractors) to calculate the baseline running emissions. For each technology combination, the sum of the running and idling emissions was calculated and the percent reduction in CO_2 emissions from the main engine idling scenario was calculated. These percent reduction values are included in 40 CFR 1037.520.

Table 2-4 Idle CO_2 Emissions per Year for Idle Reduction Technologies

	Idle Fuel Consumption (gal/hour)	Idle CO_2 emissions per hour	IRT Idle Hours per Year	Main Engine Idle Hours per Year	Idle CO_2 Emission per year (grams)
Baseline	0.8	8144		1800	14,659,200
Tamper-Proof AESS	0.3	3054	1800	0	5,497,200
Tamper-Proof AESS w/ Diesel APU	0.3	3054	1800	0	5,497,200
Tamper-Proof AESS w/ Battery APU	0.02	203.6	1800	0	366,480
Tamper-Proof AESS w/ Automatic Stop-Start	0	0	900	900	7,329,600
Tamper-Proof AESS w/ FOH Cold, Main Engine Warm	0.04	407.2	800	1000	8,469,760
Adjustable AESS w/ Diesel APU	0.3	3054	1440	360	7,329,600
Adjustable AESS w/ Battery APU	0.02	203.6	1440	360	3,225,024
Adjustable AESS w/ Automatic Stop-Start	0	0	720	1080	8,795,520
Adjustable AESS w/ FOH Cold, Main Engine Warm	0.04	407.2	640	1160	9,707,648
Adjustable AESS programmed to 5 minutes	0.3	3054	450	1350	12,368,700

Table 2-5 GEM Input for Idle Reduction Technologies

	TYPICAL G/TON-MILE	MILES PER YEAR	PAYLOAD (TONS)	GHG EMISSIONS DUE TO RUNNING (g)	GHG EMISSIONS DUE TO RUNNING PLUS IDLE (g)	% RED. FROM BASELINE
Baseline	88	125000	19	209,000,000	223,659,200	0%
Tamper-Proof AESS	88	125000	19	209,000,000	214,497,200	4.1%
Tamper-Proof AESS w/ Diesel APU	88	125000	19	209,000,000	214,497,200	4.1%
Tamper-Proof AESS w/ Battery APU	88	125000	19	209,000,000	209,366,480	6.4%
Tamper-Proof AESS w/ Automatic Stop-Start	88	125000	19	209,000,000	216,329,600	3.3%
Tamper-Proof AESS w/ FOH Cold, Main Engine Warm	88	125000	19	209,000,000	217,469,760	2.8%
Adjustable AESS w/ Diesel APU	88	125000	19	209,000,000	216,329,600	3.3%
Adjustable AESS w/ Battery APU	88	125000	19	209,000,000	212,225,024	5.1%
Adjustable AESS w/ Automatic Stop-Start	88	125000	19	209,000,000	217,795,520	2.6%
Adjustable AESS w/ FOH Cold, Main Engine Warm	88	125000	19	209,000,000	218,707,648	2.2%
Adjustable AESS programmed to 5 minutes	88	125000	19	209,000,000	221,368,700	1.0%

2.4.8.2 Stop Start

For heavy-duty vehicles to apply engine stop-start technology without a reduction in vehicle function, some additional vehicle technologies are needed. To some extent this could be considered similar to a mild hybrid system, but it is not the same as the mild hybrid system described for HD pickups and vans described below in Chapter 2.5. The agencies are projecting the presence of a battery sufficient to offer electrified power steering, and some other electrified accessories. Some systems may replace the conventional alternator with a belt or crank driven starter/alternator and may add high voltage electrical accessories (which may include electric power steering and an auxiliary automatic transmission pump). The limited electrical requirements of these systems allow the use of lead-acid batteries or supercapacitors for energy storage, or the use of a small lithium-ion battery pack.

The NACFE Idle Reduction Confidence report was written with long haul tractors in mind; however the section on vehicle electrification discusses inverters and on-vehicle solar energy capture, and offers some insights relevant to vocational vehicle electrification as it pertains to stop-start systems.[94] Inverters and beltless alternators can use DC power stored in batteries to power on-board electrical devices and re-start engines. One example of a company that supplies battery-inverter idle reduction systems for vocational vehicles is Vanner.[95] There are also systems available today that are designed to capture solar energy and store this energy for distribution to electrified accessories and engine re-starting. One example of a company that supplies on-vehicle solar energy capture for vocational vehicles is eNow.[96]

2.4.8.3 Neutral Idle

Automatic transmissions historically apply torque to an engine when in gear at zero speed because of torque converter, such as when stopped at a traffic light. A neutral idle technology can disengage transmission with torque converter, thus reducing power loss to a minimum.

2.4.9 Air Conditioning

2.4.9.1 Refrigerant Leakage

Hydrofluorocarbon (HFC) refrigerants, which are powerful GHG pollutants, can be emitted to the atmosphere through component and system leaks during operation, during maintenance and servicing, and with disposal at the end of the vehicle's life. The current widely-used refrigerant – R134a, has a much higher global warming potential (GWP) than CO_2, therefore a small leakage of this refrigerant has a much greater global warming impact than a similar amount of emissions of CO_2 or other mobile source GHGs.

Direct emissions of HFC from air conditioning systems can be reduced by minimizing system leaks. Based on measurements from 300 European light-duty vehicles (collected in 2002 and 2003), Schwarz and Harnisch estimate that the average HFC direct leakage rate from modern A/C systems was estimated to be 53 g/yr.[97] This corresponds to a leakage rate of 6.9 percent per year. This was estimated by extracting the refrigerant from recruited vehicles and comparing the amount extracted to the amount originally filled (as per the vehicle specifications). The fleet and size of vehicles differs from Europe and the United States, therefore it is conceivable that vehicles in the United States could have a different leakage rate. The authors measured the average charge of refrigerant at initial fill to be about 747 grams (it is somewhat higher in the U.S. at 770g), and that the smaller cars (684 gram charge) emitted less than the higher charge vehicles (883 gram charge). Moreover, due to the climate differences, the A/C usage patterns also vary between the two continents, which may influence leakage rates.

Vincent et al., from the California Air Resources Board estimated the in-use refrigerant leakage rate to be 80 g/yr.[98] This is based on consumption of refrigerant in commercial fleets, surveys of vehicle owners and technicians. The study assumed an average A/C charge size of 950 grams and a recharge rate of 1 in 16 years (lifetime). The recharges occurred when the system was 52 percent empty and the fraction recovered at end-of-life was 8.5 percent.

Manufacturers today are complying with the HD Phase 1 program requirements to reduce A/C leakage emissions by utilizing high-quality, low-leakage air conditioning system components in the production of new tractors, and HD pickup trucks and vans. Some of the components available to manufacturers are low-permeation flexible hoses, multiple o-ring or seal washer connections, and multiple-lip compressor shaft seals. The availability of low leakage components in the market is being driven by the air conditioning credit program in the light-duty GHG rulemaking. The cooperative industry and government Improved Mobile Air Conditioning (IMAC) program has demonstrated that new-vehicle leakage emissions can be reduced by 50 percent by reducing the number and improving the quality of the components, fittings, seals, and hoses of the A/C system.[99]

2.4.9.2 System Efficiency

CO_2 emissions and fuel consumption are also associated with air conditioner efficiency, since air conditioners create load on the engine. See 74 FR at 49529. The agencies are adopting Phase 2 provisions for tractors and vocational vehicles recognizing the opportunity for more efficient air conditioning systems.

2.4.9.3 Solar Control

Solar control glazing consists of both solar absorbing and solar reflective glazing that can reduce the temperature inside a vehicle, and therefore reduce the air conditioning requirements. The reduction in air conditioning load can lead to reductions in fuel consumption and GHG emissions. CARB's Low Emission Vehicle III Regulations (LEVIII) include a GHG credit for this technology.[100] The Enhanced Protective Glass Automotive Association indicated that new heavy-duty trucks today typically use solar absorbing glass.

Solar reflective paints reflect approximately a half of the solar energy by reflecting the infrared portion of the solar spectrum. A study conducted by National Renewable Energy Laboratory found benefits to sleeper cab tractors using reflective paint and other thermal control technologies.[101]

There are many factors that influence the level of emissions and fuel consumption reductions due to solar control glazing and solar reflective paint. The fraction of time spent idling during the daytime hours, the fraction of hours of the day that are sunny, the ambient temperatures, the wind conditions and/or vehicle speed, the fraction of the vehicles that are painted colors other than white, and other factors influence the potential impact of these technologies. Because of the difficulty in assessing the potential emission reductions from solar control paint and glazing, the agencies did not propose this technology as part of HD Phase 2. The agencies received some clarifications from ARB on our evaluation of solar technologies and some CBI from Daimler, but not a sufficient amount of information to evaluate the baseline level of solar control that exists in the heavy-duty market today, determine the effectiveness of each of the solar technologies, or to develop a definition of what qualifies as a solar control technology that could be used in the regulations. Therefore, the agencies would consider solar control to be a technology that manufacturers may consider pursuing through the off-cycle credit program.

2.4.10 Other Accessory Improvements

Electric power steering (EPS) provides a potential reduction in CO_2 emissions and fuel consumption over hydraulic power steering because of reduced overall accessory loads. This eliminates the parasitic losses associated with belt-driven power steering pumps which consistently draw load from the engine to pump hydraulic fluid through the steering actuation systems even when the wheels are not being turned. EPS is an enabler for all vehicle hybridization technologies since it provides power steering when the engine is off. EPS may be implemented on most vehicles with a standard 12V system. Some heavier vehicles such as Class 2b and 3 may require a higher voltage system which may add cost and complexity.

The 2017 light-duty final rule estimated a one to two percent effectiveness based on the 2002 NAS report, a Sierra Research report, and confidential manufacturer data. The SwRI report estimated 0.8 percent to 1 percent effectiveness. The agencies reviewed these SwRI effectiveness estimates and found them to be accurate, thus they have been retained for this rule.

In addition to the purely hybrid technologies, which decreases the proportion of propulsion energy coming from the fuel by increasing the proportion of that energy coming from electricity, there are other steps that can be taken to improve the efficiency of auxiliary functions (*e.g.*, power-assisted steering or air-conditioning) which also reduce CO_2 emissions and fuel consumption. Optimization of the auxiliary functions is collectively referred to as vehicle or accessory load electrification because they generally use electricity instead of engine power. These improvements are considered enablers for hybrid systems.

2.4.11 Predictive Cruise Control

Cruise control is commonly used in light-duty and heavy-duty applications to maintain a vehicle at a set speed. However, cruise control systems with additional intelligence and predictive control are much more complex but offer opportunities to reduce fuel consumption and GHG emissions. Many of the heavy-duty manufacturers are developing intelligent cruise control systems and though they resemble each other in overall function, each manufacturer is doing it differently.

As an example, an intelligent cruise control system partnered with a source of elevation information could detect when the vehicle is on a hill and know when it is close to cresting the hill. During this time, the vehicle may be allowed to temporarily travel at a lower speed to prevent the need for a transmission downshift, which consumes more fuel because it requires the engine to increase the rpm and run in a less efficient part of the fuel map. Similarly, predictive cruise control allows a vehicle to exceed the speed set point by a specified amount so that the vehicle will start the next hill at a higher speed and reduce the likelihood of needing to downshift on the next hill.

The amount of reduction in fuel consumption and CO_2 emissions depends significantly on the terrain. Sources estimate that the overall savings is approximately two percent.[102]

2.5 Technology Application– HD Pickups and Vans

2.5.1 Gasoline Engines

Spark ignited (gasoline) engines used in complete Class 2b and 3 pickups and vans include engines offered in a manufacturer’s light-duty truck counterparts, as well as engines specific to the Class 2b and 3 segment. Based on 2014 MY specifications, these engines typically range in displacement between 5 and 7 liters, though smaller and larger engines have also been used in this market. The majority of these engines are a V8 configuration, although the V10 configuration is also marketed.

The engine technologies are based on the technologies described in the Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards Joint Technical Support Document and in Chapter 2. 3 above.[103] (Note, however, that because this section deals specifically with application to 2b/3 vehicles, the projected effectiveness may vary from that presented in the generic discussions presented earlier). Some of the references come from the 2010 NAS Report, Technologies and Approaches to Reducing the Fuel Consumption of Medium and Heavy-Duty Vehicles. These technologies include engine friction reduction, cam phasing, cylinder deactivation and stoichiometric gas direct injection. Included with each technology description is an estimate of the improvement in fuel consumption and GHGs that is achievable through the use of the technology in heavy-duty pickup trucks and vans over their applicable operation and test cycles.

The technology effectiveness values are generally described as ranges that represent expected levels of effectiveness with appropriate implementation of the technology but actual effectiveness levels will vary with manufacturer-specific design, and with specifications for the technologies. These may include considerations for durability or other related constraints. The agencies did not receive comments disputing the expected technology effectiveness values reported in the NPRM and draft RIA.

2.5.1.1 Low Friction Lubricants

One of the most basic methods of reducing fuel consumption in both gasoline and diesel engines is the use of lower viscosity engine lubricants. More advanced multi-viscosity engine oils are available today with improved performance in a wider temperature band and with better lubricating properties. This can be accomplished by changes to the oil base stock (*e.g.*, switching engine lubricants from a Group I base oils to lower-friction, lower viscosity Group III synthetic) and through changes to lubricant additive packages (*e.g.*, friction modifiers and viscosity improvers). The use of 5W-30 motor oil is now widespread and auto manufacturers are introducing the use of even lower viscosity oils, such as 5W-20 and 0W-20, to improve cold-flow properties and reduce cold start friction. However, in some cases, changes to the crankshaft, rod and main bearings and changes to the mechanical tolerances of engine components may be required. In all cases, durability testing would be required to ensure that durability is not compromised. The shift to lower viscosity and lower friction lubricants would also improve the effectiveness of valvetrain technologies such as cylinder deactivation, which rely on a minimum oil temperature (viscosity) for operation.

Based on light-duty 2017-2025 MY vehicle rulemaking, and previously-received confidential manufacturer data, the agencies have estimated the effectiveness of low friction lubricants to be between 0 to 3 percent.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.1.2 Engine Friction Reduction

Manufacturers can reduce friction and improve fuel consumption by improving the design of engine components and subsystems. Approximately 10 percent of the energy consumed by a vehicle is lost to friction, and just over half is due to frictional losses within the engine. Examples include improvements in low-tension piston rings, piston skirt design, roller cam followers, improved crankshaft design and bearings, material coatings, material substitution, more optimal thermal management, and piston and cylinder surface treatments. Additionally, as computer-aided modeling software continues to improve, more opportunities for evolutionary friction reductions may become available.

Estimations of fuel consumption improvements due to reduced engine friction from the 2015 NHTSA Technology Study range from 1 percent to 3 percent. The agencies believe that this range is accurate.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.1.3 Engine Parasitic Demand Reduction

Manufacturers can reduce mechanical engine loads and improve fuel consumption by implementing variable-displacement oil pumps, higher-efficiency direct injection fuel pumps, and variable speed/displacement coolant pumps.

Estimations of fuel consumption improvements due to reduced engine parasitic demand from the 2015 NHTSA Technology Study range from 1 percent to 2 percent. The agencies believe that this range is accurate.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.1.4 Variable Valve Timing

Variable valve timing (VVT) classifies a family of valve-train designs that alter the timing of the intake valve, exhaust valve, or both, primarily to reduce pumping losses, increase specific power, and control the level of residual gases in the cylinder. VVT reduces pumping losses when the engine is lightly loaded by controlling valve timing closer to the optimum needed to sustain horsepower and torque. VVT can also improve volumetric efficiency at higher engine speeds and loads. Additionally, VVT can be used to alter (and optimize) the effective compression ratio where it is advantageous for certain engine operating modes (*e.g.*, in the Atkinson Cycle).

VVT has now become a widely adopted technology in the light duty fleet: in MY 2014, most of all new cars and light trucks had engines with some method of variable valve timing.[104] Manufacturers are currently using many different types of variable valve timing, which have a variety of different names and methods. Therefore, the degree of further improvement across the fleet is limited by the level of valvetrain technology already implemented on the vehicles. The three major types of VVT are listed below.

Each of the implementations of VVT uses a cam phaser to adjust the camshaft angular position relative to the crankshaft position, referred to as "camshaft phasing." The phase adjustment results in changes to the pumping work required by the engine to accomplish the gas exchange process. The majority of current cam phaser applications use hydraulically-actuated units, powered by engine oil pressure and managed by a solenoid that controls the oil pressure supplied to the phaser.

2.5.1.4.1 Coupled Cam Phasing for Overhead Valve (OHV) and Single Overhead Camshaft (SOHC) Engines

Valvetrains with coupled (or coordinated) cam phasing (CCP) can modify the timing of both the inlet valves and the exhaust valves an equal amount by varying the phasing of the camshaft across an engine's range of operating speeds; also known as VVT. For engines configured as an overhead valve (OHV) or as a single overhead camshaft (SOHC) only one cam phaser is required per camshaft to achieve CCP.

Based on the heavy-duty 2014-2018 MY vehicle rulemaking, 2015 NHTSA Technology Study, and previously-received confidential manufacturer data, the agencies estimate the fuel consumption reduction effectiveness of this technology to be between 1 and 3 percent.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.1.4.2 Intake Cam Phasing (ICP) for Dual Overhead Camshaft Engines (DOHC)

Valvetrains with ICP, which is the simplest of the cam phasing technologies, can modify the timing of the inlet valves by phasing the intake camshaft while the exhaust valve timing remains fixed. This requires the addition of a cam phaser on each bank of intake valves on the engine. An in-line 4-cylinder engine has one bank of intake valves, while V-configured engines have two banks of intake valves.

Some newer Class 2b and 3 market entries are offering dual overhead camshaft (DOHC) engine designs where two camshafts are used to operate the intake and exhaust valves independently. Consistent with the heavy-duty 2014-2018 MY vehicle rulemaking and the SwRI report, the agencies agree with the effectiveness values of 1 to 2 percent reduction in fuel consumption for this technology.

2.5.1.4.3 Dual Cam Phasing (DCP) for Dual Overhead Camshaft Engines (DOHC)

The most flexible VVT design is dual (independent) cam phasing, where the intake and exhaust valve opening and closing events are controlled independently. This option allows the option of controlling valve overlap, which can be used as an internal EGR strategy. At low engine loads, DCP creates a reduction in pumping losses, resulting in improved fuel consumption. Increased internal EGR also results in lower engine-out NO_X emissions. The amount by which fuel consumption is improved depends on the residual tolerance of the combustion system. Additional improvements are observed at idle, where low valve overlap could result in improved combustion stability, potentially reducing idle fuel consumption. DCP requires two cam phasers on each bank of the engine.

Some newer Class 2b and 3 market entries are offering dual overhead camshaft (DOHC) engine designs where two camshafts are used to operate the intake and exhaust valves independently. Consistent with the light-duty 2012-2016 MY vehicle rulemaking and the SwRI report, the agencies agree with the effectiveness values of 1 to 3 percent reduction in fuel consumption for this technology.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.1.5 Variable Valve Lift (VVL)

Controlling the lift of the valves provides a potential for further efficiency improvements. By optimizing the valve-lift profile for specific engine operating regions, the pumping losses can be reduced by reducing the amount of throttling required to produce the desired engine power output. By moving the throttling losses further downstream of the throttle valve, the heat transfer losses that occur from the throttling process are directed into the fresh charge-air mixture just prior to compression, delaying the onset of knock-limited combustion processes. Variable valve lift control can also be used to induce in-cylinder mixture motion, which improves fuel-air mixing and can result in improved thermodynamic efficiency. Variable valve lift control can also potentially reduce overall valvetrain friction. At the same time, such systems may also incur increased parasitic losses associated with their actuation mechanisms. A number of manufacturers have already implemented VVL into their fleets (Toyota, Honda, and BMW). There are two major classifications of variable valve lift, described below:

2.5.1.5.1 Discrete Variable Valve Lift (DVVL)

Discrete variable valve lift (DVVL) systems allow the selection between two or three discrete cam profiles by means of a hydraulically-actuated mechanical system. By optimizing the cam profile for specific engine operating regions, the pumping losses can be reduced by reducing the amount of throttling required to produce the desired engine power output. This increases the efficiency of the engine. These cam profiles consist of a low and a high-lift lobe, and may include an inert or blank lobe to incorporate cylinder deactivation (in the case of a 3-step DVVL system). DVVL is normally applied together with VVT control. DVVL is also known as Cam Profile Switching (CPS). DVVL is a mature technology with low technical risk.

Based on the light-duty MY 2017-2025 final rule, previously-received confidential manufacturer data, 2015 NHTSA Technology Study, and report from the Northeast States Center for a Clean Air Future (NESCCAF), the agencies estimate the fuel consumption reduction effectiveness of this technology to be between 1 and 3 percent.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.1.6 Cylinder Deactivation

In conventional spark-ignited engines throttling the airflow controls engine torque output. At partial loads, efficiency can be improved by using cylinder deactivation instead of throttling. Cylinder deactivation can improve engine efficiency by disabling or deactivating (usually) half of the cylinders when the load is less than half of the engine's total torque capability – the valves are kept closed, and no fuel is injected – as a result, the trapped air within the deactivated cylinders is simply compressed and expanded as an air spring, with reduced friction and heat losses. The active cylinders combust at almost double the load required if all of the cylinders were operating. Pumping losses are significantly reduced as long as the engine is operated in this "part-cylinder" mode.

Cylinder deactivation control strategy relies on setting maximum manifold absolute pressures or predicted torque within which it can deactivate the cylinders. Noise and vibration issues reduce the operating range to which cylinder deactivation is allowed, although manufacturers are exploring vehicle changes that enable increasing the amount of time that cylinder deactivation might be suitable. Some manufacturers may choose to adopt active engine mounts and/or active noise cancellations systems to address Noise Vibration and Harshness (NVH) concerns and to allow a greater operating range of activation.

Effectiveness improvements scale roughly with engine displacement-to-vehicle weight ratio: the higher displacement-to-weight vehicles, operating at lower relative loads for normal driving, have the potential to operate in part-cylinder mode more frequently.

Based on the 2015 NHTSA Technology Study and previously-received confidential manufacturer data, the agencies estimate the fuel consumption reduction effectiveness of this technology to be between 0 and 3 percent.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.1.7 Stoichiometric Gasoline Direct Injection

Stoichiometric gasoline direct injection (SGDI) engines inject fuel at high pressure directly into the combustion chamber (rather than the intake port in port fuel injection). SGDI requires changes to the injector design, an additional high pressure fuel pump, new fuel rails to handle the higher fuel pressures, and changes to the cylinder head and piston crown design. Direct injection of the fuel into the cylinder improves cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency without the onset of combustion knock. Recent injector design advances, improved electronic engine management systems and the introduction of multiple injection events per cylinder firing cycle promote better mixing of the air and fuel, enhance combustion rates, increase residual exhaust gas tolerance and improve cold start emissions. SGDI engines achieve higher power density and match well with other technologies, such as boosting and variable valvetrain designs.

Several manufacturers have recently introduced vehicles with SGDI engines, including GM and Ford, who have announced their plans to increase dramatically the number of SGDI engines in their light-duty portfolios.

Based on the heavy-duty 2014-2018 MY vehicle rulemaking, 2015 NHTSA Technology Study, and previously-received confidential manufacturer data, the agencies estimate the fuel consumption reduction effectiveness of SGDI to be between 1 and 2 percent.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.1.8 Turbocharging and Downsizing (TRBDS)

The specific power of a naturally aspirated engine is primarily limited by the rate at which the engine is able to draw air into the combustion chambers. Turbocharging and supercharging (grouped together here as boosting) are two methods to increase the intake manifold pressure and cylinder charge-air mass above naturally aspirated levels. Boosting increases the airflow into the engine, thus increasing the specific power level, and with it the ability to reduce engine displacement while maintaining performance. This effectively reduces the pumping losses at lighter loads in comparison to a larger, naturally aspirated engine.

Almost every major manufacturer currently markets a vehicle with some form of boosting. While boosting has been a common practice for increasing performance for several decades, turbocharging has considerable potential to improve fuel economy and reduce CO_2 emissions when the engine displacement is also reduced. Specific power levels for a boosted engine often exceed 100 hp/L, compared to average naturally aspirated engine power densities of roughly 70 hp/L. As a result, engines can be downsized roughly 30 percent or higher while maintaining similar peak output levels. In the last decade, improvements to turbocharger turbine and compressor design have improved their reliability and performance across the entire engine operating range. New variable geometry turbines and ball-bearing center cartridges allow faster turbocharger spool-up (virtually eliminating the once-common "turbo lag") while maintaining high flow rates for increased boost at high engine speeds. Low speed torque output has been dramatically improved for modern turbocharged engines. However, even with turbocharger improvements, maximum engine torque at very low engine speed conditions, for example launch from standstill, is increased less than at mid and high engine speed conditions. The potential to downsize engines may be less on vehicles with low displacement to vehicle mass ratios for example a very small displacement engine in a vehicle with significant curb weight, in order to provide adequate acceleration from standstill, particularly up grades or at high altitudes.

Use of GDI systems with turbocharged engines and charge air cooling also reduces the fuel octane requirements for knock limited combustion and allows the use of higher compression ratios. Ford's "EcoBoost" downsized, turbocharged GDI engines introduced on MY 2010 vehicles allow the replacement of V8 engines with V6 engines with improved in 0-60 mph acceleration and with fuel economy improvements of up to 12 percent.[105]

Recently published data with advanced spray-guided injection systems and more aggressive engine downsizing targeted towards reduced fuel consumption and CO_2 emissions reductions indicate that the potential for reducing CO_2 emissions for turbocharged, downsized GDI engines may be as much as 15 to 30 percent relative to port-fuel-injected engines.[14,15,16,17,18] Confidential manufacturer data suggests an incremental range of fuel consumption and CO_2 emission reduction of 4.8 to 7.5 percent for turbocharging and downsizing. Other publicly-available sources suggest a fuel consumption and CO_2 emission reduction of 8 to 13 percent compared to current-production naturally-aspirated engines without friction reduction or other fuel economy technologies: a joint technical paper by Bosch and Ricardo suggesting fuel economy gain of 8 to 10 percent for downsizing from a 5.7 liter port injection V8 to a 3.6 liter V6 with direct injection using a wall-guided direct injection system;[106] a Renault report suggesting a 11.9 percent NEDC fuel consumption gain for downsizing from a 1.4 liter port injection in-line 4-cylinder engine to a 1.0 liter in-line 4-cylinder engine, also with wall-guided direct injection;[107] and a Robert Bosch paper suggesting a 13 percent NEDC gain for downsizing to a turbocharged DI engine, again with wall-guided injection.[108] These reported fuel economy benefits show a wide range depending on the SGDI technology employed.

The agencies reviewed estimates from the LD 2017-2025 final rule, the TSD, and existing public literature. The previous estimate from the MYs 2017-2025 suggested a 12 to 14 percent effectiveness improvement, which included low friction lubricant (level one), engine friction reduction (level one), DCP, DVVL and SGDI, over baseline fixed-valve engines, similar to the estimate for Ford's EcoBoost engine, which is already in production. Additionally, the agencies analyzed Ricardo vehicle simulation data and the 2015 NHTSA Technology Study for various turbocharged engine packages. Based on these data, and considering the widespread nature of the public estimates, the agencies assume that turbocharging and downsizing, would provide a 16.4 percent effectiveness improvement over naturally aspirated engines as applied to Class 2b and 3 vehicles.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

Note that for this analysis we determined that this technology path is only applicable to heavy duty applications that have operating conditions more closely associated with light duty vehicles. This includes vans designed mainly for cargo volume or modest payloads having similar GCWR to light duty applications. These vans cannot tow trailers heavier than similar light duty vehicles and are largely already sharing engines of significantly smaller displacement and cylinder count compared to heavy duty vehicles designed mainly for trailer towing.

2.5.1.9 Cooled Exhaust-Gas Recirculation

Cooled exhaust gas recirculation or Boosted EGR is a combustion concept that involves utilizing EGR as a charge diluent for controlling combustion temperatures and cooling the EGR prior to its introduction to the combustion system. Higher exhaust gas residual levels at part load conditions reduce pumping losses for increased fuel economy. The additional charge dilution enabled by cooled EGR reduces the incidence of knocking combustion and obviates the need for fuel enrichment at high engine power. This allows for higher boost pressure and/or compression ratio and further reduction in engine displacement and both pumping and friction losses while maintaining performance. Engines of this type use GDI and both dual cam phasing and discrete variable valve lift. The EGR systems considered in this rule would use a dual-loop system with both high and low pressure EGR loops and dual EGR coolers. The engines would also use single-stage, variable geometry turbocharging with higher intake boost pressure available across a broader range of engine operation than conventional turbocharged SI engines. Such a system is estimated to be capable of an additional 3 to 5 percent effectiveness relative to a turbocharged, downsized GDI engine without cooled-EGR. The agencies have also considered a more advanced version of such a cooled EGR system that employs very high combustion pressures by using dual stage turbocharging.

2.5.2 Diesel Engines

Diesel engines in this class of vehicle have emission characteristics that present challenges to meeting federal NO_X emissions standards. It is a significant systems-engineering challenge to maintain the fuel consumption advantage of the diesel engine while meeting U.S. emissions regulations. Fuel consumption can be negatively impacted by emissions reduction strategies depending on the combination of strategies employed. Emission compliance strategies for diesel vehicles sold in the U.S. are expected to include a combination of improvements of combustion, air handling system, aftertreatment, and advanced system control optimization. These emission control strategies are being introduced on Tier 2 light-duty diesel vehicles today.

Some of the engine technologies are described in the Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards Joint Technical Support Document.[109] Others are from the 2010 NAS Report, Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles, and the 2015 NHTSA Technology Study. Several key advances in diesel technology have made it possible to reduce emissions coming from the engine prior to aftertreatment. These technologies include engine friction and parasitic loss reduction, improved fuel systems (higher injection pressure and multiple-injection capability), advanced controls and sensors to optimize combustion and emissions performance, higher EGR levels and EGR cooling to reduce NO_X, and advanced turbocharging systems.

2.5.2.1 Low Friction Lubricants

Consistent with the discussion above for gasoline engines (see Chapter 2.5.1), the agencies are expecting some engine changes to accommodate low friction lubricants. Based on the light-duty 2014-2018 MY HD vehicle rulemaking, and previously-received confidential manufacturer data, the agencies estimated the effectiveness of low friction lubricants to be between 0 and 3 percent.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

Based on a survey of the current powertrains being applied to the Class 2b and 3 segment and the level of powertrain sharing with the light duty vehicle market for these vehicles, the majority of light heavy duty gasoline engines in the 2014 Class 2b and 3 vehicle models are utilizing some form of low friction lubricants to achieve power and emission goals, and so this technology is considered to be in the baseline.

2.5.2.2 Engine Friction Reduction

Reduced friction in bearings, valve trains, and the piston-to-liner interface will improve efficiency. Friction reduction opportunities in the engine valve train and at its roller/tappet interfaces exist for several production engines. In virtually all production engines, the piston at its skirt/cylinder wall interface, wrist pin and oil ring/cylinder wall interface offer opportunities for friction reduction. Use of more advanced oil lubricant that could be available for production in the future may also eventually play a key role in reducing friction. Mechanical loads can also be reduced by converting the water, oil, and fuel pumps in the engine from fixed displacement to variable displacement.

Estimations of fuel consumption improvements due to reduced engine friction from the 2015 NHTSA Technology Study range from 1 percent to 2 percent. The agencies believe that this range is accurate.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.2.3 Turbocharger Technology

Compact two stage turbochargers can increase the boost level with wider operation range, thus improving engine thermal efficiency. Ford's new developed 6.7L Scorpion engine features a twin-compressor turbocharger[110]. Cummins has also developed its own two stage turbochargers.[111] It is expected that this type of technology will continue to be improved by better system matching and development of higher compressor and turbine efficiency.

Based on the 2015 NHTSA Technology Study and previously-received confidential manufacturer data, the agencies estimate the fuel consumption reduction effectiveness of this technology to be between 2 and 3 percent.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.2.4 Reduction of Parasitic Loads

Accessories that are traditionally gear- or belt-driven by a vehicle's engine can be optimized and/or converted to electric power. Examples include the engine water pump, oil pump, fuel injection pump, air compressor, power-steering pump, cooling fans, and the vehicle's air-conditioning system which can be converted to full electrically driven loads or an electro-mechanical arrangement that retains some mechanically connected aspects. Optimization and improved pressure regulation may significantly reduce the parasitic load of the water, air and fuel pumps. Electrification may result in a reduction in power demand, because electrically-powered accessories (such as the air compressor or power steering) operate only when needed if they are electrically powered, but they impose a parasitic demand all the time if they are engine-driven. In other cases, such as cooling fans or an engine's water pump, electric power allows the accessory to run at speeds independent of engine speed, which can reduce power consumption. The 2015 NHTSA Technology Study used a 1 to 2 percent fuel consumption reduction for diesel engine parasitic improvements.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.2.5 Aftertreatment Improvements

The HD diesel pickup and van segment has largely adopted the SCR type of aftertreatment system to comply with criteria pollutant emission standards. As the experience base for SCR expands over the next few years, many improvements in this aftertreatment system such as construction of the catalyst, thermal management, and reductant optimization may result in a reduction in the amount of fuel consumed by the engine via combustion optimization, taking advantage of the SCR's capability to reduce higher levels of NO_X emitted by the engine. However, due to uncertainties with these improvements regarding the extent of current optimization and future criteria emissions obligations, the agencies are not considering aftertreatment improvements as a fuel-saving technology in the rulemaking analysis for HD pickups and vans.

2.5.3 Drivetrain

The agencies have also reviewed the transmission technology estimates used in the light-duty 2012-2016 MY vehicle rulemaking. In doing so, the agencies have considered or reconsidered all available sources and updated the estimates as appropriate. The section below describes each of the transmission technologies considered for this rulemaking.

2.5.3.1 Automatic 8-Speed Transmissions

Manufacturers can also choose to replace 6-speed transmissions with transmissions capable of 8-speeds or more. Additional ratios allow for further optimization of engine operation over a wider range of conditions, but this is subject to diminishing returns as the number of speeds increases. As additional gear sets are added (which may be necessary in some cases to achieve the higher number of ratios), additional weight and friction are introduced. Also, the additional shifting of such a transmission can be perceived as bothersome to some consumers, so manufacturers continue to develop strategies for smooth operation.

As discussed in the heavy-duty 2014-2018 MY vehicle rulemaking, taking into account confidential manufacturer data, we projected that 8-speed transmissions could incrementally reduce fuel consumption by 1 to 3 percent from a baseline 6-speed automatic transmission. The SwRI report uses 2 to 3 percent fuel consumption reduction when replacing 6-speed baseline automatic transmissions with improved 8-speed automatic transmissions.

The agencies reviewed and revised these effectiveness estimates based on usage and testing methods for Class 2b and 3 vehicles. The agencies estimate the effectiveness for a conversion from a 6 to 8-speed transmission to be 2.7 percent.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.3.2 High Efficiency Transmission

For this rule, a high efficiency transmission refers to some or all of a suite of incremental transmission improvement technologies that should be available within the 2019 to 2025 timeframe. The majority of these improvements address mechanical friction within the transmission. These improvements include but are not limited to: shifting clutch technology improvements, improved kinematic design, dry sump lubrication systems, more efficient seals, bearings and clutches (reducing drag), component superfinishing and improved transmission lubricants.

2.5.3.3 Electric Power Steering (EPS)

Electric power steering (EPS) provides a potential reduction in CO_2 emissions and fuel consumption over hydraulic power steering because of reduced overall accessory loads. This eliminates the parasitic losses associated with belt-driven power steering pumps which consistently draw load from the engine to pump hydraulic fluid through the steering actuation systems even when the wheels are not being turned. EPS is an enabler for all vehicle hybridization technologies since it provides power steering when the engine is off. EPS may be implemented on most vehicles with a standard 12V system. Some heavier vehicles such as Class 2b and 3 may require a higher voltage system which may add cost and complexity.

The 2017 light-duty final rule estimated a 1 to 2 percent effectiveness based on the 2002 NAS report, a Sierra Research report, and confidential manufacturer data. The SwRI report estimated 0.8 percent to 1 percent effectiveness. The agencies reviewed these SwRI effectiveness estimates and found them to be accurate, thus they have been retained for this rule.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.3.4 Improved Accessories

The accessories on an engine, including the alternator, coolant and oil pumps are traditionally mechanically-driven. A reduction in CO_2 emissions and fuel consumption can be realized by driving them electrically, and only when needed ("on-demand").

Electric water pumps and electric fans can provide better control of engine cooling. For example, coolant flow from an electric water pump can be reduced and the radiator fan can be shut off during engine warm-up or cold ambient temperature conditions which would reduce warm-up time, reduce warm-up fuel enrichment, and reduce parasitic losses.

Indirect benefit may be obtained by reducing the flow from the water pump electrically during the engine warm-up period, allowing the engine to heat more rapidly and thereby reducing the fuel enrichment needed during cold operation and warm-up of the engine. Faster oil warm-up may also result from better management of the coolant warm-up period. Further benefit may be obtained when electrification is combined with an improved, higher efficiency engine alternator used to supply power to the electrified accessories.

Intelligent cooling can more easily be applied to vehicles that do not typically carry heavy payloads, so larger vehicles with towing capacity present a challenge, as these vehicles have high cooling fan loads.[A] However, towing vehicles tend to have large cooling system capacity and flow scaled to required heat rejection levels when under full load situations such as towing at GCWR in extreme ambient conditions. During almost all other situations, this design characteristic may result in unnecessary energy usage for coolant pumping and heat rejection to the radiator.

[A] In the CAFE model, improved accessories refers solely to improved engine cooling. However, EPA has included a high efficiency alternator in this category, as well as improvements to the cooling system.

The agencies considered whether to include electric oil pump technology for the rulemaking. Because it is necessary to operate the oil pump any time the engine is running, electric oil pump technology has insignificant effect on efficiency. Therefore, the agencies decided to not include electric oil pump technology.

2.5.3.5 Mild Hybrid (MHEV)

Mild hybrid systems offer idle-stop functionality and a limited level of regenerative braking and power assist. These systems replace the conventional alternator with a belt or crank driven starter/alternator and may add high voltage electrical accessories (which may include electric power steering and an auxiliary automatic transmission pump). The limited electrical requirements of these systems allow the use of lead-acid batteries or supercapacitors for energy storage, or the use of a small lithium-ion battery pack.

For the MHEV technology the agencies sized the system using a 7 kW starter/generator and 8 kWh Li-ion battery pack. The estimates were developed by Argonne National Laboratory as a supplement to the 2015 NHTSA Technology Study, resulting in an effectiveness range of 4 to 5 percent depending on the vehicle's engine.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.3.6 Strong Hybrid (SHEV)

A hybrid vehicle is a vehicle that combines two significant sources of propulsion energy, where one uses a consumable fuel (like gasoline), and one is rechargeable (during operation, or by another energy source). Hybrid technology is well established in the U.S. market and more manufacturers are adding hybrid models to their lineups. Hybrids reduce fuel consumption through three major mechanisms:

- The internal combustion engine can be optimized (through downsizing, modifying the operating cycle, or other control techniques) to operate at or near its most efficient point more of the time. Power loss from engine downsizing can be mitigated by employing power assist from the secondary power source.

- Some of the energy normally lost as heat while braking can be captured and stored in the energy storage system for later use.

- The engine is turned off when it is not needed, such as when the vehicle is coasting or when stopped.

Hybrid vehicles utilize some combination of the three above mechanisms to reduce fuel consumption and CO_2 emissions. The effectiveness of fuel consumption and CO_2 reduction depends on the utilization of the above mechanisms and how aggressively they are pursued. One area where this variation is particularly prevalent is in the choice of engine size and its effect on balancing fuel economy and performance. Some manufacturers choose not to downsize the engine when applying hybrid technologies. In these cases, performance is vastly improved, while fuel efficiency improves significantly less than if the engine was downsized to maintain the same performance as the conventional version. The non-downsizing approach is used for vehicles like trucks where towing and/or hauling are an integral part of their performance requirements. In these cases, if the engine is downsized, the battery can be quickly drained during a long hill climb with a heavy load, leaving only a downsized engine to carry the entire load. Because towing capability is currently a heavily-marketed truck attribute, manufacturers are hesitant to offer a truck with downsized engine which can lead to a significantly diminished towing performance when the battery state of charge level is low, and therefore engines are traditionally not downsized for these vehicles. As noted above, in assessing costs of this technology, the agencies assumed in all instances that the engine would not be downsized.

Strong Hybrid technology utilizes an axial electric motor connected to the transmission input shaft and connected to the engine crankshaft through a clutch. The axial motor is a motor/generator that can provide sufficient torque for launch assist, all electric operation, and the ability to recover significant levels of braking energy.

For SHEV, the agencies also relied on the study by Argonne National Laboratory to supplement the 2015 NHTSA Technology Study to determine that the effectiveness of these systems in terms of CO_2 reduction. For the SHEV technology, the agencies sized the system using a 50 kW starter/generator and a 70 kWh Li-ion battery pack. The estimates resulted in an effectiveness range of 18 to 22 percent depending on the engine. The estimates assume no engine downsizing so as to maintain vehicle performance and/or maintain towing and hauling performance.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.4 Aerodynamics

Aerodynamic drag is an important aspect of the power requirements for Class 2b and 3 trucks. Because aerodynamic drag is a function of the cube of vehicle speed, small changes in the aerodynamics of a Class 2b and 3 can reduce drag, fuel consumption, and GHG emissions. Some of the opportunities to reduce aerodynamic drag in Class 2b and 3 vehicles are similar to those in Class 1 and 2 (*i.e.*, light-duty) vehicles. In general, these transferable features make the cab shape more aerodynamic by streamlining the airflow over the bumper, grill, windshield, sides, and roof. Class 2b and 3 vehicles may also borrow from light-duty vehicles certain drag reducing accessories (*e.g.*, streamlined mirrors, operator steps, and sun visors). The great variety of applications for Class 2b and 3 trucks result in a wide range of operational speed profiles (*i.e.*, in-use drive cycles) and functional requirements (*e.g.*, shuttle buses that must be tall enough for standing passengers, trucks that must have racks for ladders). This variety makes it challenging to develop aerodynamic solutions that consider the entire vehicle.

Many factors affect a vehicle's aerodynamic drag and the resulting power required to move it through the air. While these factors change with air density and the square and cube of vehicle speed, respectively, the overall drag effect is determined by the product of its frontal area and drag coefficient. Reductions in these quantities can therefore reduce fuel consumption and CO_2 emissions. Although frontal areas tend to be relatively similar within a vehicle class (mostly due to market-competitive size requirements), significant variations in drag coefficient can be observed. Significant changes to a vehicle's aerodynamic performance may need to be implemented during a redesign (*e.g.*, changes in vehicle shape). However, shorter-term aerodynamic reductions, with a somewhat lower effectiveness, may be achieved through the use of revised exterior components (typically at a model refresh in mid-cycle) and add-on devices that are currently being applied. The latter list would include revised front and rear fascias, modified front air dams and rear valances, addition of rear deck lips and underbody panels, and lower aerodynamic drag exterior mirrors.

For this rule, the agencies considered two levels of aero improvements. The first level includes such body features as air dams, tire spats, and perhaps one underbody panel resulting in a 5 percent aerodynamic drag reduction. The agencies estimated the CO_2 and fuel consumption effectiveness of this first level of aerodynamic drag at 0.75 percent.

The second level which includes the features of level 1 plus additional body features such as active grille shutters[B], rear visors, larger under body panels or low-profile roof racks resulting in a 10 percent aerodynamic drag reduction. The agencies estimated the CO_2 and fuel consumption effectiveness of this second level of aerodynamic drag at 1.5 percent. We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.5 Tires

Typically, tires used on Class 2b/3 vehicles are not designed specifically for the vehicle. These tires are designed for broader use and no single parameter is optimized. Similar to vocational vehicles, the market has not demanded tires with improved rolling resistance thus far; therefore, manufacturers have not traditionally designed tires with low rolling resistance for Class 2b/3 vehicles. The agencies believe that a regulatory program that incentivizes the optimization of tire rolling resistance, traction and durability can bring about GHG emission and fuel consumption reductions of 1.1 percent from this segment based on a 10 percent reduction in rolling resistance.

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.5.6 Mass Reduction

Mass reduction is a technology that can be used in a manufacturer's strategy to meet the Heavy Duty Greenhouse Gas Phase 2 standards (although, as noted, it is not part of the agencies' projected technology path for either the standards for pickups and vans, or any of the other standards). Vehicle mass reduction (also referred to as "light-weighting"), decreases fuel consumption and GHG emissions by reducing the energy demand needed to overcome inertia forces, and rolling resistance. Automotive companies have worked with mass reduction technologies for many years and a lot of these technologies have been used in production vehicles. The weight savings achieved by adopting mass reduction technologies offset weight gains due to increased vehicle size, larger powertrains, and increased feature content (sound

[B] For details on how active aerodynamics are considered for off-cycle credits, see the Technical Support Document for Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy, August 2012, Chapter 5.2.2.

insulation, entertainment systems, improved climate control, panoramic roof, etc.). Sometimes mass reduction has been used to increase vehicle towing and payload capabilities.

Manufacturers employ a systematic approach to mass reduction, where the net mass reduction is the addition of a direct component or system mass reduction, also referred to as primary mass reduction, plus the additional mass reduction taken from indirect ancillary systems and components, also referred to as secondary mass reduction or mass compounding. There are more secondary mass reductions achievable for light-duty vehicles compared to heavy-duty vehicles, which are limited due to the higher towing and payload requirements.

Mass reduction can be achieved through a number of approaches, even while maintaining other vehicle functionalities. As summarized by NAS in its 2011 light duty vehicle report, there are two key strategies for primary mass reduction: 1) changing the design to use less material; 2) substituting lighter materials for heavier materials.[112]

The first key strategy of using less material compared to the baseline component can be achieved by optimizing the design and structure of vehicle components, systems and vehicle structure. Vehicle manufacturers have long used these continually-improving CAE tools to optimize vehicle designs. For example, the Future Steel Vehicle (FSV) project sponsored by WorldAutoSteel used three levels of optimization: topology optimization, low fidelity 3G (Geometry Grade and Gauge) optimization, and subsystem optimization, to achieve 30 percent mass reduction in the body structure of a vehicle with a mild steel unibody structure.[113] Using less material can also be achieved through improving the manufacturing process, such as by using improved joining technologies and parts consolidation. This method is often used in combination with applying new materials.

The second key strategy to reduce mass of an assembly or component involves the substitution of lower density and/or higher strength materials. Material substitution includes replacing materials, such as mild steel, with higher-strength and advanced steels, aluminum, magnesium, and composite materials. In practice, material substitution tends to be quite specific to the manufacturer and situation. Some materials work better than others for particular vehicle components, and a manufacturer may invest more heavily in adjusting to a particular type of advanced material, thus complicating its ability to consider others. The agencies recognize that like any type of mass reduction, material substitution has to be conducted not only with consideration to maintaining equivalent component strength, but also to maintaining all the other attributes of that component, system or vehicle, such as crashworthiness, durability, and noise, vibration and harshness (NVH).

If vehicle mass is reduced sufficiently through application of the two primary strategies of using less material and material substitution described above, secondary mass reduction options may become available. Secondary mass reduction is enabled when the load requirements of a component are reduced as a result of primary mass reduction. If the primary mass reduction reaches a sufficient level, a manufacturer may use a smaller, lighter, and potentially more efficient powertrain while maintaining vehicle acceleration performance. If a powertrain is downsized, a portion of the mass reduction may be attributed to the reduced torque requirement which results from the lower vehicle mass. The lower torque requirement enables a reduction in engine displacement, changes to transmission torque converter and gear ratios, and changes to final drive gear ratio. The reduced powertrain torque enables the downsizing and/or mass reduction of powertrain components and accompanying reduced rotating mass (e.g., for transmission, driveshafts/halfshafts, wheels, and tires) without sacrificing powertrain durability. Likewise, the combined mass reductions of the engine, drivetrain, and body in turn reduce stresses on the suspension components, steering components, wheels, tires, and brakes, which can allow further reductions in the mass of these subsystems. Reducing the unsprung masses such as the brakes, control arms, wheels, and tires further reduce stresses in the suspension mounting points, which will allow for further optimization and potential mass reduction. However, pickup trucks have towing and hauling requirements which must be taken into account when determining the amount of secondary mass reduction that is possible and so it is less than that of passenger cars.

In September 2015, Ford announced that its MY 2017 F-Series Super duty pickup (F-250) would be manufactured with an aluminum body and overall the truck will be 350 lbs lighter (5 to 6 percent) than the current gen truck with steel.[114,115] This is less overall mass reduction than the resultant lightweighting effort on the MY 2015 F-150 which achieved up to a 750 lb decrease in curb weight (12 to 13 percent) per vehicle.[116] Strategies were employed in the F-250 to "improve the productivity of the Super Duty" in addition there were several safety systems added including cameras, lane departure warning, brake assist, etc. If some of the mass reduction efforts were not offset by other vehicle upgrades (size, towing, hauling, etc.), then more mass reduction and greater fuel economy could have been realized. More details on the F-250 will be known once it is released; however, a review of the F-150 vehicle aluminum intensive design shows that it has an aluminum cab structure, body panels, and suspension components, as well as a high strength steel frame and a smaller, lighter and more efficient engine. The Executive Summary to Ducker Worldwide's 2014 report[117] states that state that the MY 2015 F-150 contains 1080 lbs of aluminum with at least half of this being aluminum sheet and extrusions for body and closures. Ford's engine options for its light duty truck fleet includes a 2.7L EcoBoost V-6. The integrated loop between Ford, the aluminum sheet suppliers, and the aluminum scrap suppliers is integral to making aluminum a feasible lightweighting technology option for Ford. It is also possible that the strategy of using aluminum body panels will be applied to the heavy duty F-350 version when it is redesigned.[118]

We present cost estimates for this technology in Chapter 2.11 of this RIA.

2.6 Technology Application– SI Engines

This section summarizes the technologies the agencies project as a feasible path to meeting the engine standards for spark-ignition engines used in vocational vehicles – that is engines that are engine-certified and intended for vocational vehicles that will be GEM-certified. These standards apply with respect to emissions measured over the FTP test cycle. This cycle is described in Chapter 3.1. See Chapter 2.5 for spark-ignited engine technologies projected for the Phase 2 HD pickup and van vehicle standards.

For the reasons discussed below, rather than setting a more stringent engine standard, the agencies will maintain the MY 2016 fuel consumption and CO_2 emission standards for SI engines for use in vocational vehicles: 7.06 gallon/100 bhp-hr and 627 g CO_2/bhp-hr, as measured over the Heavy-duty FTP engine test cycle.

Heavy-duty spark-ignited (SI) engines are used in almost 30 percent of vocational vehicles. Operators that choose gasoline engines do so for reasons similar to those for HD complete pickups and vans. Gasoline engines have the advantage of being less expensive and lower weight than diesels, but tend to also be less durable and have higher fuel consumption. Thus, gasoline engines are most likely to be purchased for applications with lower annual VMT, where fuel costs are less important than upfront costs.

When an SI-powered vocational vehicle is built by a non-integrated chassis manufacturer, the engine is generally purchased from a company that also produces complete and/or incomplete HD pickup trucks and vans. The primary certification path intended in this scenario is for the engine to be engine-certified over the FTP and the vehicle to be GEM certified under the GHG rules. This is common practice for CI engines, and in Phase 2 the agencies are continuing this as the primary certification path for SI engines intended for vocational vehicles.

In Phase 1 we adopted a special provision aimed at simplifying compliance for manufacturers of complete HD pickups and vans that also sell a relatively small number of engines to non-integrated chassis manufacturers. This flexibility provision enables these manufacturers to avoid meeting the separate SI engine standard, instead averaging them into the applicable HD pickup and van fleet-wide average.[C] These "loose" engine sales represent a very small fraction of the SI-powered vocational vehicle market. The final Phase 2 program allows SI engine manufacturers to sell a limited number of these "loose" SI engines to other chassis manufacturers for use in vocational vehicles, through MY 2023.

The SI engines certified and sold as loose engines into the heavy-duty vocational vehicle market are typically large V8 and V10 engines produced by General Motors and Ford. The number of engine families certified in the past for this segment of vehicles is very limited and has ranged between three and five engine models.[119] Unlike the heavy-duty diesel engines typical of this segment that are built for vocational vehicles, these SI engines are primarily developed for chassis-certified heavy-duty pickup trucks and vans, but are also installed in incomplete vocational vehicles.

Under the special Phase 1 provision, these loose engines need not be certified to engine-based GHG and fuel consumption standards, but instead may be treated under the regulations as though they are additional sales of the manufacturer's complete pickup and van products, on a one-for-one basis. The pickup/van vehicle so chosen must be the vehicle with the highest emission test weight that uses the engine (as this vehicle is likely to have the highest GHG emissions and fuel consumption).[D] However, if this vehicle is a credit-generator under the HD pickup and van fleet averaging program, no credits would be generated by these engine-as-vehicle contributors to the fleet average; they would be treated as just achieving the target standard. If, on the other hand, the vehicle is a credit-user, the appropriate number of additional credits would be needed to offset the engine-as-vehicle contributors. The purchaser of the

[C] See 40 CFR 1037.150(m) and 49 CFR 535.5(a)(7).

[D] Equivalent test weight is defined at 40 CFR 1037.104(d)(11) and is determined based on a vehicle's adjusted loaded vehicle weight as specified in 40 CFR 86.129, except that for vehicles over 14,000 pounds, this may be rounded to the nearest 500 pound increment.

engine would treat it as any other certified engine, and would still need to meet applicable vocational vehicle standards for the vehicles in which the engine is installed.

In deriving the stringency of the Phase 2 SI engine standard, the agencies first reviewed the technology that was presumed in the MY 2010 Phase 1 baseline and the technology that was projected to be adopted to meet the MY 2016 SI engine standard, finalized as part of the Phase 1 program. Engines certified to this standard would represent a logical level at which to set a Phase 2 baseline performance level.

The agencies finalized MY 2016 standards that require manufacturers to achieve a 5 percent reduction in CO_2 compared to the Phase 1 MY 2010 baseline. That MY 2010 baseline engine was described in the Phase 1 Preamble at Section III.B.2.a.iii, as a naturally aspirated, overhead valve V8 engine.[120]

In deriving the stringency of the MY 2016 gasoline engine standards, the agencies projected 100 percent adoption of engine friction reduction, coupled cam phasing, and stoichiometric gasoline direct injection (SGDI) to produce an overall 5 percent reduction from the reference engine, over the engine FTP test cycle. Table 2-6 presents the technologies projected to be present on an engine following this technology path.

Table 2-6 MY 2016 Technology Projection for SI Engines

TECHNOLOGY	ADOPTION RATE
Coupled Cam Phasing	100%
Engine friction reduction	100%
SGDI	100%

In deciding whether to consider the above package as representing the Phase 2 baseline performance of SI engines, the agencies reviewed available certification information and consulted with stakeholders to determine the degree to which these projections match with engines being produced today and engine product plans during the Phase 1 time frame. The agencies have learned that no SI engine manufacturer has applied SGDI to this type of engine to date, though cam phasing and engine friction reduction are widely being employed.

Section II.D.2(b) and Section V.C.1(b) of the Preamble discuss the agencies' response to comments received on the application of SI engine technologies in the Phase 2 SI engine standard and the vocational vehicle program, respectively. None of the comments received by the agencies provided technical data on engine technology performance over the HD gasoline engine FTP test procedure. Further, many engine technologies suggested to the agencies are already presumed to be applied to SI engines, at application rates of 100 percent (see Table 2-6 above), to meet the MY 2016 engine standard. Because the agencies cannot count the performance of those Phase 1 technologies in a Phase 2 standard, the difference between what the commenters seek and what the agencies are adopting is considerably less than initially appears (and that the commenters appear to believe).

2.7 Technology Application and Estimated Costs – CI Engines

2.7.1 Phase 1 Engine Standards

The agencies' initial premise is that the baseline CI engine for purposes of the Phase 2 engine standard must be the engine needed to meet the Phase 1 CI engine standard. Table 2-7 shows CO_2 performance at the end of Phase 1. However, as explained in the next few sections, there are some issues associated with these baselines for both tractor and vocational engines. Consequently, the agencies adjusted these baseline values from those proposed.

Table 2-7 Baseline Phase 1 CO_2 Standards (g/bhp-hr)

LHDD - FTP	MHDD - FTP	HHDD - FTP	MHDD - SET	HHDD - SET
576	576	555	487	460

2.7.2 Individual Technology Feasibility and Cost

The cost for combustion system optimization includes costs associated with several individual technologies, specifically, improved cylinder head, turbo efficiency improvements, EGR cooler improvements, higher pressure fuel rail, improved fuel injectors and improved pistons. The cost estimates for each of these technologies are presented in Chapter 2.7 of this RIA for heavy HD, medium HD and light HD engines, respectively.

The agencies have included the costs of model-based control development in the research and development costs applied separately to each engine manufacturer.

2.7.3 Test Cycle Weighting

The current SET modes used for tractor engine certification in Phase 1 have a relatively large weighting in C speed as shown in the middle column of the following table:

Table 2-8 SET Modes Weighting Factors

SPEED/% LOAD	WEIGHTING FACTOR IN PHASE 1 (%)	WEIGHTING FACTOR IN PHASE 2 (%)
Idle	15	12
A, 100	8	9
B, 50	10	10
B, 75	10	10
A, 50	5	12
A, 75	5	12
A, 25	5	12
B, 100	9	9
B, 25	10	9
C, 100	8	2
C, 25	5	1
C, 75	5	1
C, 50	5	1
Total	100	100
A:	23	45
B:	39	38
C:	23	5

It can be seen from the above table that 23 percent weighting is in C speed, which is typically in the range of 1800 rpm for HHD engines. However, many of today's HHD engines do not commonly operate at such a high speed in real world driving conditions, specifically during cruise vehicle speed between 55 and 65 mph. The agencies received confidential business information from a few vehicle manufacturers that support this observation. Furthermore, one of the key technology trends is to down speed, moving the predominant engine speed from the range of 1300-1400 rpm to the range of 1150-1200 rpm at a vehicle speed of 65 mph. This trend would make the predominant engine speed even further away from C speed. Therefore, it can be argued that, if the current SET weighting factors were retained in Phase 2, the test would not properly reflect real-world driving operations. A more detailed explanation with supportive data on this matter can be found in the article.[121] Accordingly, the agencies are adjusting the weighting of the various modes in the SET cycle as presented in the third column of Table 2-8.

As shown, the new SET mode weighting basically moves most of the C speed weighting to A speed. It also slightly reduces the weighting factor on the idle speed. These values are based on the confidential business information obtained from vehicle manufacturers.

2.7.4 Phase 2 Baseline for Tractor and Vocational Engines

As mentioned above, the Phase 2 baseline engine numerical values are changed from those used at proposal. However, the reasons for these changes differ for tractor and vocational engines. For the tractor engine, the reason for the change in the SET cycle baseline values is due to the new SET weighting factors, shown in Table 2-8, even though the engine fueling map as a function of the engine torque and speed is the same whether Phase 1 or Phase 2 SET weighting factors are used. Since the tractor engine standards are set up based on a composite value over the 13 modes of the SET, using the weighting factors shown in Table 2-8, the new adjusted standards with the new weighting factors result in a new set of numerical values shown in Table 2-9. Compared to the values in Table 2-7, the values are about 1.1 to 1.2 percent lower because of the new SET weighting structure.[122]

Table 2-9 Tractor Engine Baseline CO_2 Performance (g/bhp-hr)

MHDD - SET	HHDD - SET
481	455

For the vocational engine standard, the new baselines are required because GHG performance of vocational vehicle engines has improved significantly since the inception of the Phase 1 standards, and therefore, the baselines reflecting the level of the Phase 1 standard are unrepresentative. The latest 2016 federal certification data, as well as data posted on California Air Resource Board (CARB) websites, show that many of the Phase 1 engines are not only easily achieving the Phase 1 2017 standard, but in some instances, the proposed 2027 engine standards as well! See Figure 2-15 and Figure 2-16.

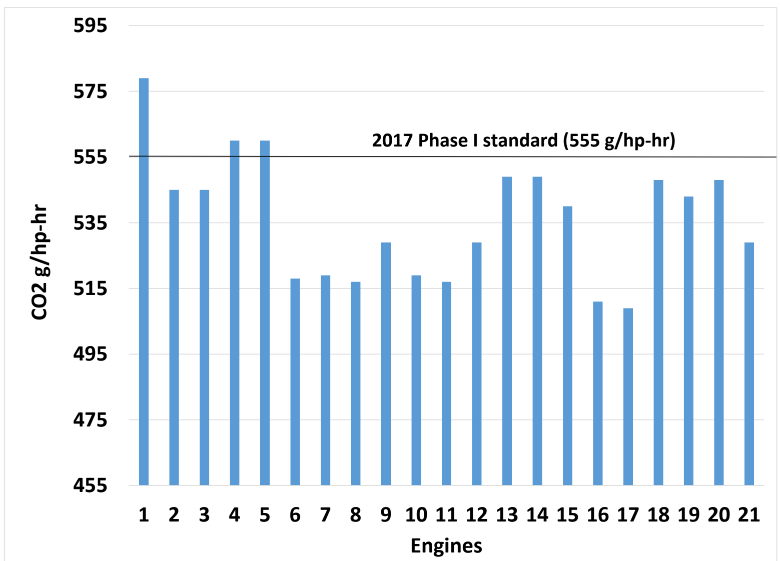


Figure 2-15 2016 certified HHD engines over FTP cycle

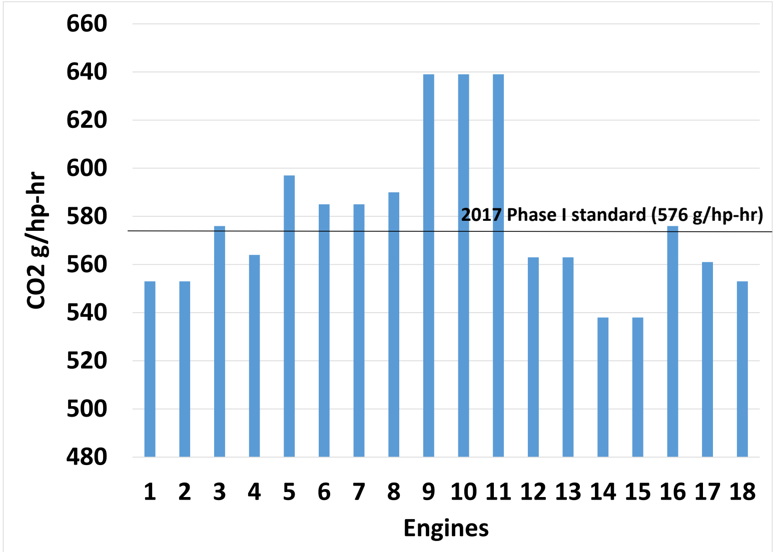


Figure 2-16 2016 certified MHD/LHD engines over FTP cycle

The major contributor to this achievement in the vocational engine sector is transient control related technologies, such as thermal management. This is one of the most challenging areas for which to project improvement due to the nature of transient behaviors and the limited data available. These improvements were not yet reflected in the 2010 certification data available at proposal. Specifically, an integrated SCR and DPF system, including their hardware, composition of catalytic material, urea dosing strategy, was in an early, non-optimized stage in 2010. The early production SCR+DPF system had not been fully optimized for thermal management and urea dosing strategy. As a result, some of the thermal management measures, such as tailpipe back pressure control, post-fuel injection, and intake throttle control, tended to be less efficient during transient operation. The agencies have also learned from the recent certification data, illustrated in the figures above, that LHD engines perform differently than MHD engines, and therefore that it makes more sense to separate MHD and LHD engines rather than combine them in a single standard as in Phase 1. In view of this situation, after the agencies analyzed all available certification data, we average the best possible engines from each manufacturer, and consequently, the baselines of 2018 vocational engines for Phase 2 are adjusted as follows.

Table 2-10 Vocational Engine Baseline CO_2 Performance (g/bhp-hr)

LHD - FTP	MHD- FTP	HHD - FTP
576	558	525

2.7.5 Technology Packages

The agencies assessed the impact of technologies over each of the SET modes to project an overall improvement for a tractor engine. It should be pointed out that the technology packages discussed in this section are relevant for both tractor and vocational engines, with the exception of WHR related technologies. The agencies considered improvements in parasitic and friction losses through bearing and piston ring designs to reduce friction, improved lubrication and oils, and improved water pump and oil pump designs to reduce parasitic losses. The after-treatment improvements are available through additional improvements that lower backpressure of the systems, further optimization of the engine-out NO_X levels, and further reduction in ammonia slip from the SCR. Improvements to the EGR system and air flow through the intake and exhaust systems, including through turbochargers, can also produce engine efficiency improvements. Improvements in combustion chamber design and materials and fuel injection control can reduce the fuel consumption of the engine. Engine downsizing is part of this consideration with respect to improving efficiency, specifically when this technology is used together with engine down-speeding. Although one of the most effective single technologies to improve engine efficiency is the application of waste heat recovery (WHR) via the Rankine heat engine cycle, the agencies do not project that this technology will have significant market adoption until MY 2024. The reason for this is that this type of WHR system is currently only at a pre-prototype stage of development. Furthermore, the system itself includes many components that still require extensive field testing to assure reliability. The high technology cost, longer payback period (if the cost and benefit of using WHR is considered in isolation), concern about commercial acceptance (given the technology complexity, cost, concern about reliability leading to demurrage costs and warranty claims in early model years) again point to a longer necessary lead time for introducing this technology. See Chapter 2.3.9 above for more detailed discussions on WHR. The agencies received detailed information from various stakeholders, who provided information that was claimed as confidential business information (CBI). Examples include technology improvement effectiveness information at each or some of 13 SET modes, information on the list of components in the system, the working fluid of the system, and the overall design.

While many effective technologies are considered for this rulemaking, it is important to point out that the benefits of these technologies are not additive. For example, when multiple technologies are applied to an engine, it is incorrect to simply sum the individual technologies' effectiveness to arrive at an overall combined effectiveness of the technologies. We have received a number of public comments regarding this non-additive effect. Most of them focus on the agencies' projections of our so-called "dis-synergy" effect and our use of a dis-synergy factor to account for this effect. This effect could also be called a negative synergy because it is a decrease in technology effectiveness as a result of multiple technologies being applied to an engine. Some commenters recommended that we adopt lower numeric values of our dis-synergy factors, but a few commenters recommended higher dis-synergy factors than what we proposed. A number of NGOs maintained that it was inappropriate to have a single dis-synergy factor. The following paragraphs provide some background on this effect and our rationale for how we developed numeric dis-synergy factors and applied them within our final stringency analysis.

As background, it is helpful to first review how engine fuel efficiency technologies interact with one another. One example is the interaction between WHR and other technologies, such as combustion, friction reduction, and fuel injection system improvements. WHR effectiveness is directly proportional to the amount of thermodynamic available energy (i.e., energy available for conversion into mechanical work) provided from an engine's sources of waste heat. In a modern internal combustion engine, these sources include exhaust gas energy available from the EGR cooler and tailpipe, and from the coolant and lubricating oil systems.

Therefore, decreasing the amount of available energy from these sources reduces the effectiveness of WHR. Some of the fuel efficiency technologies we identify in our stringency analysis decrease the amount of available energy from these sources. For example, advancing fuel injection timing will improve efficiency to a certain point, but it will also decrease available exhaust energy by lowering exhaust temperature, and thus exhaust WHR effectiveness would decrease. To a lesser extent, reducing bearing friction or piston ring-wall friction improves fuel efficiency, but this also leads to less heat transfer to the coolant; and hence lower available energy for WHR. As another example, increasing compression ratio can improve combustion thermal efficiency (until the peak cylinder pressure rises past a given mechanical limit), but this in turn increases friction losses at piston rings and bearings. As another example increasing fuel injection pressure provides more opportunity for fuel injection optimization (e.g., enabling more multiple injection events), which can improve fuel efficiency, but this will in turn increase fuel pump parasitic energy losses. In another example, increasing turbocharger efficiency can improve fuel efficiency, but this will also reduce EGR flow due to lower back pressure, thus potentially increasing NO_X, and also reducing the exhaust gas energy that can be utilized by waste heat recovery devices, such as turbo-compound and Rankine cycle systems. Increasing NO_X would also put more demand on the after-treatment system or force less fuel efficient fuel injection timing. There are more examples, but in conclusion, there are numerous complex interactions between fuel efficiency technologies. In the next few paragraphs we describe how we accounted for those interactions that lead to a dis-synergy effect.

If the agencies possessed the resources to conduct a multi-million dollar multi-year effort to very accurately quantify all of the potential engine technology fuel efficiency dis-synergies, we would have embarked on the development and calibration of a comprehensive engine cycle computer simulation model several years ago. Such an effort would lead to the development of an engine cycle simulation model, which would consist of all engine components, including sub-models for fuel injection systems and combustion chambers; piston ring and bearing friction and heat transfer; intake and exhaust systems, including EGR system, turbochargers, after-treatment devices; and Rankine cycle or other WHR systems. Calibrating and validating such a model would require tremendous laboratory testing resources to conduct the requisite component-level and engine-level testing to gain confidence in the prediction capability of such a model. The most challenging, and perhaps somewhat impossible, part of this comprehensive approach would be to complete some sort of experimental validation step to demonstrate that the model accurately predicts the combined performance of engine technologies that do not yet exist.

This level of effort is beyond the scope of the agencies' resources. However, fortunately, other research and development programs have sufficiently reported on the magnitude of these dis-synergies to the point that reliable estimates may be projected. The agencies were able to rely upon information made available through research programs like DOE's SuperTruck Program, where a number of major engine manufacturers partnered with DOE to co-fund advanced high-efficiency engine development.[23,25,26,30] In each of the manufacturer's SuperTruck programs, more than five years and greater than ten million dollar budgets were spent to model and develop pre-prototype engines. The agencies initially asked manufacturers if they would share their proprietary SuperTruck engine cycle simulation models with the agencies. This request was understandably declined because such models contain manufacturers' most advanced and valuable competitive information. Therefore, based on the best information available, the agencies developed a single set of empirical constants to account for these known dis-synergies, and we applied these constants within our stringency analyses.

In this empirical approach, all technologies under consideration are combined according to the National Academies recommended formula for combining the fuel efficiency benefits of multiple engine (and vehicle) technologies:[1]

Equation 2-1: Formula for Combining Fuel Efficiency Benefits

$$\%FE_{\text{total}} = 1 - \prod_{i} (1 - f_{\text{i}} \cdot \%FE_{\text{i}})$$

In this equation, f_{i} represents the market penetration of technology *i*, and $\%FE_{\text{i}}$ is the percent fuel efficiency improvement (i.e., effectiveness) associated with technology *i*. The resulting $\%FE_{\text{total}}$ is the combined fuel efficiency improvement due to all technologies, but with no accounting of technology dis-synergies, like those described above. To account for dis-synergies, $\%FE_{\text{total}}$ is multiplied by a single numerical constant, which we call a dis-synergy factor. This dis-synergy factor has two extreme bounds: a lower bound of 0.0 and an upper bound of 1.0. And practically speaking, it is highly unlikely that adding a technology to an engine that leads toward a dis-synergy factor on the order of 0.5 would even be considered a fuel efficiency improving technology. Therefore, the agencies focused on determining where within the range of 0.5-1.0 we should project this dis-synergy factor to be.

There are two key steps in determining an overall dis-synergy factor. The first step is to determine the effectiveness of each key technology. For this step we relied upon our collection of technology information from DOE's SuperTruck Program, from individual manufacturers and technology suppliers, and from peer reviewed journal articles and presentations at technical conferences. This information includes performance data on individual components and data on engines with different combinations of technology. The second step is to iteratively solve for the most probable single dis-synergy factor that matches the diverse set of data that we collected. This step started by first running a simplified engine cycle simulation model (GT Power) to simulate individual technology benefits, and then we ran the model with different technology combinations. Finally, the results of the simplified model were compared to the data we had collected. Note that while we were not able to validate this model to be accurate in an absolute sense, the relative trends output by the model were consistent with the data we have in-hand. With this model we determined a range of dis-synergy factors and the value of the factor depended in part on the selection of technology packages. We found that this constant varies in the range of 0.75 - 0.90. This range is further supported by separate, independent studies performed by SwRI that were sponsored by SwRI report.[7] Based upon our conclusion of this range, the agencies are not going to adopt a dis-synergy factor of 0.95, which was requested of us in comment. Based on our modeling and corroborative data, 0.95 would be inappropriately high and likely not achievable.

Table 2-11 lists the potential emission reduction technologies together with the agencies' estimated market penetration for tractor engines, along with the dis-synergy factors developed by the agencies. A dis-synergy factor of 0.85 is adopted for 2021, and 0.90 is used for 2024 and 2027. This increase in the value of the dis-synergy factor represents the results of manufacturers increasing their research and development efforts to optimize engine technologies together as a package, in order to comply with the HD Phase 2 engine standards. The agencies have accounted for our projected increased investment in research and design by including respective incremental vehicle cost increases in our cost analysis. By increasing the dis-synergy factor from 0.85 to 0.90 in MY 2024, our MY 2024 and MY 2027 engine standards are based on our projections of increased technology package optimization. For example, we project that the friction increase associated with the use of higher compression ratios leading to higher peak cylinder pressures will be compensated for by friction reduction via improvements in piston ring and crankshaft bearing design, as well as by improved oil lubricants. It should be noted that Table 2-11 does not include individual modes of technology improvement over the 13 individual modes of the SET. This is a result of the fact that we aggregated CBI data obtained from manufacturers in order to avoid releasing proprietary intellectual property within this presentation of our analysis.

Table 2-11 Projected Tractor Engine Technologies and Reduction, Percent Improvements Beyond Phase 1, 2017 Engine as Baseline

SET MODE	SET WEIGHTED REDUCTION (%) 2020-2027	MARKET PENETRATION (2021)	MARKET PENETRATION (2024)	MARKET PENETRATION (2027)
Turbo compound with clutch	1.8%	5%	10%	10%
WHR (Rankine cycle)	3.6%	1%	5%	25%
Parasitic/Friction (Cyl Kits, pumps, FIE), lubrication	1.4%	45%	95%	100%
Aftertreatment (lower dP)	0.6%	30%	95%	100%
EGR/Intake & exhaust manifolds/Turbo /VVT/Ports	1.1%	45%	95%	100%
Combustion/FI/Control	1.1%	45%	95%	100%
Downsizing	0.3%	10%	20%	30%
Weighted reduction (%)		1.8%	4.0%	4.8%
Down speed impact on 13 modes		0.1%	0.2%	0.3%
Total reduction		1.8%	4.2%	5.1%

The agencies used the current market information and literature values to project what technologies would be available in the time frame beyond 2021 and what their market penetration would be. Chapter 2.3.9 details the reasons of why many of the technology market penetration rates would follow an S-shape curve, which is most applicable to WHR with the Rankine cycle technology. In spite of the fact that all trucks with WHR Ranking cycle technology were still in the R/D stage or in the pre-prototype stage, the successful demonstrations in real world driving conditions such as the DOE-sponsored SuperTruck program, shows the technology that could be brought into market earlier because of the technology's effectiveness. The agencies project that WHR with Rankine cycle will gain momentum with time because of the potential for large emission reductions. It is unlikely that we will see large scale production of WHR in the 2021 MY because of the many challenges that industry faces, as described in Chapter 2.3.9. The agencies expect a market penetration of 1 percent in 2021. It will take time for WHR to have a sizeable market penetration due to system complexity and it is estimated to be 5 percent in 2024; 25 percent in 2027, which follows an S-shape curve, beginning with slow initial adoption, then more rapid adoption, and then a leveling off as the market saturates. More discussion on WHR market penetration can be seen in Chapter 2.3.9. As there discussed, this projected trend is consistent with the finding reported by NACEF[36] in terms of the S-shape curve.

As for WHR with turbo-compound technology, only Daimler uses turbo-compound in their DD15 and DD16 engines. They are phasing out turbo-compounding in the future and replacing it with asymmetric turbo technology for most applications. Volvo just announced that it would bring its newly-developed turbo-compound technology to market in mainly tractor applications. Combining both manufacturers' market shares, the agencies estimate a 5 percent market share for turbo-compound technologies in 2021. Additional production from these manufacturers or from some additional manufacturers that could adopt this technology in some of their trucks could push the market penetration up to 10 percent after 2024.

All other technologies, with the exception of downsizing, such as parasitic/friction loss, aftertreatment, air breathing system, and combustion, which have been on the market already for substantial periods and are relatively mature when compared to WHR, would follow the same path for market penetration, 45 percent in 2021, 95 percent in 2024, and 100 percent in 2027. The agencies don't expect high market penetration of engine downsizing, because downsizing has a trade-off with reliability and resale values. We do see the potential for this type of technology as it can be effective when combined with down speeding, specifically when power demand drops due to more efficient engine and vehicle platforms. However, unlike other technologies, such as parasitic/friction, aftertreatment, and combustion, the technology of down-speeding together with downsizing would face the issue associated with resale value. As such, the fleet may be reluctant to accept this technology as others until the reliability is proven. Therefore, we don't expect that the market penetration would be as high as other technologies. It comes down to a matter of choice. We project 10 percent, 20 percent, and 30 percent market penetration rates in 2021, 2024, and 2027 respectively.

The tractor engine technology compliance pathway shown in Table 2-11 is only one of many paths that manufacturers might adopt in order to achieve the 1.8 percent, 4.2, and 5.1 percent reduction goals in 2021, 2024 and 2027 respectively. This particular compliance pathway relies on some use of WHR – small initial market penetration in 2021 and 2024, increasing to 25 percent in MY 2027.[E] This projected rate of penetration in MY 2027 is greater than projected at proposal (where the agencies' compliance pathway had WHR used in tractor engines). One of the key reasons to increase the market penetration on WHR with Rankine cycle technology was based on the valuable and credible CBI information obtained from a meeting with Cummins.[123] It can be mentioned that, during the meeting, Cummins provided detailed technical information on both technology effectiveness and reliability on an entire engine system level as well as a component level, indicating that the agency's early projection with 15 percent on WHR was conservative, and should be increased even with their current engine platform. Considering that sleeper cab and day cab are about 50-50 percent share on the market, and also considering that Cummins' engine Class 8 market share is in the range of 35-45 percent in the past few years and is expected to stay in the same range, this can be translated to 17.5-22.5 percent market share in the sleeper cab segment just from one manufacturer. Although the WHR

[E] As will be seen in Chapter 2.8, much higher market penetration of WHR is used in the sleeper cab engine.

technology is most likely and most effectively applied to sleeper cabs, it would not be surprising that a very small portion of day cabs could utilize this type of technology depending on their driving routes. If other manufacturers can put their WHR Rankine cycle system in a pilot trial manner with just a few percent market share, it could reach 25 percent share on the market.

In addition to the technologies mentioned above, down speeding effects are also part of a projected technology package for tractor engines, and for vocational engines that share the same hardware as tractor engines. Down speeding is performed by systematically shifting the engine peak torque curve to a lower speed region of the engine map and also increasing the overall peak torque at this lower speed. This allows you to take advantage of the use of a lower vehicle axle ratio to enable the engine to spend much of its operating time in its most efficient spot on the map. We expect that down speeding will take place in three sequential steps in 2021, 2024, and 2027, with engine peak torque shifting to the highest torque at the lowest speed in 2027.

The changes to engine peak torque and associated power for down speed engines has a different effect on the 13 modes of the SET when compared to a 2018 baseline engine. The effect is varied based on the engine map characteristics, such as the location of the sweet spot and the shape of the peak torque curve. We utilized a large number of engine fuel maps to investigate the impact of down speeding on composite fuel consumption over the SET certification cycle for different engine fuel map shapes. We found that the benefit varied from no improvement to 0.6 percent while the average benefit is around 0.3 percent for the 2027 torque curve used in our analysis. Engine fuel maps that are less aggressive in peak torque behavior, such as 2021 engine map, show less of an effect on fuel consumption reduction. Therefore, we conclude that fuel consumption reductions due solely to the changes in the 13 mode SET speed and load are 0.1 percent, 0.2 percent, and 0.3 percent for 2021, 2024, and 2027, respectively.

Figure 2-17, Figure 2-18, and Figure 2-19 contain the 2018 baseline engine fuel maps for 350 Hp, 455 Hp, and 600 Hp rating engines. The 350 Hp engine will be used for class 7 tractors and some HHD vocational vehicles. The 455 Hp engine will be used for all HHD tractors with sleeper cabs and day cabs as well as some HHD vocational vehicles. The 600 Hp engine is only used for Heavy Haul tractors.

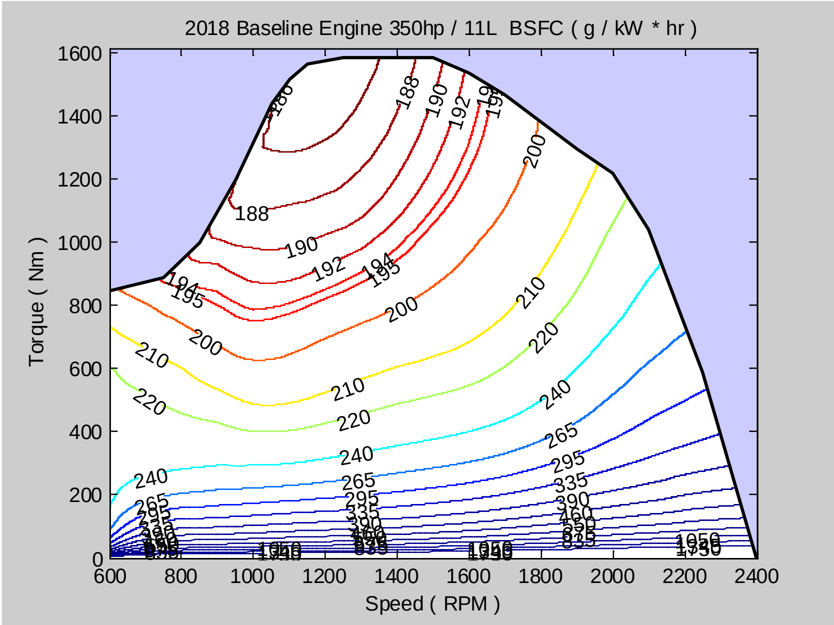


Figure 2-17 2018 Baseline Engine Fuel Map used in GEM for a 350 Hp Rating

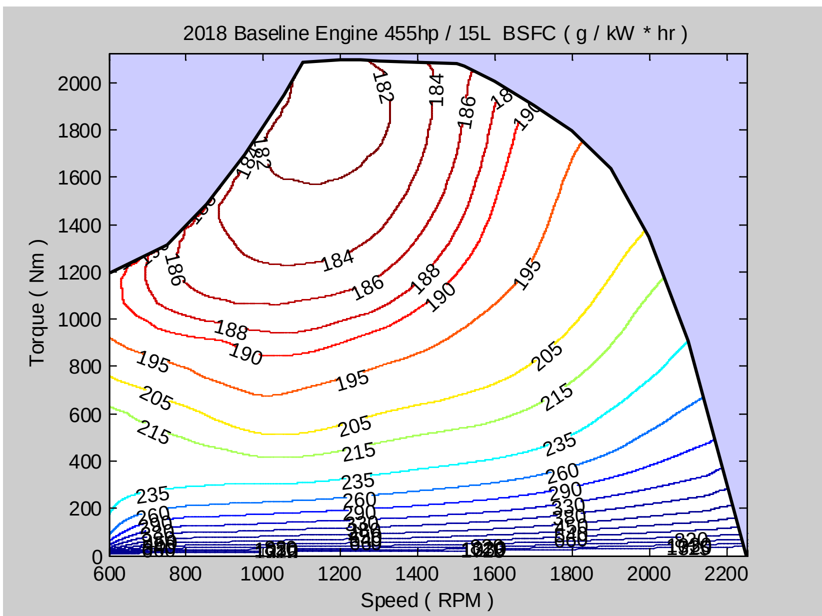


Figure 2-18 2018 Baseline Engine Fuel Map used in GEM for a 455 Hp Rating

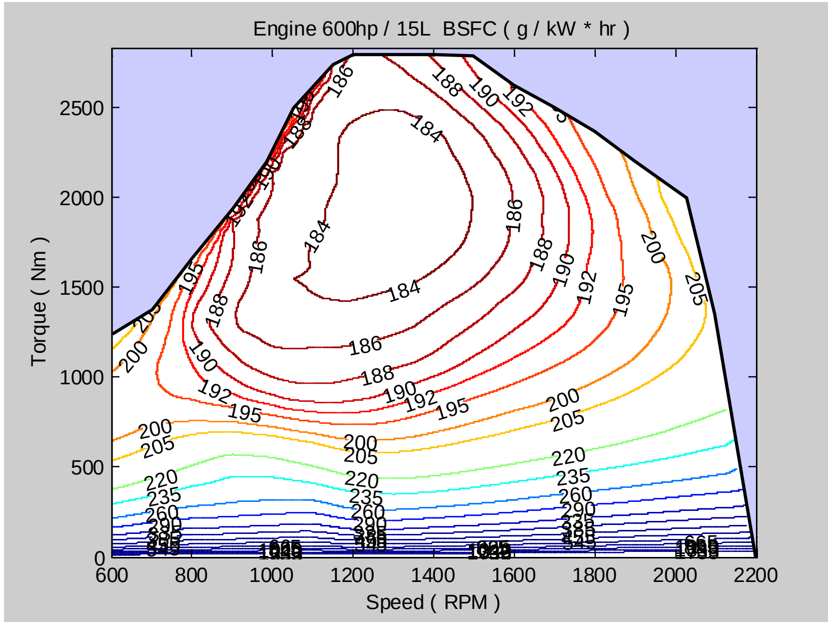


Figure 2-19 2018 Baseline Engine Fuel Map used in GEM for a 600 Hp Rating

The agencies considered the same technology package developed for the HHD diesel engines for vocational LHD diesel and MHD diesel engines. The technology package includes parasitic and friction reduction, improved lubrication, aftertreatment improvements, EGR system and air flow improvements, and combustion improvements. WHR technology is not part of the package as WHR is not as efficient over transient operation, which is the principal operating mode for vocational vehicles, even regional vehicles, since transient operation still comprises a large portion of overall regional vehicle operation. One difference between tractor and vocational engines is the model based control used over transient operation, which is applied to operation over the FTP cycle. Chapter 2.3.3 details the model based control. Table 2-12 below lists technologies and projected penetration rates which are the predicate for the standard for the various vocational vehicle engines. The same dis-synergy factors that were generated for tractors are also used. As is true of all the projected compliance pathways,[F] there are other (usually myriad) ways to achieve the standard.

The market penetration rate and technology effectiveness estimates shown in Table 2-12 were developed using CBI data provided by engine manufacturers in conjunction with the agencies' engineering judgment using the same principles outlined previously for tractor engines. In terms of effectiveness, the model based control used over transient operation, which is described in Chapter 2.3.3, would be one of the most effective technologies, but it would take significant effort to develop and put it into production. An example of this technology is the neural network approach developed by Daimler.[19,20] One concern surrounding the use of this technology is that it is still not clear how it will interact with on-board diagnostics (OBD). For example, one of the purposes of the model based control is to use physical models to predict the engine performance. As a result of that, the number of sensors in theory could be reduced, such as one of the NO_x sensors, or a few temperature sensors. On the other hand, OBD would largely

[F] The exception being those standards where a design is mandated, as for certain non-aero trailers.

rely on the sensors to collect data. If one of the engine components malfunctions, and the sensors that were in place to identify the issue were removed because of model based control, OBD would not be able to diagnose the issue correctly. It is not clear how this issue can be effectively resolved if some of sensors would be removed. We expect a 25 percent market penetration in 2021, 30 percent in 2024, and 40 percent in 2027. All other technologies in Table 2-10 are relatively more mature than model based control, and therefore, higher market penetration is projected. It should be pointed out that in developing standard stringency, the technologies' effectiveness is applied to all the engines including Regional, Multipurpose, and Urban vehicles, since the same engine hardware will be used for all of these applications.

Table 2-12 Projected Vocational Engine Technologies and Reduction, Percent Improvements Beyond Baseline Engine

TECHNOLOGY	GHG EMISSIONS REDUCTION 2020-2027	MARKET PENETRATION 2021	MARKET PENETRATION 2024	MARKET PENETRATION 2027
Model based control	2.0%	25%	30%	40%
Parasitic /Friction	1.5%	60%	90%	100%
EGR/Air/VVT /Turbo	1.0%	60%	90%	100%
Improved AT	0.5%	30%	60%	100%
Combustion Optimization	1.0%	60%	90%	100%
Weighted reduction (%)-L/M/HHD		2.3%	3.6%	4.2%

Figure 2-20 and Figure 2-21 are the 2018 baseline engine fuel maps used in GEM for the 270 Hp and 200 Hp rated engines. The 2018 baseline engines with 350 Hp and 455 Hp that are used for vocational vehicles share the same engines as tractors, and therefore, there is no need to display their maps here.

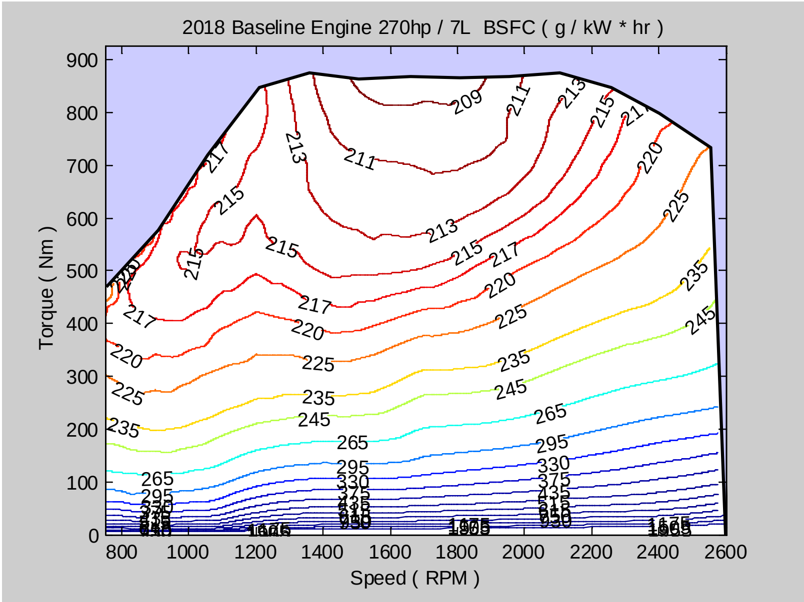


Figure 2-20 2018 Baseline Engine Fuel Map used in GEM for a 270 Hp Rating

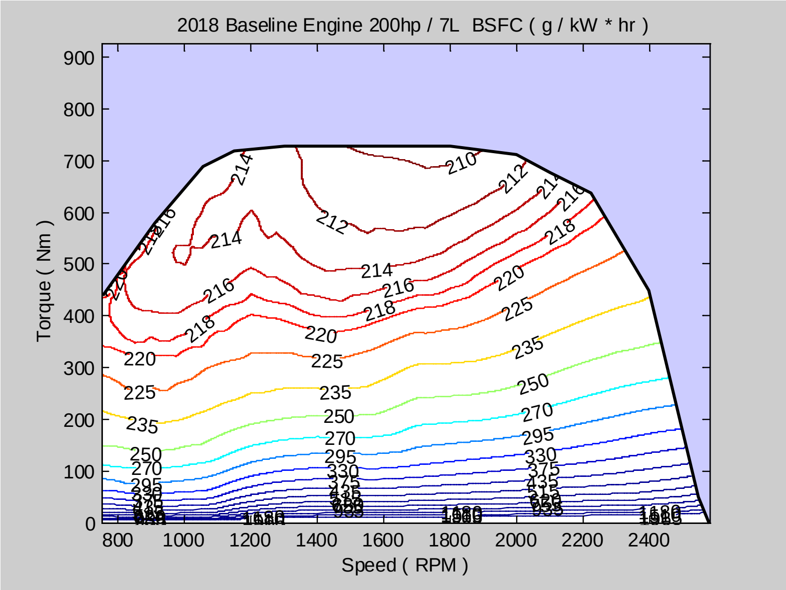


Figure 2-21 2018 Baseline Engine Fuel Map used in GEM for a 200 Hp Rating

2.7.6 2021 Model Year HHD Diesel Engine Package for Tractors

As can be seen in Table 2-11, the composite CO_2 reduction (the product of the technology efficiency and projected technology penetration rates shown in that table) for a MY 2021 tractor engine over the SET cycle is 1.8 percent. With this reduction, the numerical stringency values for 2021 can be derived from the baseline engine with new Phase 2 weighting factors. Table 2-13 below shows the 2021 model year tractor engine standards.

Table 2-13 2021 Model Year Standards – Tractors

	MHDD- SET	HHDD - SET
CO_2 Emissions (g CO_2/bhp-hr)	473	4474
Fuel Consumption (gal/100 bhp-hr)	4.6464	4.3910

The cost estimates for the MY 2021 HHD diesel engine packages can be developed from the same information (i.e. technologies on which standard stringency is premised and projected penetration rates) as shown in Table 2-14. We present technology cost estimates along with adoption rates in Chapter 2.11 of this RIA. We present package cost estimates in greater detail in Chapter 2.12 of this RIA.

Table 2-14 Technology Costs as Applied in Expected Packages for MY2021 Tractor Diesel Engines relative to the Flat Baseline (2013$)[a]

	MEDIUM HD	HEAVY HD
Aftertreatment system (improved effectiveness SCR, dosing, DPF)	$7	$7
Valve Actuation	$84	$84
Cylinder Head (flow optimized, increased firing pressure, improved thermal management)	$3	$3
Turbocharger (improved efficiency)	$9	$9
Turbo Compounding	$51	$51
EGR Cooler (improved efficiency)	$2	$2
Water Pump (optimized, variable vane, variable speed)	$44	$44
Oil Pump (optimized)	$2	$2
Fuel Pump (higher working pressure, increased efficiency, improved pressure regulation)	$2	$2
Fuel Rail (higher working pressure)	$5	$5
Fuel Injector (optimized, improved multiple event control, higher working pressure)	$5	$5
Piston (reduced friction skirt, ring and pin)	$1	$1
Valve Train (reduced friction, roller tappet)	$39	$39
Waste Heat Recovery	$71	$71
“Right sized” engine	-$41	-$41
Total	$284	$284

Note:
[a] Costs presented here include projected technology penetration rates presented in Table 2-11. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the RIA (see RIA 2.11).

2.7.7 2021 Model Year LHD/MHD/HHD Diesel Engine Package for Vocational Vehicles

From Table 2-12, the reduction of CO_2 for 2021 model years of all LHD/MHD/HHD vocational diesel engines is 2.3 percent. Table 2-15 below shows the 2021 model year vocational engine standards.

Table 2-15 2021 Model Year Standards -- Vocational

	LHDD - FTP	MHDD - FTP	HHDD - FTP
CO_2 Emissions (g CO_2/bhp-hr)	563	545	513
Fuel Consumption (gal/100 bhp-hr)	5.5305	5.3536	5.0393

The cost estimates for the MY 2021 vocational diesel engines are shown in Table 2-16. We present technology cost estimates along with adoption rates in Chapter 2.11 of this RIA. We present package cost estimates in greater detail in Chapter 2.12 of this RIA and adoption rates in Chapter 2.9.1.2.2.

Table 2-16 Technology Costs as Applied in Expected Packages for MY2021 Vocational Diesel Engines relative to the Flat Baseline (2013$)[a]

	LIGHT HD	MEDIUM HD	HEAVY HD
Aftertreatment system (improved effectiveness SCR, dosing, DPF)	$8	$8	$8
Valve Actuation	$93	$93	$93
Cylinder Head (flow optimized, increased firing pressure, improved thermal management)	$6	$3	$3
Turbocharger (improved efficiency)	$10	$10	$10
EGR Cooler (improved efficiency)	$2	$2	$2
Water Pump (optimized, variable vane, variable speed)	$58	$58	$58
Oil Pump (optimized)	$3	$3	$3
Fuel Pump (higher working pressure, increased efficiency, improved pressure regulation)	$3	$3	$3
Fuel Rail (higher working pressure)	$8	$6	$6
Fuel Injector (optimized, improved multiple event control, higher working pressure)	$8	$6	$6
Piston (reduced friction skirt, ring and pin)	$1	$1	$1
Valve Train (reduced friction, roller tappet)	$70	$52	$52
Model Based Controls	$29	$29	$29
Total	$298	$275	$275

Note:
[a] Costs presented here includes projected technology penetration rates presented in Table 2-12. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the RIA (see RIA 2.11).

2.7.8 2024 Model Year HHDD Engine Package for Tractors

The agencies assessed the impact of technologies over each of the SET modes to project an overall improvement in the 2024 model year. The agencies considered additional improvements in the technologies included in the 2021 model year package. Compared to the 2021 technology package, the technology package in 2024 considers higher market adoption as shown in Table 2-11, thus deriving a reduction of 4.2 percent. Table 2-17 below shows the 2024 model year tractor engine standards.

Table 2-17 2024 Model Year Standards – Tractors

	MHDD- SET	HHDD - SET
CO_2 Emissions (g CO_2/bhp-hr)	461	436
Fuel Consumption (gal/100 bhp-hr)	4.5285	4.2829

The cost estimates for the MY 2024 tractor diesel engines are shown in Table 2-18. We present technology cost estimates along with adoption rates in Chapter 2.11 of this RIA. We present package cost estimates in greater detail in Chapter 2.12 of this RIA.

Table 2-18 Technology Costs as Applied in Expected Packages for MY2024 Tractor Diesel Engines relative to the Flat Baseline (2013$)[a]

	MEDIUM HD	HEAVY HD
Aftertreatment system (improved effectiveness SCR, dosing, DPF)	$14	$14
Valve Actuation	$169	$169
Cylinder Head (flow optimized, increased firing pressure, improved thermal management)	$6	$6
Turbocharger (improved efficiency)	$17	$17
Turbo Compounding	$93	$93
EGR Cooler (improved efficiency)	$3	$3
Water Pump (optimized, variable vane, variable speed)	$85	$85
Oil Pump (optimized)	$4	$4
Fuel Pump (higher working pressure, increased efficiency, improved pressure regulation)	$4	$4
Fuel Rail (higher working pressure)	$9	$9
Fuel Injector (optimized, improved multiple event control, higher working pressure)	$10	$10
Piston (reduced friction skirt, ring and pin)	$3	$3
Valve Train (reduced friction, roller tappet)	$77	$77
Waste Heat Recovery	$298	$298
"Right sized" engine	-$82	-$82
Total	$712	$712

Note:
[a] Costs presented here reflect projected technology penetration rates presented in Table 2-11. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the RIA (see RIA 2.11).

2.7.9 2024 Model Year LHD/MHD/HHD Diesel Engine Package for Vocational Vehicles

The agencies developed the 2024 model year LHD/MHD/HHD vocational diesel engine package based on additional improvements in the technologies included in the 2021 model year package as shown in Table 2-12. The projected impact of these technologies provides an overall reduction of 3.6 percent over the 2018 model year baseline. Table 2-19 below shows the 2024 model year vocational engine standards.

Table 2-19 2024 Model Year Standards – Vocational

	LHDD - FTP	MHDD - FTP	HHDD - FTP
CO_2 Emissions (g CO_2/bhp-hr)	555	538	506
Fuel Consumption (gal/100 bhp-hr)	5.4519	5.2849	4.9705

Costs for the MY 2024 vocational diesel engines are shown in Table 2-20. We present technology cost estimates along with adoption rates in Chapter 2.11 of this RIA. We present package cost estimates in greater detail in Chapter 2.12 of this RIA.

Table 2-20 Technology Costs as Applied in Expected Packages for MY2024 Vocational Diesel Engines relative to the Flat Baseline (2013$)[a]

	LIGHT HD	MEDIUM HD	HEAVY HD
Aftertreatment system (improved effectiveness SCR, dosing, DPF)	$14	$14	$14
Valve Actuation	$160	$160	$160
Cylinder Head (flow optimized, increased firing pressure, improved thermal management)	$10	$6	$6
Turbocharger (improved efficiency)	$16	$16	$16
EGR Cooler (improved efficiency)	$3	$3	$3
Water Pump (optimized, variable vane, variable speed)	$81	$81	$81
Oil Pump (optimized)	$4	$4	$4
Fuel Pump (higher working pressure, increased efficiency, improved pressure regulation)	$4	$4	$4
Fuel Rail (higher working pressure)	$11	$9	$9
Fuel Injector (optimized, improved multiple event control, higher working pressure)	$13	$10	$10
Piston (reduced friction skirt, ring and pin)	$2	$2	$2
Valve Train (reduced friction, roller tappet)	$97	$73	$73
Model Based Controls	$32	$32	$32
Total	$446	$413	$413

Note:
[a] Costs presented here include project technology penetration rates presented in Table 2-12. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the RIA (see RIA 2.11).

2.7.10 2027 Model Year HHDD Engine Package for Tractor

The agencies assessed the impact of technologies over the SET composite test cycle to project an overall improvement in the 2027 model year. The agencies considered additional improvements in the technologies included in the 2024 model year package. Compared to 2021 technology package, the technology package in 2027 considers higher market adoption, thus deriving emission reductions of 5.1 percent as shown in Table 2-11. Table 2-21 below shows the 2027 model year tractor engine standards.

Table 2-21 2027 Model Year Standards – Tractors

	MHDD- SET	HHDD - SET
CO_2 Emissions (g CO_2/bhp-hr)	457	432
Fuel Consumption (gal/100 bhp-hr)	4.4892	4.2436

The costs for the MY 2027 tractor diesel engines are shown in Table 2-22. We present technology cost estimates along with adoption rates in Chapter 2.12 of this RIA. We present package cost estimates in greater detail in Chapter 2.13 of this RIA.

Table 2-22 Technology Costs as Applied in Expected Packages for MY2027 Tractor Diesel Engines relative to the Flat Baseline (2013$)[a]

	MEDIUM HD	HEAVY HD
Aftertreatment system (improved effectiveness SCR, dosing, DPF)	$15	$15
Valve Actuation	$172	$172
Cylinder Head (flow optimized, increased firing pressure, improved thermal management)	$6	$6
Turbocharger (improved efficiency)	$17	$17
Turbo Compounding	$89	$89
EGR Cooler (improved efficiency)	$3	$3
Water Pump (optimized, variable vane, variable speed)	$85	$85
Oil Pump (optimized)	$4	$4
Fuel Pump (higher working pressure, increased efficiency, improved pressure regulation)	$4	$4
Fuel Rail (higher working pressure)	$9	$9
Fuel Injector (optimized, improved multiple event control, higher working pressure)	$10	$10
Piston (reduced friction skirt, ring and pin)	$3	$3
Valve Train (reduced friction, roller tappet)	$77	$77
Waste Heat Recovery	$1,208	$1,208
“Right sized” engine	-$123	-$123
Total	$1,579	$1,579

Note:
[a] Costs presented here include projected technology penetration rates presented in Table 2-11. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the RIA (see RIA 2.11).

2.7.11 2027 Model Year LHD/MHD/HHD Diesel Engine Package for Vocational Vehicles

The agencies developed the 2027 model year LHD/MHD/HHD vocational diesel engine package based on additional improvements in the technologies included in the 2021 model year package as shown in Table 2-12. The projected impact of these technologies provides an overall emission reduction of 4.2 percent over the 2017 model year baseline. Table 2-23 below shows the 2027 model year standards.

Table 2-23 2027 Model Year Standards – Vocational

	LHDD - FTP	MHDD- FTP	HHDD - FTP
CO_2 Emissions (g CO_2/bhp-hr)	552	535	503
Fuel Consumption (gal/100 bhp-hr)	5.4224	5.2554	4.9411

Costs for MY 2027 vocational diesel engines are shown in Table 2-24. We present individual technology cost estimates in Chapter 2.11 of this RIA and adoption rates for vocational vehicle engines in Chapter 2.9.1 of this RIA. We present package cost estimates in greater detail in Chapter 2.12 of this RIA.

Table 2-24 Technology Costs as Applied in Expected Packages for MY2027 Vocational Diesel Engines relative to the Flat Baseline (2013$)[a]

	LIGHT HD	MEDIUM HD	HEAVY HD
Aftertreatment system (improved effectiveness SCR, dosing, DPF)	$15	$15	$15
Valve Actuation	$172	$172	$172
Cylinder Head (flow optimized, increased firing pressure, improved thermal management)	$10	$6	$6
Turbocharger (improved efficiency)	$17	$17	$17
EGR Cooler (improved efficiency)	$3	$3	$3
Water Pump (optimized, variable vane, variable speed)	$85	$85	$85
Oil Pump (optimized)	$4	$4	$4
Fuel Pump (higher working pressure, increased efficiency, improved pressure regulation)	$4	$4	$4
Fuel Rail (higher working pressure)	$11	$9	$9
Fuel Injector (optimized, improved multiple event control, higher working pressure)	$14	$10	$10
Piston (reduced friction skirt, ring and pin)	$3	$3	$3
Valve Train (reduced friction, roller tappet)	$102	$77	$77
Model Based Controls	$41	$41	$41
Total	$481	$446	$446

Note:

[a] Costs presented here include projected technology penetration rates presented in Table 2-12. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the RIA (see RIA 2.11).

2.8 Technology Application and Estimated Costs – Tractors

2.8.1 Defining the Baseline Tractors

The fuel efficiency and CO_2 emissions of combination tractors vary depending on the configuration of the tractor. Many aspects of the tractor impact its performance, including the engine fuel map (independent of improvements measured under the engine standard), the transmission, drive axle, aerodynamics, and rolling resistance. For each tractor subcategory, the agencies selected a theoretical tractor to represent the average 2017 model year tractor that meets the Phase 1 standards (see 76 FR 57212, September 15, 2011). These tractors are used as baselines from which to evaluate costs and effectiveness of additional technologies and standards. The specific attributes of each tractor subcategory baseline are listed below in Table 2-25. Using these values, the agencies assessed the CO_2 emissions and fuel consumption performance of the baseline tractors using the final version of Phase 2 GEM. The results of these simulations are shown below in Table 2-26.

The Phase 1 2017 model year tractor standards and the baseline 2017 model year tractor results are not directly comparable. The same set of aerodynamic and tire rolling resistance technologies were used in both setting the Phase 1 standards and determining the baseline of the Phase 2 tractors. However, there are several aspects that differ. First, a new version of GEM was developed and validated to provide additional capabilities, including more refined modeling of transmissions and engines. Second, the determination of the HD Phase 2 C_dA value takes into account a revised test procedure, a new standard reference trailer, and wind averaged drag. Additionally, the HD Phase 2 version of GEM includes road grade in the 55 mph and 65 mph highway cycles, as discussed in Preamble Section III.E.

The agencies used the same adoption rates of tire rolling resistance for the Phase 2 baseline as we used to set the Phase 1 2017 MY standards. See 76 FR 57211. The tire rolling resistance level assumed to meet the 2017 MY Phase 1 standard high roof sleeper cab is considered to be a weighted average of 10 percent pre-Phase 1 baseline rolling resistance, 70 percent Level 1, and 20 percent Level 2. The tire rolling resistance to meet the 2017MY Phase 1 standards for the high roof day cab, low roof sleeper cab, and mid roof sleeper cab includes 30 percent pre-Phase 1 baseline level, 60 percent Level 1 and 10 percent Level 2. Finally, the low and mid roof day cab 2017 MY standards were premised on a weighted average rolling resistance consisting of 40 percent baseline, 50 percent Level 1, and 10 percent Level 2. The agencies did not receive comments on the tire packages in the NPRM used to develop the Phase 2 baseline.

The Phase 2 baseline in the NPRM was determined based on the aerodynamic bin adoption rates used to determine the Phase 1 MY 2017 tractor standards. The vehicles that were tested prior to the NPRM were used to develop the proposed aerodynamic bin structure for Phase 2. In both the NPRM and this final rulemaking, we developed the Phase 2 bins such that there is an alignment between the Phase 1 and Phase 2 aerodynamic bins after taking into consideration the changes in aerodynamic test procedures and reference trailers required in Phase 2. The Phase 2 bins were developed so that tractors that performed as a Bin III in Phase 1 would also perform as Bin III tractors in Phase 2. The baseline aerodynamic value for the Phase 2 final rulemaking was determined in the same manner as the NPRM, using the adoption rates of the bins used to determine the Phase 1 standards, but reflect the final Phase 2 bin C_dA values.

The agencies determined the rear axle ratio and final drive ratio in the 2017 MY baseline tractor based on axle market information shared by Meritor,[124] one of the primary suppliers of heavy-duty axles and confidential business information provided by Daimler. Our assessment of this information found that a rear axle ratio of 3.70 and a top gear ratio of 0.73 (equivalent to a final drive ratio of 2.70) is a commonly spec'd tractor. Meritor's white paper on downspeeding stated that final drive ratios of less than 2.64 are considered to be "downsped."[125] The agencies recognize that there is a significant range in final drive ratios that will be utilized by tractors built in 2017 MY, we do not believe that the average (i.e., baseline) tractor in 2017 MY will downsped.

In the proposal, the agencies noted that the manufacturers were not using tamper-proof automatic engine shutdown systems (AESS) to comply with the Phase 1 standards. As a result the agencies reverted back to the baseline auxiliary power unit (APU) adoption rate of 30 percent used in the Phase 1 baseline. In response to comments, the agencies reassessed the baseline idle reduction adoption rates. The latest NACFE confidence report found that 9 percent of tractors had auxiliary power units and 96 percent of vehicles are equipped with adjustable automatic engine shutdown systems.[126] Therefore, the agencies are projecting that 9 percent of sleeper cabs will contain an adjustable AESS and APU, while the other 87 percent will only have an adjustable AESS.

Table 2-25 GEM Inputs for the 2017 Baseline Class 7 and 8 Tractors

CLASS 7			CLASS 8					
Day Cab			Day Cab			Sleeper Cab		
Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine								
2017 MY 11L Engine 350 HP	2017 MY 11L Engine 350 HP	2017 MY 11L Engine 350 HP	2017 MY 15L Engine 455 HP	2017 MY 15L Engine 455 HP	2017 MY 15L Engine 455 HP	2017 MY 15L Engine 455 HP	2017 MY 15L Engine 455 HP	2017 MY 15L Engine 455 HP
Aerodynamics (CdA in m²)								
5.41	6.48	6.38	5.41	6.48	6.38	5.41	6.48	5.90
Steer Tires (CRR in kg/metric ton)								
6.99	6.99	6.87	6.99	6.99	6.87	6.87	6.87	6.54
Drive Tires (CRR in kg/metric ton)								
7.38	7.38	7.26	7.38	7.38	7.26	7.26	7.26	6.92
Extended Idle Reduction – Adjustable AESS with no Idle Red Tech Adoption Rate @ 1% Effectiveness								
N/A	N/A	N/A	N/A	N/A	N/A	87%	87%	87%
Extended Idle Reduction – Adjustable AESS with Diesel APU Adoption Rate @ 3% Effectiveness								
N/A	N/A	N/A	N/A	N/A	N/A	9%	9%	9%
Transmission = 10 Speed Manual Transmission **Gear Ratios =** 12.8, 9.25, 6.76, 4.90, 3.58, 2.61, 1.89, 1.38, 1.00, 0.73								
Drive Axle Configuration = 4x2			**Drive Axle Configuration** = 6x4					
Tire Revs/Mile = 512								
Drive Axle Ratio = 3.70								

Table 2-26 Class 7 and 8 Tractor 2017 Baseline CO_2 Emissions and Fuel Consumption

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
CO_2 (grams CO_2/ton-mile)	119.1	127.2	129.7	91.3	96.6	98.2	84.0	90.2	87.8
Fuel Consumption (gal/1,000 ton-mile)	11.69941	12.49509	12.74067	8.96857	9.48919	9.64637	8.25147	8.86051	8.62475

The 2017 model year baseline fuel maps in the HD Phase 2 version of GEM are different than those used in 2017 year fuel maps in the HD Phase 1 version. The baseline map in the HD Phase 2 version takes two major factors into consideration. The first is the likelihood of engine down speeding beyond the 2020 model year and the second is making the gradient of brake specific fuel consumption rate (BSFC) around the fuel consumption sweet spot less radical when compared to the HD Phase 1 version's engine fuel map. All the baseline engine fuel maps for use in 2017 can be seen in Chapter 2.7.5. All other maps from 2021 to 2027 can be seen in Chapter 2.8.4.1.

The agencies received comments regarding the heavy-haul baseline vehicle with respect to the transmission and axle ratio. Upon consideration of these comments, the agencies find that the baseline heavy-haul tractor is better represented by an 18-speed transmission with a 3.73 rear axle ratio. The heavy-haul tractor baseline configuration inputs to GEM for the Phase 2 final rule are shown below in Table 2-27. The baseline 2017 MY heavy-haul tractor will emit 56.9 grams of CO_2 per ton-mile and consume 5.59 gallons of fuel per 1,000 ton-mile.

Table 2-27 Heavy-Haul Tractor Baseline Configuration

BASELINE HEAVY-HAUL TRACTOR CONFIGURATION
Engine = 2017 MY 15L Engine with 600 HP
Aerodynamics (CdA in m^2) = 5.00
Steer Tires (CRR in kg/metric ton) = 7.0
Drive Tires (CRR in kg/metric ton) = 7.4
Transmission = 18 speed Manual Transmission Gear ratio= 14.4, 12.29, 8.51, 7.26, 6.05, 5.16, 4.38, 3.74, 3.2, 2.73, 2.28, 1.94, 1.62, 1.38, 1.17, 1.00, 0.86, 0.73
Drive axle Ratio = 3.73
All Technology Improvement Factors = 0%

2.8.2 Defining the Tractor Technology Packages

The agencies' assessment of the technology effectiveness was developed through the use of GEM in coordination with modeling conducted by Southwest Research Institute. The agencies developed the standards through a three-step process, similar to the approach used in Phase 1. First, the agencies developed technology performance characteristics or effectiveness for each technology, as described below. Each technology is associated with an input parameter which in turn is used as an input to the Phase 2 GEM simulation tool (i.e. the final version of GEM used both to develop standard stringency and to evaluate compliance at certification) and its effectiveness thereby modeled. Second, the agencies combined the technology performance levels with a projected technology adoption rate to determine the GEM inputs used (in step 3) to set the stringency of the final standards. Third, the agencies input these parameters into Phase 2 GEM and used the output to determine the final CO_2 emissions and fuel consumption levels. All percentage improvements noted below are over the 2017 baseline tractor.

2.8.2.1 Engine

Please see RIA Chapter 2.7 for a discussion on engine technologies.

2.8.2.2 Aerodynamics

The aerodynamic packages are categorized as Bin I, Bin II, Bin III, Bin IV, Bin V, Bin VI, or Bin VII based on the wind averaged drag aerodynamic performance determined through testing conducted by the manufacturer. In general, the C_dA values for each package and tractor subcategory were developed through EPA's coastdown testing of tractor-trailer combinations, the 2010 NAS report, and SAE papers.[127,128] The agencies also discuss aerodynamic technologies for tractors in Chapter 2.4.1 of the RIA.

As noted in Section III.D of the Preamble, the agencies received comments from manufacturers about the feasibility of developing tractors with aerodynamics that could achieve the proposed Bins V and above. After the proposal, the agencies reviewed new information regarding the aerodynamic improvements achieved in the SuperTruck program for high roof sleeper cabs and box trailers. Also after the proposal, the truck manufacturers conducted CFD analysis of a "typical Bin III" high roof sleeper cab tractor with a Phase 2 standard trailer (with a trailer skirt), a SuperTruck tractor with a Phase 2 standard trailer, and a SuperTruck tractor with a SuperTruck trailer. Even though the agencies did not conduct the CFD testing, we agree with the methodology and the results. As shown in Figure 2-22, the difference between a Bin III high roof sleeper cab tractor and a SuperTruck tractor, both with a Phase 2 standard trailer, is approximately 1.0 m^2. As shown in Table 2-28, the C_dA difference between Bin III and Bin IV is approximately 0.5 m^2 and the difference between Bin III and Bin V is approximately 1.0 m^2. Therefore, a SuperTruck tractor would be able to achieve a Bin V level in Phase 2 with the Phase 2 standard trailer.

Table 2-28 Phase 2 Aerodynamic Bin Values for High Roof Sleeper

PHASE 2 AERO BINS FOR HIGH ROOF SLEEPER CABS	
Phase 2 Bin	C_dA Range (m^2)
Bin III	5.7-6.2
Bin IV	5.2-5.6
Bin V	4.7-5.1

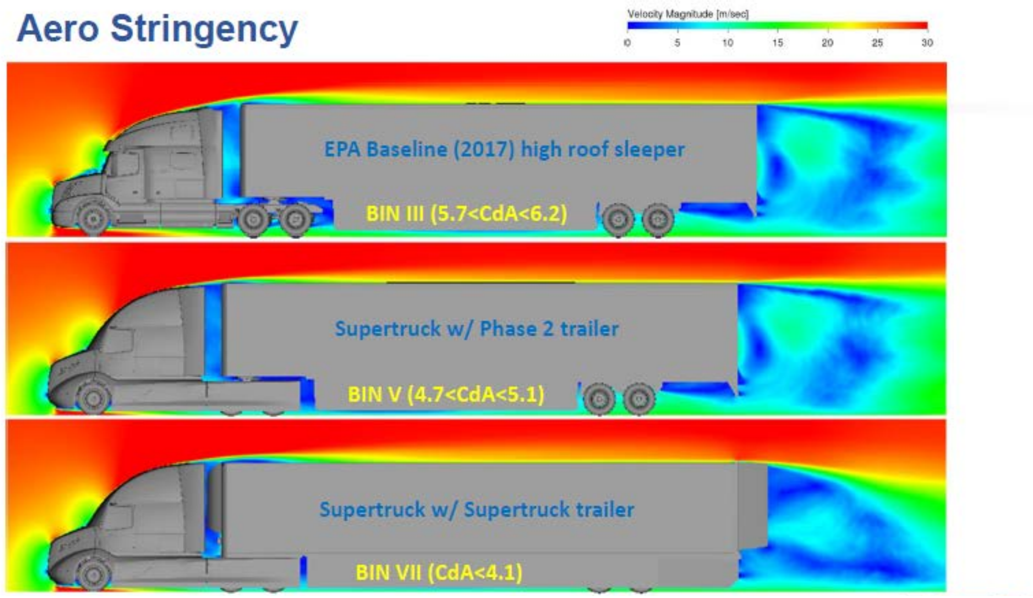


Figure 2-22 Truck & Engine Manufacturers Aerodynamic Analysis of SuperTruck tractor and trailer combinations. Presented to EPA and NHTSA on July 23, 2015 and updated to reflect Phase 2 bins on June 30, 2016.

The agencies conducted additional aerodynamic testing for the final rule. As shown in RIA Chapter 3.2.1.2, the most aerodynamic high roof sleeper cabs tested had a C_dA of approximately 5.4 m^2, which is a Bin IV tractor. Therefore we can conclude that today manufacturers are producing high roof sleeper cabs that range in aerodynamic performance between Bins I and IV. Bin V is achievable through the addition of aerodynamic features that improve the aerodynamics on the best sleeper cabs tested by at least 0.3 m^2 C_dA. The features that could be added to today's best tractors include technologies such as wheel covers, drive axle wrap around splash guards, and roof fairing rear edge filler, and active grill shutters. In addition, manufacturers continue to improve the aerodynamic designs of the front bumper, grill, hood, and windshield. The agencies' analysis of high roof day cabs is similar to our assessment of high roof sleeper cabs. Also as shown in RIA Chapter 3.2.1.2, the most aerodynamic high roof day cab tested by the agencies achieved Bin IV. Our assessment is that the same types of additional technologies that could be applied to high roof sleeper cabs could also be applied to high roof day cabs to achieve Bin V aerodynamic performance. Finally, because the manufacturers have the ability to determine the aerodynamic bin of low and mid roof tractors from the equivalent high roof tractor, this assessment also applies to low and mid roof tractors.

The agencies also considered the ICCT workshop findings that stated opportunities exist for high roof line haul tractor aerodynamic improvements that could lead to a three to nine percent improvement in fuel consumption over a 2010 baseline.[129] This is equivalent to approximately six to 18 percent improvement in C_dA. Our assessment from Phase 1 is that a Bin II high roof sleeper cab is equivalent to a "2010 baseline." See 76 FR 57206. Therefore, the ICCT assessment of a 6-18 percent improvement in aerodynamics equates to performance up to a Bin IV level.

The effectiveness of aerodynamic improvements depends on the drive cycle. As shown below in Figure 2-23, aerodynamics on sleeper cabs that operate a higher fraction of their miles at highway speeds have a greater impact on fuel consumption and CO_2 emissions.

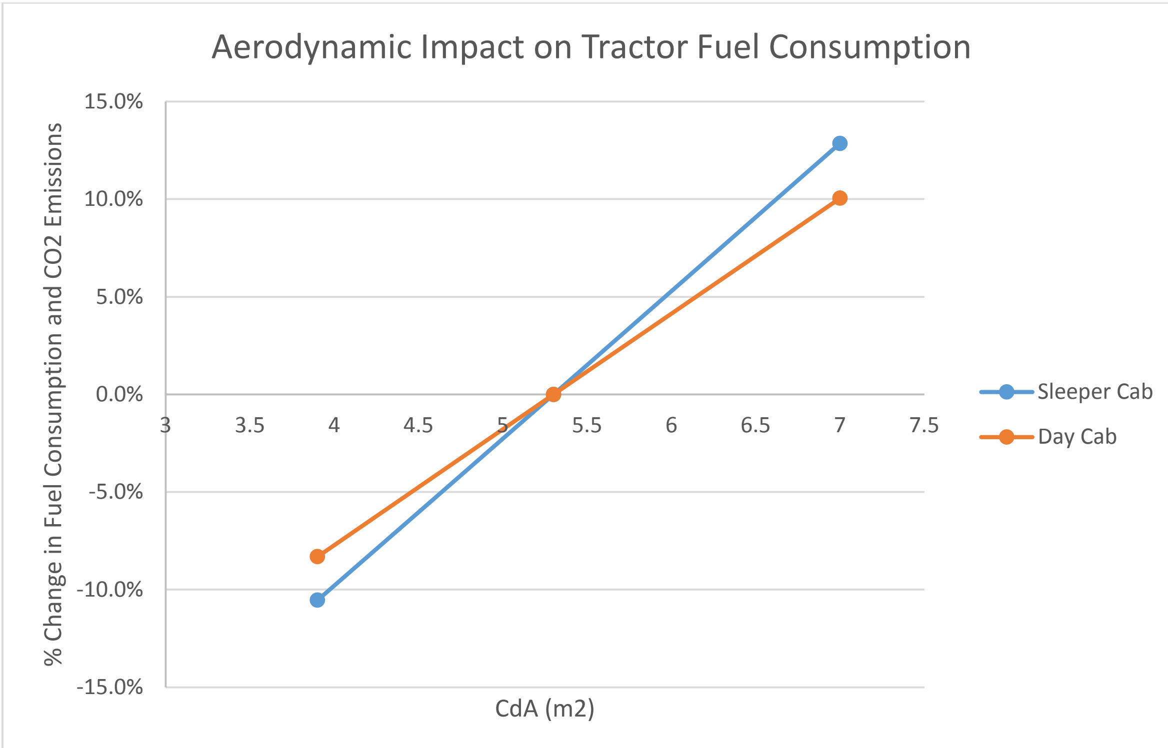


Figure 2-23 Aerodynamic Impact on Tractor CO_2 Emissions based on Phase 2 GEM Simulations

2.8.2.3 Tire Rolling Resistance

The rolling resistance coefficient target for the Phase 2 NPRM was developed from SmartWay's tire testing to develop the SmartWay certification and testing a selection of tractor tires as part of the Phase 1 and Phase 2 programs. Even though the coefficient of tire rolling resistance comes in a range of values, to analyze this range, the tire performance was evaluated at four levels for both steer and drive tires, as determined by the agencies. The four levels in the Phase 2 proposal included the baseline (average) from 2010, Level I and Level 2 from Phase 1, and Level 3 that achieves an additional 25 percent improvement over Level 2. The Level 1 rolling resistance performance represents the threshold used to develop SmartWay designated tires for long haul tractors. The Level 2 threshold represents an incremental step for improvements beyond today's SmartWay level and represents the best in class rolling resistance of the tires we tested for Phase 1. The Level 3 values in the NPRM represented the long-term rolling resistance value that the agencies predicts could be achieved in the 2025 timeframe. Given the multiple year phase-in of the standards, the agencies expect that tire manufacturers will continue to respond to demand for more efficient tires and will offer increasing numbers of tire models with rolling resistance values significantly better than today's typical low rolling resistance tires.

ICCT found in their workshop that opportunities exist for improvements in rolling resistance for tractor tires that could lead to a two to six percent improvement in fuel consumption when compared to a 2010 baseline tractor.[130] A fuel consumption improvement in this range would require a six to 18 percent improvement in the tractor tire rolling resistance levels. Michelin commented that the proposed values for the drive tires seem reasonable, though the 4.5 kg/ton level would require significantly higher adoption rate of new generation wide base single tires. Michelin also stated that the value of 4.3 kg/ton target for steer tires is highly unlikely based on current evolution and that research shows that 5.0 kg/ton would be more likely.

The agencies have evaluated this comment and find it persuasive. The agencies analyzed the 2014MY certification data for tractors between the NPRM and final rulemaking. We found that the lowest rolling resistance value submitted for 2014 MY GHG and fuel efficiency certification for tractors was 4.9 and 5.1 kg/metric ton for the steer and drive tires respectively, while the highest rolling resistance tire had a CRR of 9.8 kg/metric ton.[131] We have accordingly increased the coefficient of rolling resistance for Level 3 tires in the final rule based on the comments and the certification data.

Figure 2-24 shows the impact of changing the rolling resistance on CO_2 emissions and fuel consumption of tractors.

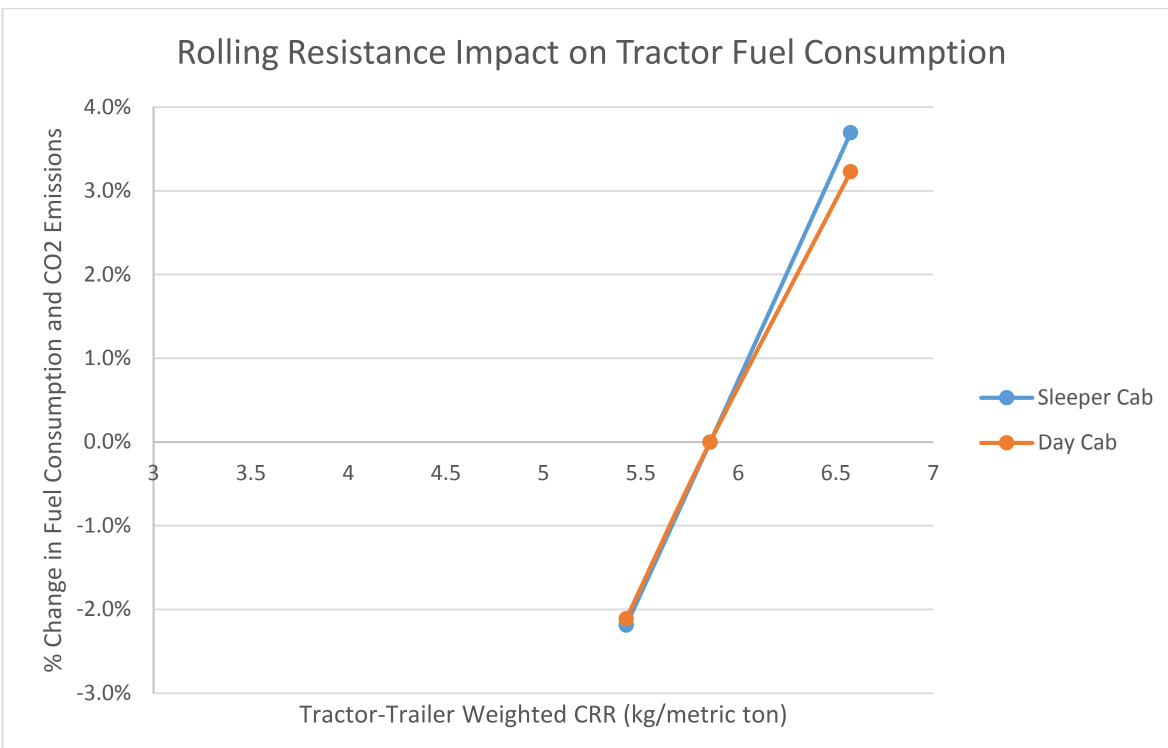


Figure 2-24 Impact of the Coefficient of Rolling Resistance (CRR) on Fuel Consumption based on Phase 2 GEM Simulations

2.8.2.4 Tire Pressure Monitoring and Automatic Tire Inflation Systems

As noted in RIA Chapter 2.4.3.3, automatic tire inflation systems (ATIS) provide fuel consumption improvement opportunities because they keep the tires at the proper inflation pressure. Tire pressure monitoring systems (TPMS) notify the operator of tire pressure, but require the operator to manually inflate the tires to the optimum pressure. The agencies did not propose to include TPMS as a GEM input because of this dependence on the operator. Instead, we requested comment and sought data to support a reduction level. Many commenters suggested that the agencies should recognize TPMS in GEM and provided some additional studies.

After consideration of the comments, the agencies are adopting provisions in Phase 2 to allow GEM inputs for either ATIS or TPMS. The agencies believe there is sufficient incentive for truck operators to address low tire pressure conditions if they are notified that the condition exists by TPMS.

The agencies considered the comments and the studies to determine the effectiveness of TPMS and ATIS. ICCT found in their workshop that opportunities exist for ATIS that could lead to a 0.5 to two percent improvement in fuel consumption.[132] The agencies conducted a further review of the FCMSA study cited by commenters and we interpret the results of the study to indicate that overall a combination of TPMS and ATIS in the field achieved 1.4 percent reduction. However, it did not separate the results from each technology, therefore it did not indicate that TPMS and ATIS achieved the same levels of reduction. Therefore, we set the effectiveness of TPMS slightly lower than ATIS to reflect that operators will be required to take some action to insure that the proper inflation pressure is maintained. The input values to the Phase 2 GEM are set to 1.2 percent reduction in CO_2 emissions and fuel consumption for ATIS and 1.0 percent reduction for TPMS.

2.8.2.5 Idle Reduction

The benefits for the extended idle reductions were developed from literature, SmartWay work, and the 2010 NAS report. Additional details regarding the comments and calculations are included in RIA Chapter 2.4.8.1.

2.8.2.6 Transmission

The benefits for automated manual (AMT) and automatic (AT) transmissions were developed from literature, from simulation modeling conducted by Southwest Research Institute, and powertrain testing at Oak Ridge National Laboratory. The agencies' assessment of the comments is that Allison, ICCT, and Volvo support the proposed two percent effectiveness for AT and AMT transmission types. In addition, the agencies reviewed the NACFE report on electronically controlled transmissions (AT, AMT, and DCT).[133] This report had similar findings as those noted above in the NAS 2010 report. Electronically controlled transmissions were found to be more fuel efficient than manual transmissions, though the amount varied significantly. The report also stated that fleets found that electronically controlled transmissions also reduced the fuel efficiency variability between drivers. Therefore after considering the comments related to effectiveness and additional reports, the agencies are adopting as proposed a two percent effectiveness for AMT.

The agencies conducted powertrain testing at Oak Ridge National Laboratory using the same HD diesel engine paired with an Eaton AMT and an Allison TC10 AT to evaluate the impact of the transmission type on the CO_2 emissions and fuel consumption.[134] The Allison TC10 transmission is their newest and most efficient heavy-duty automatic transmission and contains the neutral-idle and first gear lock-up features. The agencies swept final drive ratio during the testing to recognize that the proper spec'ing of the rear axle ratio will vary depending on the type of transmission and the top gear ratio of the transmission. As shown in Figure 2-25 and Figure 2-26, the fuel consumption over the highway cycles simulating a Class 8 tractor-trailer was similar between the two transmissions. Figure 2-27 shows that the TC10 automatic transmission had lower fuel consumption over the transient cycle, but because the drive cycle weighting of the ARB transient cycle is low in tractors, the agencies expect that automatic transmissions designed for long haul operation and automated manual transmissions to perform similarly and have similar effectiveness when compared to a manual transmission.

The benefit of the AMT's automatic shifting compared to a manual transmission is recognized in GEM by simulating the MT as an AMT and increasing the emission results from the simulation by two percent. For ATs, the agencies developed the default automatic transmission inputs to GEM to represent a typical heavy-duty automatic transmission, which is less efficient than the TC10. The agencies selected more conservative default transmission losses in GEM so that we would not provide a false efficiency improvement for the less efficient automatic transmissions that exist in the market today. Under the regulations in this rulemaking, manufacturers that certify using the TC10 transmission would need to either conduct the optional transmission gear efficiency testing or powertrain testing to recognize the benefits of this type of automatic transmission in GEM. However, as noted in Section II.C.5 of the FRM Preamble, the agencies could determine in a future action that it would be appropriate to modify GEM to be equivalent to powertrain testing technology, rather than to require manufacturers to perform powertrain testing to be credited for the full benefits of technologies such as advanced transmissions. In such a case, the agencies would not consider the modification to GEM to impact the effective stringency of the Phase 2 standards because the new version of GEM would be equivalent to performing powertrain testing. Thus, we encourage manufacturers to work with us in the coming years to investigate the potential to streamline the process for fully recognizing advanced transmissions in GEM.

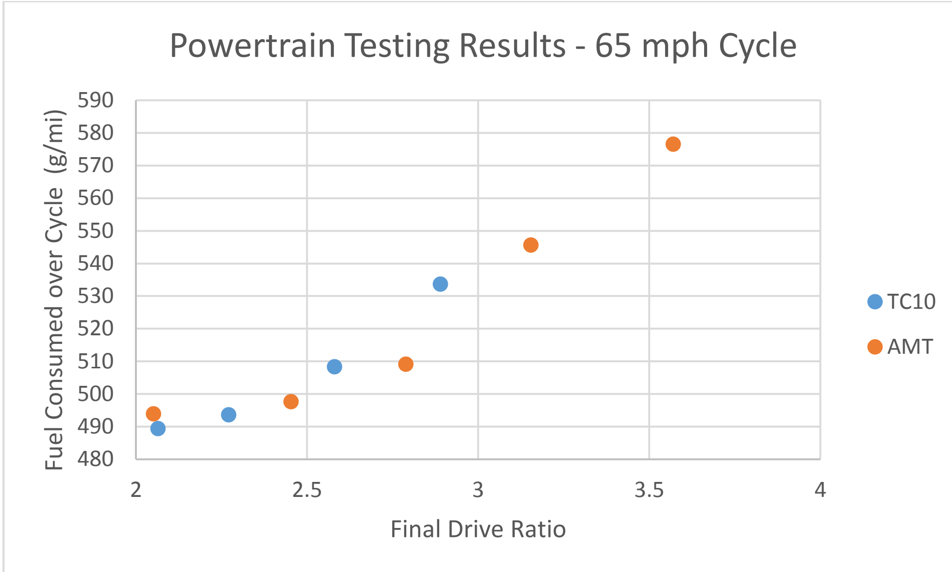


Figure 2-25 Powertrain Test Results of AMT and AT over the 65 mph Cycle

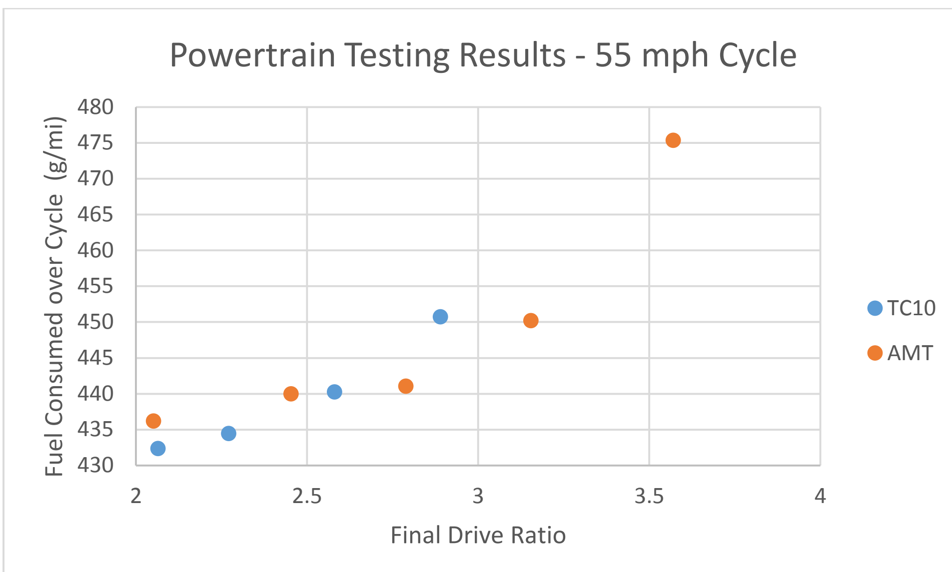


Figure 2-26 Powertrain Test Results of AMT and AT over the 55 mph Cycle

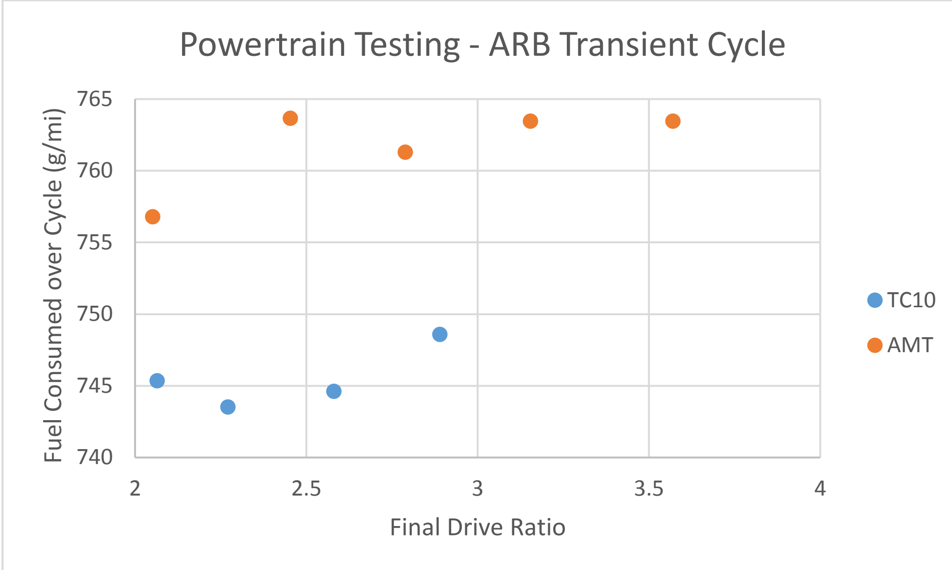


Figure 2-27 Powertrain Test Results of AMT and AT over the Transient Cycle

2.8.2.6.1 Transmission Efficiency

The agencies also proposed standards that considered the efficiency benefit of transmissions that operate with top gear direct drive instead of overdrive. In the proposal, we estimated that direct drive had 2 percent higher gear efficiency than an overdrive gear. 80 FR 40229. The benefit of direct drive was recognized through the transmission gear ratio inputs to GEM. Direct drive leads to greater CO_2 emissions and fuel consumption reductions in highway operation, but virtually none in transient operation. ICCT cited a finding that highlighted opportunities to improve transmission efficiency, including direct drive, which would provide about two percent fuel consumption reduction.[135] The agencies did not receive any negative comments regarding the efficiency difference between direct drive and overdrive; therefore, we continued to include the default transmission gear efficiency advantage of 2 percent for a gear with a direct drive ratio in the version of GEM adopted for the final Phase 2 rules.

The agencies are also adopting in Phase 2 an optional transmission efficiency test (40 CFR 1037.565) for generating an input to GEM that overrides the default efficiency of each gear based on the results of the test. Although optional, the transmission efficiency test will allow manufacturers to reduce the CO_2 emissions and fuel consumption by designing better transmissions with lower friction due to better gear design and/or mandatory use of better lubricants. The agencies project that transmission efficiency could improve 1 percent over the 2017 baseline transmission in Phase 2. Our assessment was based on comments received and discussions with transmission manufacturers.[136]

2.8.2.6.2 Neutral Idle

Automatic transmissions historically apply torque to an engine when in gear at zero speed because of torque converter, such as when stopped at a traffic light. A neutral idle technology can disengage transmission with torque converter, thus reducing power loss to a minimum. The agencies simulated the impact of reducing the load on the engine at idle in GEM for tractors. As expected, neutral idle had zero impact on the highway cycles because those cycles do not include any idle time. During the ARB Transient cycle, neutral idle reduced CO_2 emissions and fuel consumption by 3.8 percent. The composite impact of neutral idle on CO_2 emissions and fuel consumption for day cabs is 1.2 percent and is 0.3 percent for sleeper cabs.

2.8.2.7 Drivetrain and Engine Downspeeding

Axle Configurations: Please see RIA Chapter 2.4.5.3 for the discussion on axle configurations.

The agencies' assessments of these technologies show that the reductions are in the range of 2 to 3 percent. For the final rule, the agencies are simulating 6x2, 4x2, and disengageable axles within GEM instead of providing a fixed value for the reduction. This approach is more technically sound because it will take into account future changes in axle efficiency. Tractor simulations using Phase 2 GEM indicated that 6x4 and 4x2 axle configurations lead to a 2 percent improvement in day cab and sleeper cab tractor efficiency.

Downspeeding: Downspeeding would be as demonstrated through the Phase 2 GEM inputs of transmission gear ratio, drive axle ratio, and tire diameter. Volvo offers an XE package for fuel efficiency in 2017 MY that includes a downspeed package with a 2.64 rear axle ratio and 0.78 top transmission gear ratio, equivalent to a 2.06 final drive ratio (FDR). The agencies evaluated the impact of downspeeding during a powertrain test of a heavy HD diesel engine and automated manual transmission while simulating a Class 8 tractor-trailer.[137] The results are shown in Figure 2-28. Downspeeding from a 2.6 FDR to a 2.3 FDR reduced fuel consumption by 2.5 percent.

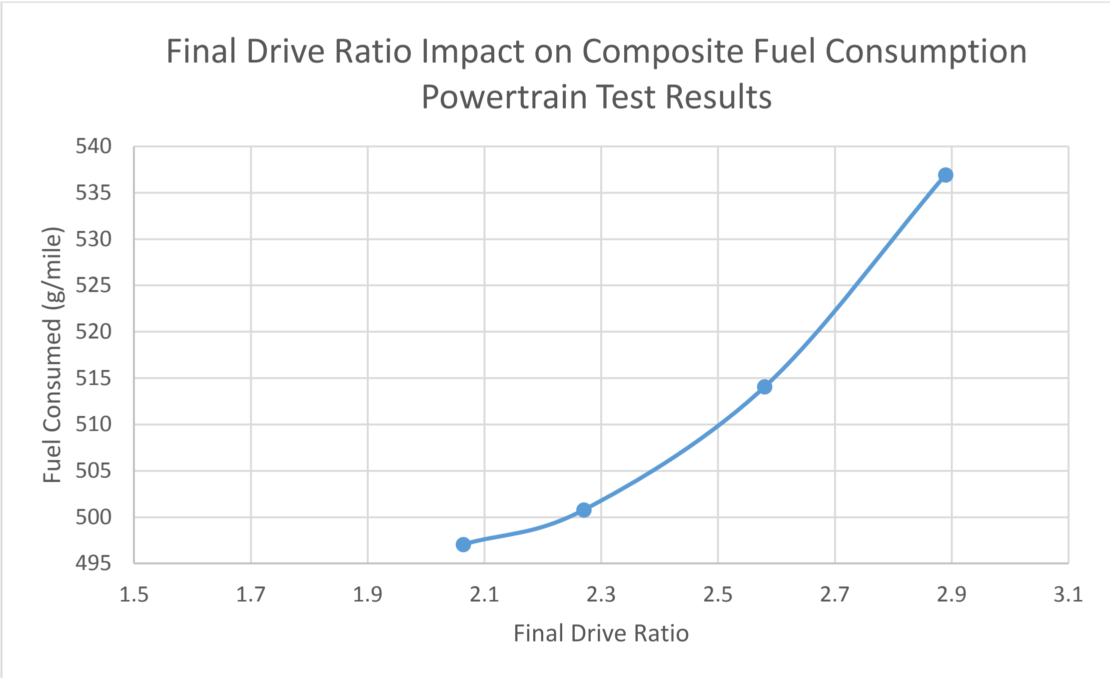


Figure 2-28 Downspeeding Impact on Fuel Consumption

Axle Efficiency: Please see RIA Chapter 2.4.5.1 for additional discussion on opportunities to improve axle efficiency. The 2010 NAS report assessed low friction lubricants for the drivetrain as providing a 1 percent improvement in fuel consumption based on fleet testing.[138] The light-duty 2012-16 MY vehicle rule and the pickup truck portion of this program estimate that low friction lubricants can have an effectiveness value between 0 and 1 percent compared to traditional lubricants. In the Phase 2 proposal, the agencies proposed the reduction in friction due to low viscosity axle lubricants of 0.5 percent. 80 FR 40217.

The agencies' assessment of axle improvements found that axles built in the Phase 2 timeline could be 2 percent more efficient than a 2017 baseline axle.[139] In lieu of a fixed value for low friction axle lubricants, the agencies are adopting an axle efficiency test procedure (40 CFR 1037.560), as discussed in the NPRM. 80 FR 40185. The axle efficiency test will be optional, but will allow manufacturers to recognize in GEM reductions in CO_2 emissions and fuel consumption through improved axle gear designs and/or mandatory use of low friction lubricants.

2.8.2.8 Accessories and Other Technologies

Reducing the mechanical and electrical loads of accessories reduce the power requirement of the engine and in turn reduces the fuel consumption and CO_2 emissions. Modeling in GEM, as shown in Table 2-29, demonstrates the impact of reducing 1 kW of accessory load for each tractor subcategory.

Table 2-29 Impact of 1 kW Accessory Load Reduction on CO_2 Emissions

Tractor Subcategory	%CO_2 per kW
Class 8 High Roof Sleeper	0.5%
Class 8 Mid Roof Sleeper	0.5%
Class 8 Low Roof Sleeper	0.6%
Class 8 High Roof Day	0.6%
Class 8 Mid Roof Day	0.6%
Class 8 Low Roof Day	0.7%
Class 7 High Roof Day	0.8%
Class 7 Mid Roof Day	0.8%
Class 7 Low Roof Day	0.8%
Heavy Haul	0.5%

Compared to 2017 MY air conditioners, air conditioners with improved efficiency compressors could reduce CO_2 emissions by 0.5 percent. Improvements in accessories, such as power steering, can lead to an efficiency improvement of 1 percent over the 2017MY baseline (also see RIA Chapter 2.4.10). The agencies received several comments related to accessories. Due to the complexity in determining a definition of that qualifies as an efficient accessory, we are maintaining the proposed language for tractor accessories which provides defined effectiveness values only for electric or high efficiency air conditioning compressors, electric power steering pumps, and electric coolant pumps (if not already accounted for during the engine fuel mapping procedure).

The agencies proposed to provide a two percent reduction for intelligent controls, such as predictive cruise. Control. ICCT found in their workshop that opportunities exist for road load optimization through predictive cruise, GPS, and driver feedback that could lead to a zero to five percent reduction in fuel consumption and CO_2 emissions.[140] Daimler commented that eCoast should also be recognized as an intelligent control within GEM. Eaton offers similar technology, known as Neutral Coast Mode. The feature places an automated transmission in neutral on downhill grades which allows the engine speed to go idle speed. A fuel savings is recognized due to the difference in engine operating conditions. Based on literature information, the agencies are adopting intelligent controls such as predictive cruise control with an effectiveness of two percent (also see RIA Chapter 2.4.11) and neutral coasting with an effectiveness of 1.5 percent.

2.8.2.9 Weight Reduction

The weight reductions were developed from tire manufacturer information, the Aluminum Association, the Department of Energy, SABIC and TIAX. The fuel consumption and CO_2 emissions impact of a 1,000 pound weight reduction on tractors is approximately 1.2 to 1.5 percent based on simulations conducted in Phase 2 GEM. This reduction includes the impact of both reducing the overall weight of the vehicle for the fraction of the fleet that is cubed-out and the increase in payload capability for the fraction of the fleet that is weighed-out.

2.8.2.10 Vehicle Speed Limiter

The agencies did not include vehicle speed limiters in setting the Phase 1 stringency levels. The agencies likewise are not including vehicle speed limiters in the technology package for setting the standards for Class 7 and 8 tractors in Phase 2. The effectiveness of VSLs depend on the type of tractor because it is dependent on the drive cycle. The greater the amount of time spent at 65 mph, the greater the impact of a VSL set below 65 mph. Figure 2-29 shows the effectiveness of VSL on sleeper and day cab tractors based on modeling conducted using Phase 2 GEM.

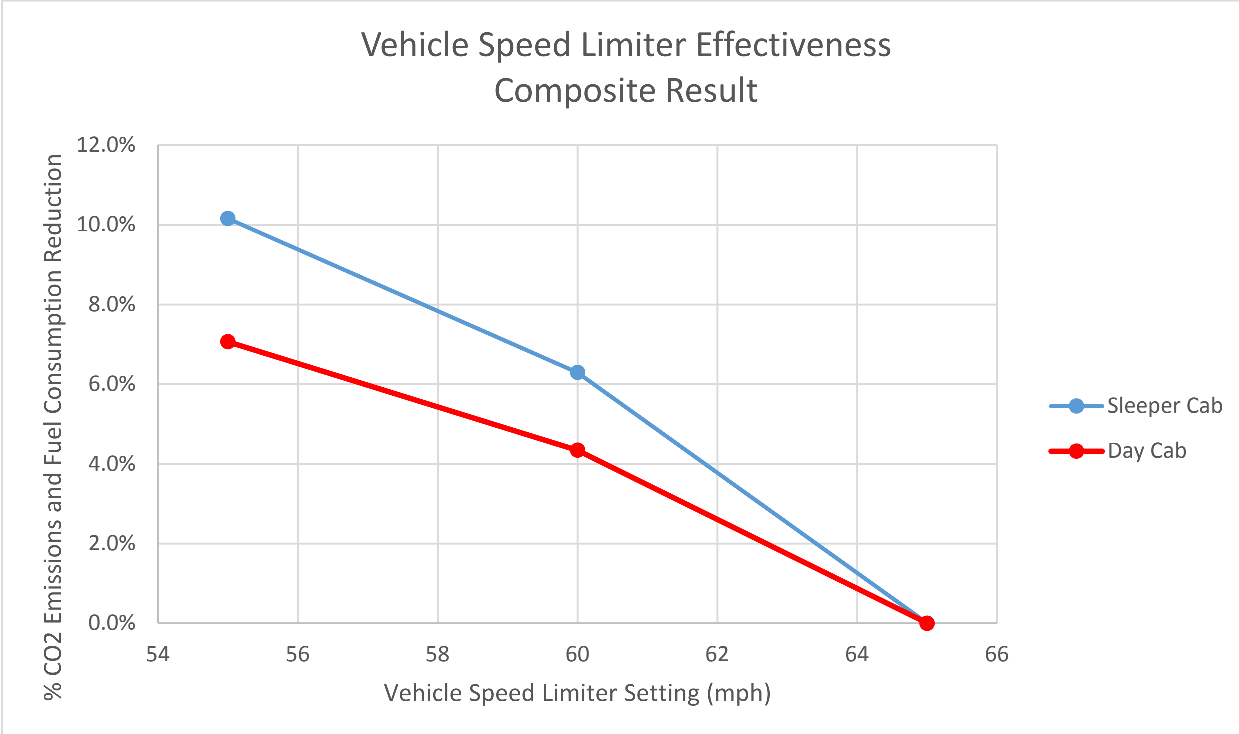


Figure 2-29 Vehicle Speed Limiter Impact on Tractor Fuel Consumption

2.8.2.11 Consideration of Phase 1 Credits in Phase 2 Stringency Setting

The agencies requested comment regarding the treatment of Phase 1 credits, as discussed in Section I.C.1.b. See 80 FR 40251. As examples, the agencies discussed limiting the use of Phase 1 credits in Phase 2 and factoring credit balances into the 2021 standards. Daimler commented that allowing Phase 1 credits in Phase 2 is necessary to smooth the transition into a new program that is very complex and that HD manufacturers cannot change over an entire product portfolio at one time. The agencies evaluated the status of Phase 1 credit balances in 2015 by sector. For tractors, we found that manufacturers are generating significant credits, and that it appears that many of the credits result from their use of an optional provision for calculating aerodynamic drag. However, we also believe that manufacturers will generate fewer credits in MY 2017 and later when the final Phase 1 standards begin. Still, the agencies believe that manufacturers will have significant credits balances available to them for MYs 2021-2023, and that much of these balances would be the result of the test procedure provisions rather than pull ahead of any technology. Based on confidential product plans for MYs 2017 and later, we expect this total windfall amount to be three percent of the MY 2021 standards or more. Therefore, the agencies are factoring in a total credit amount equivalent to this three percent credit (i.e. three years times 1 percent per year). Thus, we are increasing the stringency of the CO_2 and fuel consumption tractor standards for MYs 2021-2023 by 1 percent to reflect these credits.

2.8.2.12 Summary of Technology Performance

Table 2-30 describes the performance levels for the range of Class 7 and 8 tractor technologies.

Table 2-30 Phase 2 Technology Inputs for Tractors

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine									
	2021MY 11L Engine 350 HP	2021MY 11L Engine 350 HP	2021MY 11L Engine 350 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP
Aerodynamics (C_dA in m²)									
Bin I	6.00	7.00	7.45	6.00	7.00	7.45	6.00	7.00	7.15
Bin II	5.60	6.65	6.85	5.60	6.65	6.85	5.60	6.65	6.55
Bin III	5.15	6.25	6.25	5.15	6.25	6.25	5.15	6.25	5.95
Bin IV	4.75	5.85	5.70	4.75	5.85	5.70	4.75	5.85	5.40
Bin V	4.40	5.50	5.20	4.40	5.50	5.20	4.40	5.50	4.90
Bin VI	4.10	5.20	4.70	4.10	5.20	4.70	4.10	5.20	4.40
Bin VII	3.80	4.90	4.20	3.80	4.90	4.20	3.80	4.90	3.90
Steer Tires (CRR in kg/metric ton)									
Base	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
Level 1	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
Level 2	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
Level 3	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
Drive Tires (CRR in kg/metric ton)									
Base	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1
Level 1	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
Level 2	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Level 3	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Idle Reduction (% reduction)									
Tamper Proof AESS	N/A	N/A	N/A	N/A	N/A	N/A	4%	4%	4%
Tamper Proof AESS with Diesel APU	N/A	N/A	N/A	N/A	N/A	N/A	4%	4%	4%
Tamper Proof AESS with Battery APU	N/A	N/A	N/A	N/A	N/A	N/A	6%	6%	6%

Tamper Proof AESS with Automatic Stop-Start	N/A	N/A	N/A	N/A	N/A	N/A	3%	3%	3%
Tamper Proof AESS with FOH	N/A	N/A	N/A	N/A	N/A	N/A	3%	3%	3%
Adjustable AESS	N/A	N/A	N/A	N/A	N/A	N/A	1%	1%	1%
Adjustable AESS with Diesel APU	N/A	N/A	N/A	N/A	N/A	N/A	3%	3%	3%
Adjustable AESS with Battery APU	N/A	N/A	N/A	N/A	N/A	N/A	5%	5%	5%
Adjustable AESS with Automatic Stop-Start	N/A	N/A	N/A	N/A	N/A	N/A	5%	5%	5%
Adjustable AESS with FOH	N/A	N/A	N/A	N/A	N/A	N/A	2%	2%	2%
Transmission (% reduction)									
Manual	0%	0%	0%	0%	0%	0%	0%	0%	0%
AMT	2%	2%	2%	2%	2%	2%	2%	2%	2%
Auto	2%	2%	2%	2%	2%	2%	2%	2%	2%
Dual Clutch	2%	2%	2%	2%	2%	2%	2%	2%	2%
Top Gear Direct Drive	2%	2%	2%	2%	2%	2%	2%	2%	2%
Transmission Efficiency Improvements	1%	1%	1%	1%	1%	1%	1%	1%	1%
Neutral Idle	Modeled in GEM	Modeled in GEM	Modeled in GEM	Modeled in GEM	Modeled in GEM	Modeled in GEM	Modeled in GEM	Modeled in GEM	Modeled in GEM
Driveline (% reduction)									
Axle Efficiency Improvements	2%	2%	2%	2%	2%	2%	2%	2%	2%
6x2, 6x4 Axle Disconnect or 4x2 Axle	N/A	N/A	N/A	Modeled in GEM	Modeled in GEM	Modeled in GEM	Modeled in GEM	Modeled in GEM	Modeled in GEM
Downspeed	Modeled in GEM	Modeled in GEM	Modeled in GEM	Modeled in GEM	Modeled in GEM	Modeled in GEM	Modeled in GEM	Modeled in GEM	Modeled in GEM
Accessory Improvements (% reduction)									
A/C Efficiency	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Electric Access.	1%	1%	1%	1%	1%	1%	1%	1%	1%

Other Technologies (% reduction)									
Predictive Cruise Control	2%	2%	2%	2%	2%	2%	2%	2%	2%
Automated Tire Inflation System	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
Tire Pressure Monitoring System	1%	1%	1%	1%	1%	1%	1%	1%	1%
Neutral Coast	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%

2.8.3 Tractor Technology Adoption Rates

Often tractor manufacturers introduce major product changes together, as a package. This allows manufacturers to optimize their available resources, including engineering, development, manufacturing and marketing activities to create a product with multiple new features. In some limited cases, manufacturers may implement an individual technology outside of a vehicle's redesign cycle. It is recognized by the manufacturers that a vehicle design will need to remain competitive over the intended life of the design and meet future regulatory requirements.

With respect to the levels of technology adoption used to develop the HD Phase 2 standards, NHTSA and EPA established two types of technology adoption constraints. The first type of constraint was established based on the application of fuel consumption and CO_2 emission reduction technologies into the different types of tractors. For example, extended idle reduction technologies are limited to Class 8 sleeper cabs based on the (reasonable) assumption that day cabs are not used for overnight hoteling.

A second type of constraint was applied to most other technologies and limited their adoption based on factors reflecting the real world operating conditions that some combination tractors encounter. This second type of constraint was applied to the aerodynamic, tire, powertrain, vehicle speed limiter, and other technologies. Table 2-34,

Table 2-35 and Table 2-36 specify the adoption rates that EPA and NHTSA used to develop the final Phase 2 standards

NHTSA and EPA believe that within each of these individual vehicle categories there are particular applications where the use of the identified technologies would be either ineffective or not technically feasible. The addition of ineffective technologies provides no environmental or fuel efficiency benefit, increases costs and is not a basis upon which to set a maximum feasible improvement under 49 USC Section 32902 (k), or appropriate under 42 U.S.C. Section 7521 (a)(2). For example, the agencies are not predicating the standards on the use of full aerodynamic vehicle treatments on 100 percent of tractors, because we know that in many applications (for example gravel truck engaged in local aggregate delivery) the added weight of the aerodynamic technologies would increase fuel consumption and hence CO_2 emissions to a greater degree than the reductions from the aerodynamic technology. .

Discussions related to our responses to comments received on technology adoption rates for each of the technologies are included in Preamble Section III.D.1.c and in Section 4.3 of the response to comments document. The sections below contain the final decisions based on the consideration of these comments and any new data or information.

2.8.3.1 Aerodynamics Adoption Rate

The impact of aerodynamics on a tractor-trailer's efficiency increases with vehicle speed. Therefore, the usage pattern of the vehicle will determine the benefit of various aerodynamic technologies. Sleeper cabs are often used in line haul applications and drive the majority of their miles on the highway travelling at speeds greater than 55 mph. The industry has focused aerodynamic technology development, including SmartWay tractors, on these types of trucks. Therefore the most aggressive aerodynamic technologies are applied to this regulatory subcategory. All of the major manufacturers today offer at least one SmartWay sleeper cab tractor model, which is represented as Bin III aerodynamic performance. For the NPRM, the agencies developed a technology package for 2027 MY that included the aerodynamic adoption rates shown in Table 2-31. 80 FR 40227.

Table 2-31 Proposed Aerodynamic Bin Adoption Rates for 2027 MY Tractors

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Aerodynamics									
Bin I	0%	0%	0%	0%	0%	0%	0%	0%	0%
Bin II	50%	50%	0%	50%	50%	0%	50%	50%	0%
Bin III	40%	40%	20%	40%	40%	20%	40%	40%	20%
Bin IV	10%	10%	20%	10%	10%	20%	10%	10%	20%
Bin V	N/A	N/A	35%	N/A	N/A	35%	N/A	N/A	35%
Bin VI	N/A	N/A	20%	N/A	N/A	20%	N/A	N/A	20%
Bin VII	N/A	N/A	5%	N/A	N/A	5%	N/A	N/A	5%

In Phase 1, the agencies determined the stringency of the tractor standards through the use of a mix of aerodynamic bins in the technology packages. For example, we included 10 percent Bin II, 70 percent Bin III, and 20 percent Bin IV in the high roof sleeper cab tractor standard. The weighted average aerodynamic performance of this technology package is equivalent to Bin III. 76 FR 57211. In consideration of the comments, the agencies have adjusted the aerodynamic adoption rate for Class 8 high roof sleeper cabs used to set the final standards in 2021, 2024, and 2027 MYs (*i.e.*, the degree of technology adoption on which the stringency of the standard is premised). Upon further analysis of simulation modeling of a SuperTruck tractor with a Phase 2 reference trailer with skirts, we agree with the manufacturers that a SuperTruck tractor technology package would only achieve the Bin V level of C_dA, as discussed above in RIA Chapter 2.8.2.2. Consequently, the final standards are not premised on any adoption of Bin VI and VII technologies. Accordingly, we determined the adoption rates in the technology packages developed for the final rule using a similar approach as Phase 1 - spanning three aerodynamic bins and not setting adoption rates in the most aerodynamic bin(s) - to reflect that there are some vehicles whose operation limits the applicability of some aerodynamic technologies. We set the MY 2027 high roof sleeper cab tractor standards using a technology package that included 20 percent of Bin III, 30 percent Bin IV, and 50 percent Bin V reflecting our assessment of the fraction of high roof sleeper cab tractors that we project could successfully apply these aerodynamic packages with this amount of lead time. The weighted average of this set of adoption rates is equivalent to a tractor aerodynamic performance near the border between Bin IV and Bin V. We believe that there is sufficient lead time to develop aerodynamic tractors that can move the entire high roof sleeper cab aerodynamic performance to be as good as or better than today's SmartWay designated tractors.

The agencies phased-in the aerodynamic technology adoption rates within the technology packages used to determine the MY 2021 and 2024 standards so that manufacturers can gradually introduce these technologies. The changes required for Bin V performance reflect the kinds of improvements projected in the Department of Energy's SuperTruck program. That program has demonstrated tractor-trailers in 2015 with significant aerodynamic technologies. For the final rule, the agencies are projecting that truck manufacturers will be able to begin implementing some of these aerodynamic technologies on high roof tractors as early as 2021 MY on a limited scale. For example, in the 2021 MY technology package, the agencies have assumed that 10 percent of high roof sleeper cabs will have aerodynamics better than today's best tractors. This phase-in structure is consistent with the normal manner in which manufacturers introduce new technology to manage limited research and development budgets as well as to allow them to work with fleets to fully evaluate in-use reliability before a technology is applied fleet-wide. The agencies believe the phase-in schedule will allow manufacturers to complete these normal processes. Overall, while the agencies are now projecting slightly less benefit from aerodynamic improvements than we did in the NPRM, the actual aerodynamic *technologies* being projected are very similar to what was projected at the time of NPRM (however, these vehicles fall into Bin V in the final rule, instead of Bin VI and VII in the NPRM). Importantly, our averaging, banking and trading provisions provide manufacturers with the flexibility (and incentive) to implement these technologies over time even though the standard changes in a single step.

The agencies also received comment regarding our aerodynamic assessment of the other tractor subcategories. Aerodynamic improvements through new tractor designs and the development of new aerodynamic components is an inherently slow and iterative process. The agencies recognize that there are tractor applications that require on/off-road capability and other truck functions which restrict the type of aerodynamic equipment applicable. We also recognize that these types of trucks spend less time at highway speeds where aerodynamic technologies have the greatest benefit. The 2002 VIUS data ranks trucks by major use.[141] The heavy trucks usage indicates that up to 35 percent of the trucks may be used in on/off-road applications or heavier applications. The uses include construction (16 percent), agriculture (12 percent), waste management (5 percent), and mining (2 percent). Therefore, the agencies analyzed the technologies to evaluate the potential restrictions that will prevent 100 percent adoption of more advanced aerodynamic technologies for all of the tractor regulatory subcategories and developed standards with new penetration rates reflecting that these vehicles spend less time at highway speeds. For the final rule, the agencies evaluated the certification data to assess how the aerodynamic performance of high roof day cabs compare to high roof sleeper cabs. In 2014, the high roof day cabs on average are certified to one bin lower than the high roof sleeper cabs.[142] Consistent with the public comments, and the certification data, the aerodynamic adoption rates used to develop the final Phase 2 standards for the high roof day cab regulatory subcategories are less aggressive than for the Class 8 sleeper cab high roof tractors. In addition, the agencies are also accordingly reducing the adoption rates in the highest bins for low and mid roof tractors to follow the changes made to the high roof subcategories because we neither proposed nor expect the aerodynamics of a low or mid roof tractor to be better than a high roof tractor.

2.8.3.2 Low Rolling Resistance Tire Adoption Rate

For the tire manufacturers to further reduce tire rolling resistance, the manufacturers must consider several performance criteria that affect tire selection. The characteristics of a tire also influence durability, traction control, vehicle handling, comfort, and retreadability. Tire design requires balancing performance, since changes in design may change different performance characteristics in opposing directions. A single performance parameter can easily be enhanced, but an optimal balance of all the criteria would require improvements in materials and tread design at a higher cost, as estimated by the agencies.

For the final rulemaking, the agencies evaluated the tire rolling resistance levels in the Phase 1 certification data.[143] We found that high roof sleeper cabs are certified today with steer tire rolling resistance levels that ranged between 4.9 and 7.6 kg/ton and with drive tires ranging between 5.1 and 9.8 kg/ton. In the same analysis, we found that high roof day cabs are certified with rolling resistance levels ranging between 4.9 and 9.0 kg/ton for steer tires and between 5.1 and 9.8 kg/ton for drive tires. This range spans the baseline through Level 3 rolling resistance performance levels. Therefore, for the final rule we took an approach similar to the one taken in Phase 1 and proposed in Phase 2 that considers adoption rates across a wide range of tire rolling resistance levels to recognize that operators may have different needs. 76 FR 57211 and 80 FR 40227.

In our analysis of the Phase 1 certification data, we found that the drive tires on low and mid roof sleeper cab tractors on average had 10 to 17 percent higher rolling resistance than the high roof sleeper cabs. But we found only a minor difference in rolling resistance of the steer tires between the tractor subcategories. Based on comments received and further consideration of our own analysis of the difference in tire rolling resistance levels that exist today in the certification data, the agencies are adopting Phase 2 standards using a technology pathway that utilizes higher rolling resistance levels for low and mid roof tractors than the levels used to set the high roof tractor standards. This is also consistent with the approach that we took in setting the Phase 1 tractor standards. 76 FR 57211. In addition, the final rule reflects a reduction in Level 3 adoption rates for low and mid roof tractors from 25 percent in MY 2027 used at proposal (80 FR 40227) to zero percent adoption rate. The technology packages developed for the low and mid roof tractors used to determine the stringency of the MY 2027 standards in the final rule do not include any adoption rate of Level 3 drive tires to recognize the special needs of these applications, consistent with the comments noted above raising concerns about applications that limit the use of low rolling resistance tires.

The agencies phased-in the low rolling resistance tire adoption rates within the technology packages used to determine the MY 2021 and 2024 standards so that manufacturers can gradually introduce these technologies. In addition, the levels of rolling resistance used in all of the technology packages are achievable with either dual or wide based single tires, so the agencies are not forcing one technology over another. See Table 2-34 through Table 2-36 for the adoption rates of each tractor subcategory.

2.8.3.3 Tire Pressure Monitoring System and Automatic Tire Inflation System Adoption Rates

The agencies used a 20 percent adoption rate of ATIS in MY 2021 and a 40 percent adoption rate in setting the proposed Phase 2 MY 2024 and 2027 tractor standards. 80 FR 40227.

The agencies received a number of comments on ATIS and TPMS. The agencies find the comments related to a greater acceptance of TPMS in the tractor market to be persuasive. However, available information indicates that it is feasible to utilize either TPMS or ATIS to reduce the prevalence on underinflated tires in-use on all tractors. As a result, we are finalizing tractor standards that are predicated on the performance of a mix of TPMS and ATIS adoption rates in all tractor subcategories. The agencies are using adoption rates of 30 percent of ATIS and 70 percent of TPMS in the technology packages used in setting the final Phase 2 MY 2027 tractor standards. This represents a lower adoption rate of ATIS than used in the NPRM, but the agencies have added additional adoption rate of TPMS because none of the comments or available information disputed the ability to use it on all tractors. The agencies have developed technology packages for setting the 2021 and 2024 MY standards which reflect a phase in of adoption rates of each of these technologies. In 2021 MY, the adoption rates consist of 20 percent TPMS and 20 percent ATIS. In 2024 MY, the adoption rates are 50 percent TPMS and 25 percent ATIS.

2.8.3.4 Weight Reduction Technology Adoption Rate

The agencies set the 2021 through 2027 model year tractor standards without using weight reduction as a technology on whose performance the standard is predicated. The agencies view weight reduction as a technology with a high cost that offers a small benefit in the tractor sector. For example, our estimate of a 400 pound weight reduction would cost $2,050 (2012$) in MY2021, but offer a 0.3 percent reduction in fuel consumption and CO_2 emissions. Nonetheless, the agencies are adopting an expanded list of weight reduction options which could be input into the GEM by the manufacturers to reduce their certified CO_2 emission and fuel consumption levels.

2.8.3.5 Idle Reduction Technology Adoption Rate

Idle reduction technologies provide significant reductions in fuel consumption and CO_2 emissions for Class 8 sleeper cabs and are available on the market today. There are several different technologies available to reduce idling. These include APUs, diesel fired heaters, and battery powered units. Our discussions with manufacturers prior to the Phase 2 NPRM indicated that idle technologies are sometimes installed in the factory, but that it is also a common practice to have the units installed after the sale of the truck. We want to continue to incentivize this practice and to do so in a manner that the emission reductions associated with idle reduction technology occur in use. We proposed to continue the Phase 1 approach into Phase 2 where we recognize only idle emission reduction technologies that include a tamper-proof automatic engine shutoff system (AESS) with some override provisions.[G]

We used an overall 90 percent adoption rate of tamper-proof AESS for Class 8 sleeper cabs in setting the proposed MY 2024 and 2027 standards. Id. The agencies stated in the Phase 2 NPRM that we were unaware of reasons why AESS with extended idle reduction technologies could not be applied to this high fraction of tractors with a sleeper cab, except those deemed a vocational tractor, in the available lead time.

The agencies received numerous comments on idle reduction adoption rates and the need to consider adjustable AESS (see Section III.D.1.c.v of the Preamble). The agencies find the comments regarding the concerns for using 90 percent adoption rates of tamper-proof AESS to be persuasive. For the final rule, the agencies developed a menu of idle reduction technologies that include both tamper-proof and adjustable AESS (as discussed in Section III.D.1.b) that are

[G] The agencies are retaining the HD Phase 1 AESS override provisions included in 40 CFR 1037.660(b) for driver safety.

recognized at different levels of effectiveness in GEM. As discussed in the discussion of tractor baselines (Section III.D.1.a), the latest NACFE confidence report found that 96 percent of HD vehicles are equipped with adjustable automatic engine shutdown systems.[144] Therefore, the agencies built this level of idle reduction into the baseline for sleeper cab tractors. Due to the high percentage acceptance of adjustable AESS today, the agencies project that by 2027 MY it is feasible for 100 percent of sleeper cabs to contain some type of AESS and idle reduction technology to meet the hoteling needs of the driver. However, we recognize that there are a variety of idle reduction technologies that meet the various needs of specific customers and not all customers will select diesel powered APUs due to the cost or weight concerns highlighted in the comments. Therefore, we developed an idle reduction technology package for each MY that reflects this variety. The idle reduction packages developed for the final rule contain lower AESS adoption rates than used at proposal. The AESS used during the NPRM assumed that it also included a diesel powered APU in terms of determining the effectiveness and costs. In the final rule, the idle reduction technology mix actually has an overall lower cost (even after increasing the diesel APU technology cost for the final rule) than would have been developed for the final rule. In addition, the stringency of the tractor standards are not affected because the higher penetration rate of other idle reduction technologies, which are not quite as effective, but will be deployed more. We developed the technology package to set the 2027 MY sleeper cab tractor standards that includes 15 percent adoption rate of adjustable AESS only, 40 percent of adjustable AESS with a diesel powered APU, 15 percent adjustable AESS with a battery APU, 15 percent adjustable AESS with automatic stop/start, and 15 percent adjustable AESS with a fuel operated heater. We continued the same approach of phasing in different technology packages for the 2021 and 2024 MY standards, though we included some type of idle reduction on 100 percent of the sleeper cab tractors. The 2021 MY technology package had a higher adoption rate of adjustable AESS with no other idle reduction technology and lower adoption rates of adjustable AESS with other idle reduction technologies.

2.8.3.6 Transmission Adoption Rates

The agencies' proposed standards included a 55, 80, and 90 percent adoption rate of automatic, automated manual, and dual clutch transmissions in MYs 2021, 2024, and 2027 respectively. 80 FR 40225-7. The agencies did not receive any comments regarding these proposed transmission adoption rates, and have not found any other information suggesting a change in approach. Therefore, we are including the same level of adoption rates in setting the final rule standards. The MY 2021 and 2024 standards are likewise premised on the same adoption rates of these transmission technologies as at proposal.

The agencies have added neutral idle as a technology input to GEM for Phase 2 in the final rulemaking. The TC10 that was tested by the agencies for the final rule included this technology. Therefore, we projected that neutral idle would be included in all of the automatic transmissions and therefore the adoption rates of neutral idle match the adoption rates of the automatic transmission in each of the MYs.

Transmissions with direct drive as the top gear and numerically lower axles are better suited for applications with primarily highway driving with flat or low rolling hills. Therefore, this technology is not appropriate for use in 100 percent of tractors. The agencies proposed standards reflected the projection that 50 percent of the tractors would have direct drive in top gear in MYs 2024 and 2027. 80 FR 40226-7. The agencies did not receive any comments regarding the adoption rates of transmissions with direct drive in those MYs. We therefore are including the same level of adoption rates in setting the final rule standards for MYs 2024 and 2027. Transmissions with direct drive top gears exist in the market today, therefore, the agencies determined it is feasible to also include this technology in the package for setting the 2021 MY standards. For the final rule, the agencies included a 20 percent adoption rate of direct drive in the 2021 MY technology package.

The agencies received comments supporting establishing a transmission efficiency test that measures the efficiency of each transmission gear and could be input into GEM. In the final rule, the agencies are adopting Phase 2 standards that project that 20, 40, and 70 percent of the AMT and DCT transmissions will be tested and achieve a fuel consumption and CO_2 emissions reduction of one percent in MYs 2021, 2024, and 2027, respectively.

2.8.3.7 Engine Downspeeding Adoption Rates

The agencies proposed to include lower final drive ratios in setting the Phase 2 standards to account for engine downspeeding. In the NPRM, we used a transmission top gear ratio of 0.73 and baseline drive axle ratio of 3.70 in 2017 going down to a rear axle ratio of 3.55 in 2021 MY, 3.36 in 2024 MY, and 3.20 in 2027 MY. 80 FR 40228-30.

UCS commented that downspeeding was only partially captured as proposed. The agencies also received additional information from vehicle manufacturers and axle manufacturers that we believe supports using lower numerical drive axle ratios in setting the final Phase 2 standards for sleeper cabs that spend more time on the highway than day cabs, directionally consistent with the UCS comment. For the final rules, the agencies have used 3.70 in the baseline and 3.16 for sleeper cabs and 3.21 for day cabs in MY 2027 to account for continued downspeeding opportunities. The final drive ratios used for setting the other model years are shown in Table 2-32. These values represent the "average" tractor in each of the MYs, but there will be a range of final drive ratios that contain more aggressive engine downspeeding on some tractors and less aggressive on others.

Table 2-32 Final Drive Ratio for Tractor Technology Packages

MODEL YEAR	REAR AXLE RATIO	TRANSMISSION TOP GEAR RATIO	FINAL DRIVE RATIO
Sleeper Cabs			
2018	3.70	0.73	2.70
2021	3.31	0.73	2.42
2024	3.26	0.73	2.38
2027	3.16	0.73	2.31
Day Cabs			
2018	3.70	0.73	2.70
2021	3.36	0.73	2.45
2024	3.31	0.73	2.42
2027	3.21	0.73	2.34

2.8.3.8 Drivetrain Adoption Rates

The agencies' proposed standards included 6x2 axle adoption rates in high roof tractors of 20 percent in 2021 MY and 60 percent in MYs 2024 and 2027. Because 6x2 axle configurations could raise concerns of traction, the agencies proposed standards that reflected lower adoption rates of 6x2 axles in low and mid roof tractors recognizing that these tractors may require some unique capabilities. The agencies proposed standards for low and mid roof tractors that included 6x2 axle adoption rates of 10 percent in MY 2021 and 20 percent in MYs 2024 and 2027. 80 FR 40225-7.

ATA and others commented that limitations to a high penetration rate of 6x2 axles include curb cuts, other uneven terrain features that could expose the truck to traction issues, lower residual values, traction issues, driver dissatisfaction, tire wear, and the legality of their use. Upon further consideration, the agencies have reduced the adoption rate of 6x2 axles and projected a 30 percent adoption rate in the technology package used to determine the Phase 2 2027 MY standards. The 2021 MY standards include an adoption rate of 15 percent and the 2024 MY standards include an adoption rate of 25 percent 6x2 axles. This adoption rate represents a combination of liftable 6x2 axles (which as noted in ATA's comments are allowed in all states but Utah, and Utah is expected to revise their law) and 4x2 axles. In addition, it is worth recognizing that state regulations related to 6x2 axles could change significantly over the next ten years.

In the NPRM, the agencies projected that 20 percent of 2021 MY and 40 percent of the 2024 and 2027 MY axles would use low friction axle lubricants. 80 FR 40225-7. In the final rule, we are requiring that manufacturers conduct an axle efficiency test if they want to include the benefit of low friction lubricant or other axle design improvements when certifying in GEM. The axle efficiency test will be optional, but will allow manufacturers to reduce CO_2 emissions and fuel consumption if the manufacturers have improved axle gear designs and/or mandatory use of low friction lubricants. The agencies' assessment of axle improvements found that 80 percent of the axles built in MY 2027 could be two percent more efficient than a 2017 baseline axle. Because it will take time for axle manufacturers to make improvements across the majority of their product offerings, the agencies phased in the amount of axle efficiency improvements in the technology packages in setting the 2021 and 2024 MY standards to include 30 and 65 percent adoption rates, respectively.

2.8.3.9 Accessories and Other Technology Adoption Rates

In the NPRM, the agencies projected adoption rates as show in Table 2-33. 80 FR 40227. The agencies are adopting the same level of adoption rates for setting the final Phase 2 standards because we did not receive any comments or new data to support a change in the adoption rates used in the proposal.

Table 2-33 Adoption Rates used in the Tractor Technology Packages in the NPRM

MODEL YEAR	PREDICTIVE CRUISE CONTROL	ELECTRIFIED ACCESSORIES	HIGHER EFFICIENCY AIR CONDITIONING
2021	20%	10%	10%
2024	40%	20%	20%
2027	40%	30%	30%

2.8.3.10 Vehicle Speed Limiter Adoption Rate

As adopted in Phase 1, we are continuing the approach where vehicle speed limiters may be used as a technology to aid in meeting the standard. In setting the standard, however, we assumed a zero percent adoption rate of vehicle speed limiters. Although we believe vehicle speed limiters are a simple, easy to implement, and inexpensive technology, we want to leave the use of vehicle speed limiters to the truck purchaser. Since truck fleets purchase tractors today with owner-set vehicle speed limiters, we considered not allowing GEM to recognize performance of VSLs due to potential issues regarding whether any reductions would accrue from installing VSLs, since they can be turned off. We ultimately concluded, as we did in Phase 1, that we should allow the use of VSLs that cannot be overridden by the operator as a means of compliance for vehicle manufacturers that wish to offer it and truck purchasers that wish to purchase the technology. In doing so, we are providing another means of meeting that standard that can lower compliance cost and provide a more optimal vehicle solution for some truck fleets. For example, a local beverage distributor may operate trucks in a distribution network of primarily local roads. Under those conditions, aerodynamic fairings used to reduce aerodynamic drag provide little benefit due to the low vehicle speed while adding additional mass to the vehicle. A vehicle manufacturer could choose to install a VSL set at 55 mph for this customer. The resulting tractor would be optimized for its intended application and would be fully compliant with our program all at a lower cost to the ultimate tractor purchaser.[H]

However, as in Phase 1, we have chosen not to base the standards on performance of VSLs because of concerns about how to set a realistic adoption rate that avoids unintended adverse impacts. Although we expect there will be some use of VSL, currently it is used when the fleet involved decides it is feasible and practicable and increases the overall efficiency of the freight system for that fleet operator. To date, the compliance data provided by manufacturers indicate that none of the tractor configurations include a tamper-proof VSL setting less than 65 mph. At this point the agencies are not in a position to determine in how many additional situations use of a VSL would result in similar benefits to overall efficiency or how many customers would be willing to accept a tamper-proof VSL setting. We are not able at this time to quantify the potential loss in utility due to the use of VSLs. Absent this information, we cannot make a determination regarding the reasonableness of setting a standard based on a particular

[H] The agencies note that because a VSL value can be input into GEM, its benefits can be directly assessed with the model and off cycle credit applications therefore are not necessary even though the standard is not based on performance of VSLs (i.e. VSL is an on-cycle technology).

VSL level. Therefore, the agencies are not premising the standards on use of VSL, and instead would continue to rely on the industry to select VSL when circumstances are appropriate for its use. The agencies have not included either the cost or benefit due to VSLs in analysis of the program's costs and benefits.

2.8.3.11 Adoption Rates Used to Set the Heavy-Haul Tractor Standards

The agencies recognize that certain technologies used to determine the stringency of the Phase 2 tractor standards are less applicable to heavy-haul tractors. Heavy-haul tractors are not typically used in the same manner as long-haul tractors with extended highway driving, and therefore will experience less benefit from aerodynamics. Aerodynamic technologies are very effective at reducing the fuel consumption and GHG emissions of tractors, but only when traveling at highway speeds. At lower speeds, the aerodynamic technologies may have a detrimental impact due to the potential of added weight. The agencies therefore proposed not considering the use of aerodynamic technologies in the development of the Phase 2 heavy-haul tractor standards. Moreover, because aerodynamics will not play a role in the heavy-haul standards, the agencies proposed to combine all of the heavy-haul tractor cab configurations (day and sleeper) and roof heights (low, mid, and high) into a single heavy-haul tractor subcategory.

The agencies received comments regarding the applicability of aerodynamic technologies on heavy-haul vehicles. After considering these comments, the agencies are using a technology package that does not use aerodynamic improvements in setting the Phase 2 heavy-haul tractor standards, as we proposed. [I]

Certain powertrain and drivetrain components are also impacted during the design of a heavy-haul tractor, including the transmission, axles, and the engine. Heavy-haul tractors typically require transmissions with 13 or 18 speeds to provide the ratio spread to ensure that the tractor is able to start pulling the load from a stop. Downspeed powertrains are typically not an option for heavy-haul operations because these vehicles require more torque to move the vehicle because of the heavier load. Finally, due to the loading requirements of the vehicle, it is not likely that a 6x2 axle configuration can be used in heavy-haul applications.

We received comments from stakeholders about the application of technologies other than aerodynamics for heavy-haul tractors. After considering these comments and the information regarding the tire rolling resistance improvement opportunities, discussed in Section III.D.1.b.iii, the agencies have adjusted the adoption rate of low rolling resistance tires. Consistent with the changes made in the final rule for the adoption of low rolling resistance tires in low and mid roof tractors, the agencies did not project any adoption of Level 3 tires for heavy-haul tractors in the final rule.

2.8.3.12 Summary of the Adoption Rates used to determine the Standards

Table 2-34,

[I] Since aerodynamic improvements are not part of the technology package, the agencies likewise are not adopting any aero bin structure for the heavy-haul tractor subcategory.

Table 2-35, and Table 2-36 provide the adoption rates of each technology broken down by weight class, cab configuration, and roof height.

Table 2-34 Technology Adoption Rates for Class 7 and 8 Tractors for Determining the 2021 MY Standards

	CLASS 7			**CLASS 8**					
	Day Cab			**Day Cab**			**Sleeper Cab**		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine									
	2021MY 11L Engine 350 HP	2021MY 11L Engine 350 HP	2021MY 11L Engine 350 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP
Aerodynamics									
Bin I	10%	10%	0%	10%	10%	0%	0%	10%	0%
Bin II	10%	10%	0%	10%	10%	0%	20%	10%	0%
Bin III	70%	70%	60%	70%	70%	60%	60%	70%	60%
Bin IV	10%	10%	35%	10%	10%	35%	20%	10%	30%
Bin V	0%	0%	5%	0%	0%	5%	0%	0%	10%
Bin VI	0%	0%	0%	0%	0%	0%	0%	0%	0%
Bin VII	0%	0%	0%	0%	0%	0%	0%	0%	0%
Steer Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	35%	35%	35%	35%	35%	35%	35%	35%	35%
Level 2	50%	50%	50%	50%	50%	50%	50%	50%	50%
Level 3	10%	10%	10%	10%	10%	10%	10%	10%	10%
Drive Tires									
Base	15%	15%	5%	15%	15%	5%	15%	15%	5%
Level 1	35%	35%	35%	35%	35%	35%	35%	35%	35%
Level 2	50%	50%	50%	50%	50%	50%	50%	50%	50%
Level 3	0%	0%	10%	0%	0%	10%	0%	0%	10%
Idle Reduction									
Tamper Proof AESS	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%
Tamper Proof AESS with Diesel APU	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%
Tamper Proof AESS with Battery APU	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%
Tamper Proof AESS with Automatic Stop-Start	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%
Tamper Proof AESS with FOH	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%

Adjustable AESS	N/A	N/A	N/A	N/A	N/A	N/A	40%	40%	40%
Adjustable AESS with Diesel APU	N/A	N/A	N/A	N/A	N/A	N/A	30%	30%	30%
Adjustable AESS with Battery APU	N/A	N/A	N/A	N/A	N/A	N/A	10%	10%	10%
Adjustable AESS with Automatic Stop-Start	N/A	N/A	N/A	N/A	N/A	N/A	10%	10%	10%
Adjustable AESS with FOH	N/A	N/A	N/A	N/A	N/A	N/A	10%	10%	10%
Transmission									
Manual	0%	0%	0%	0%	0%	0%	0%	0%	0%
AMT	40%	40%	40%	40%	40%	40%	40%	40%	40%
Auto	10%	10%	10%	10%	10%	10%	10%	10%	10%
Dual Clutch	5%	5%	5%	5%	5%	5%	5%	5%	5%
Top Gear Direct Drive	20%	20%	20%	20%	20%	20%	20%	20%	20%
Transmission Efficiency Improvement	20%	20%	20%	20%	20%	20%	20%	20%	20%
Neutral Idle	10%	10%	10%	10%	10%	10%	10%	10%	10%
Driveline									
Axle Efficiency Improvement	30%	30%	30%	30%	30%	30%	30%	30%	30%
6x2, 6x4 Axle Disconnect or 4x2 Axle	N/A	N/A	N/A	15%	15%	15%	15%	15%	15%
Downspeed (Rear Axle Ratio)	3.36	3.36	3.36	3.36	3.36	3.36	3.31	3.31	3.31
Accessory Improvements									
A/C Efficiency	10%	10%	10%	10%	10%	10%	10%	10%	10%
Electric Access.	10%	10%	10%	10%	10%	10%	10%	10%	10%
Other Technologies									
Predictive Cruise Control	20%	20%	20%	20%	20%	20%	20%	20%	20%
Automated Tire Inflation System	20%	20%	20%	20%	20%	20%	20%	20%	20%
Tire Pressure Monitoring System	20%	20%	20%	20%	20%	20%	20%	20%	20%
Neutral Coast	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 2-35 Technology Adoption Rates for Class 7 and 8 Tractors for Determining the 2024 MY Standards

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine									
	2024MY 11L Engine 350 HP	2024MY 11L Engine 350 HP	2024MY 11L Engine 350 HP	2024MY 15L Engine 455 HP	2024MY 15L Engine 455 HP	2024MY 15L Engine 455 HP	2024MY 15L Engine 455 HP	2024MY 15L Engine 455 HP	2024MY 15L Engine 455 HP
Aerodynamics									
Bin I	0%	0%	0%	0%	0%	0%	0%	0%	0%
Bin II	20%	20%	0%	20%	20%	0%	20%	20%	0%
Bin III	60%	60%	40%	60%	60%	40%	60%	60%	40%
Bin IV	20%	20%	40%	20%	20%	40%	20%	20%	40%
Bin V	0%	0%	20%	0%	0%	20%	0%	0%	20%
Bin VI	0%	0%	0%	0%	0%	0%	0%	0%	0%
Bin VII	0%	0%	0%	0%	0%	0%	0%	0%	0%
Steer Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	25%	25%	15%	25%	25%	15%	25%	25%	15%
Level 2	55%	55%	60%	55%	55%	60%	55%	55%	60%
Level 3	15%	15%	20%	15%	15%	20%	15%	15%	20%
Drive Tires									
Base	10%	10%	5%	10%	10%	5%	10%	10%	5%
Level 1	25%	25%	15%	25%	25%	15%	25%	25%	15%
Level 2	65%	65%	60%	65%	65%	60%	65%	65%	60%
Level 3	0%	0%	20%	0%	0%	20%	0%	0%	20%
Idle Reduction									
Tamper Proof AESS	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%
Tamper Proof AESS with Diesel APU	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%
Tamper Proof AESS with Battery APU	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%
Tamper Proof AESS with Automatic Stop-Start	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%
Tamper Proof AESS with FOH	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%
Adjustable AESS	N/A	N/A	N/A	N/A	N/A	N/A	30%	30%	30%

Adjustable AESS with Diesel APU	N/A	N/A	N/A	N/A	N/A	N/A	40%	40%	40%
Adjustable AESS with Battery APU	N/A	N/A	N/A	N/A	N/A	N/A	10%	10%	10%
Adjustable AESS with Automatic Stop-Start	N/A	N/A	N/A	N/A	N/A	N/A	10%	10%	10%
Adjustable AESS with FOH	N/A	N/A	N/A	N/A	N/A	N/A	10%	10%	10%
Transmission									
Manual	0%	0%	0%	0%	0%	0%	0%	0%	0%
AMT	50%	50%	50%	50%	50%	50%	50%	50%	50%
Auto	20%	20%	20%	20%	20%	20%	20%	20%	20%
Dual Clutch	10%	10%	10%	10%	10%	10%	10%	10%	10%
Top Gear Direct Drive	50%	50%	50%	50%	50%	50%	50%	50%	50%
Transmission Efficiency Improvement	40%	40%	40%	40%	40%	40%	40%	40%	40%
Neutral Idle	20%	20%	20%	20%	20%	20%	20%	20%	20%
Driveline									
Axle Efficiency Improvement	65%	65%	65%	65%	65%	65%	65%	65%	65%
6x2, 6x4 Axle Disconnect or 4x2 Axle	N/A	N/A	N/A	25%	25%	25%	25%	25%	25%
Downspeed (Rear Axle Ratio)	3.31	3.31	3.31	3.31	3.31	3.31	3.26	3.26	3.26
Accessory Improvements									
A/C Efficiency	20%	20%	20%	20%	20%	20%	20%	20%	20%
Electric Access.	20%	20%	20%	20%	20%	20%	20%	20%	20%
Other Technologies									
Predictive Cruise Control	40%	40%	40%	40%	40%	40%	40%	40%	40%
Automated Tire Inflation System	25%	25%	25%	25%	25%	25%	25%	25%	25%
Tire Pressure Monitoring System	50%	50%	50%	50%	50%	50%	50%	50%	50%
Neutral Coast	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 2-36 Technology Adoption Rates for Class 7 and 8 Tractors for Determining the 2027 MY Standards

	CLASS 7			CLASS 8					
	Day Cab			Day Cab			Sleeper Cab		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine									
	2027MY 11L Engine 350 HP	2027MY 11L Engine 350 HP	2027MY 11L Engine 350 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP
Aerodynamics									
Bin I	0%	0%	0%	0%	0%	0%	0%	0%	0%
Bin II	20%	20%	0%	20%	20%	0%	20%	20%	0%
Bin III	50%	50%	30%	50%	60%	30%	40%	50%	20%
Bin IV	30%	30%	30%	30%	20%	30%	40%	30%	30%
Bin V	0%	0%	40%	0%	0%	40%	0%	0%	50%
Bin VI	0%	0%	0%	0%	0%	0%	0%	0%	0%
Bin VII	0%	0%	0%	0%	0%	0%	0%	0%	0%
Steer Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	20%	20%	10%	20%	20%	10%	20%	20%	10%
Level 2	50%	50%	50%	50%	50%	50%	50%	50%	50%
Level 3	25%	25%	35%	25%	25%	35%	25%	25%	35%
Drive Tires									
Base	5%	5%	5%	5%	5%	5%	5%	5%	5%
Level 1	10%	10%	10%	10%	10%	10%	10%	10%	10%
Level 2	85%	85%	50%	85%	85%	50%	85%	85%	50%
Level 3	0%	0%	35%	0%	0%	35%	0%	0%	35%
Idle Reduction									
Tamper Proof AESS	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%
Tamper Proof AESS with Diesel APU	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%
Tamper Proof AESS with Battery APU	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%
Tamper Proof AESS with Automatic Stop-Start	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%
Tamper Proof AESS with FOH	N/A	N/A	N/A	N/A	N/A	N/A	0%	0%	0%
Adjustable AESS	N/A	N/A	N/A	N/A	N/A	N/A	15%	15%	15%

Adjustable AESS with Diesel APU	N/A	N/A	N/A	N/A	N/A	N/A	40%	40%	40%
Adjustable AESS with Battery APU	N/A	N/A	N/A	N/A	N/A	N/A	15%	15%	15%
Adjustable AESS with Automatic Stop-Start	N/A	N/A	N/A	N/A	N/A	N/A	15%	15%	15%
Adjustable AESS with FOH	N/A	N/A	N/A	N/A	N/A	N/A	15%	15%	15%
Transmission									
Manual	0%	0%	0%	0%	0%	0%	0%	0%	0%
AMT	50%	50%	50%	50%	50%	50%	50%	50%	50%
Auto	30%	30%	30%	30%	30%	30%	30%	30%	30%
Dual Clutch	10%	10%	10%	10%	10%	10%	10%	10%	10%
Top Gear Direct Drive	50%	50%	50%	50%	50%	50%	50%	50%	50%
Transmission Efficiency Improvement	70%	70%	70%	70%	70%	70%	70%	70%	70%
Neutral Idle	30%	30%	30%	30%	30%	30%	30%	30%	30%
Driveline									
Axle Efficiency Improvement	80%	80%	80%	80%	80%	80%	80%	80%	80%
6x2, 6x4 Axle Disconnect or 4x2 Axle	N/A	N/A	N/A	30%	30%	30%	30%	30%	30%
Downspeed (Rear Axle Ratio)	3.21	3.21	3.21	3.21	3.21	3.21	3.16	3.16	3.16
Accessory Improvements									
A/C Efficiency	30%	30%	30%	30%	30%	30%	30%	30%	30%
Electric Access.	30%	30%	30%	30%	30%	30%	30%	30%	30%
Other Technologies									
Predictive Cruise Control	40%	40%	40%	40%	40%	40%	40%	40%	40%
Automated Tire Inflation System	30%	30%	30%	30%	30%	30%	30%	30%	30%
Tire Pressure Monitoring System	70%	70%	70%	70%	70%	70%	70%	70%	70%
Neutral Coast	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 2-37 includes the adoption rates of each technology used in setting the heavy-haul tractor standards for 2021, 2024, and 2027 MY.

Table 2-37 Technology Adoption Rates for Heavy-Haul Tractors for Determining the 2021, 2024, and 2027 MY Standards

HEAVY-HAUL TRACTOR APPLICATION RATES			
	2021MY	**2024MY**	**2027MY**
Engine	2021 MY 15L Engine with 600 HP with 2% reduction over 2018 MY	2024 MY 15L Engine with 600 HP with 4.2% reduction over 2018 MY	2027 MY 15L Engine with 600 HP with 5.4% reduction over 2018 MY
Aerodynamics – 0%			
Steer Tires			
Phase 1 Baseline	15%	10%	5%
Level I	35%	30%	10%
Level 2	50%	60%	85%
Level 3	0%	0%	0%
Drive Tires			
Phase 1 Baseline	15%	10%	5%
Level I	35%	30%	10%
Level 2	50%	60%	85%
Level 3	0%	0%	0%
Transmission			
AMT	40%	50%	50%
Automatic with Neutral Idle	10%	20%	20%
DCT	5%	10%	10%
Other Technologies			
6x2 Axle	0%	0%	0%
Transmission Efficiency	20%	40%	70%
Axle Efficiency	30%	65%	80%
Predictive Cruise Control	20%	40%	40%
Accessory Improvements	10%	20%	20%
Air Conditioner Efficiency Improvements	10%	20%	20%
Automatic Tire Inflation Systems	20%	25%	30%
Tire Pressure Monitoring System	20%	50%	70%

The agencies are also adopting in Phase 2 provisions that allow the manufacturers to meet an optional heavy Class 8 tractor standard that reflects both aerodynamic improvements, along with the powertrain requirements that go along with higher GCWR. Table 2-38 reflects the adoption rates for each of the technologies for each of the subcategories in MY 2021. The technology packages closely reflect those in the primary Class 8 tractor program. The exceptions include less aggressive targets for low rolling resistance tires, no 6x2 axle adoption rates, and no downspeeding due to the heavier loads of these vehicles.

Table 2-38 GEM Inputs for 2021 MY Heavy Class 8 Tractor Standards

OPTIONAL HEAVY CLASS 8 TRACTOR APPLICATION RATES – 2021 MY				
	Low/Mid Roof Day Cab	**High Roof Day Cab**	**Low/Mid Roof Sleeper Cab**	**High Roof Sleeper Cab**
Engine	2021 MY 15L Engine with 600 HP with 2% reduction over 2018 MY	2021 MY 15L Engine with 600 HP with 2% reduction over 2018 MY	2021 MY 15L Engine with 600 HP with 2% reduction over 2018 MY	2021 MY 15L Engine with 600 HP with 2% reduction over 2018 MY
Aerodynamics				
Bin I	10%	0%	10%	0%
Bin II	10%	0%	10%	0%
Bin III	70%	60%	70%	60%
Bin IV	10%	35%	10%	30%
Bin V	0%	5%	0%	10%
Bin VI	0%	0%	0%	0%
Bin VII	0%	0%	0%	0%
Steer Tires				
Phase 1 Baseline	10%	5%	10%	5%
Level I	25%	35%	25%	35%
Level 2	65%	60%	65%	60%
Level 3	0%	0%	0%	0%
Drive Tires				
Phase 1 Baseline	20%	10%	20%	10%
Level I	40%	30%	40%	30%
Level 2	40%	60%	40%	60%
Level 3	0%	0%	0%	0%
Transmission				
AMT	40%	40%	40%	40%
Automatic with Neutral Idle	10%	10%	10%	10%
DCT	5%	5%	5%	5%
Other Technologies				
Adjustable AESS w/ Diesel APU	N/A	N/A	30%	30%
Adjustable AESS w/ Battery APU	N/A	N/A	10%	10%
Adjustable AESS w/ Automatic Stop-Start	N/A	N/A	10%	10%
Adjustable AESS w/ FOH Cold, Main Engine Warm	N/A	N/A	10%	10%
Adjustable AESS programmed to 5 minutes	N/A	N/A	40%	40%
Transmission Efficiency	20%	20%	20%	20%
Axle Efficiency	30%	30%	30%	30%
Predictive Cruise Control	20%	20%	20%	20%
Accessory Improvements	10%	10%	10%	10%

Air Conditioner Efficiency Improvements	10%	10%	10%	10%
Automatic Tire Inflation Systems	20%	20%	20%	20%
Tire Pressure Monitoring System	20%	20%	20%	20%

2.8.4 Derivation of the Tractor Standards

The agencies used the technology effectiveness inputs and technology adoption rates to develop GEM inputs to derive the HD Phase 2 fuel consumption and CO_2 emissions standards for each subcategory of Class 7 and 8 combination tractors. Note that we have analyzed one technology pathway for each level of stringency, but tractor manufacturers are free to use any combination of technology to meet the standards on average.

2.8.4.1 2021 through 2027 MY Engine Fuel Maps

One of the most significant changes in the HD Phase 2 version of GEM is the allowance for manufacturers to enter their own engine fuel maps by following the test procedure described in the Chapter 3 Test Procedure section of this RIA. The GEM engine fuel map input file consists of information in csv format. It contains a steady-state engine fueling map that includes three columns: engine speed in rpm, engine torque in Nm, and engine fueling rate in g/s. New for the final Phase 2 rule, the input file also includes a cycle average fuel map represented by engine cycle work, the cycle-average engine speed to vehicle speed ratio, and the fuel mass in grams. The input file also contains the engine full torque or lug curve in two columns: engine speed in rpm and torque in NM. The input file also contains the motoring torque and uses the same format and units as the full load torque curve. The idle fuel map is also included.

The agencies developed default engine fuel maps for all tractor subcategories, utilizing the same format that the manufacturers would be required to provide. Fuel maps were developed for the 2021, 2024, and 2027 model years by applying the technologies assumed in deriving the engine standards and the additional technology effectiveness of new engine platforms (for 2027) to the 2018 baseline engine fuel maps. Those default maps are derived from multiple sources of confidential business information from different stakeholders together with engineering judgment. A list of all of the engine fuel maps used in setting the standards for each subcategory is given in Table 2-39. The model years covered by the maps are 2021, 2024, and 2027 are shown from Figure 2-30 to Figure 2-38. In lieu of using 2021, 2024, and 2027 MY fuel maps for the 15L 600 HP engine used in heavy-haul tractor standards and optional 2021 MY Heavy Class 8 tractor standards, we used the 2018 MY fuel map shown in Figure 2-19. We then applied a 2 percent reduction in 2021 MY, a 4.2 percent reduction in 2024 MY, and a 5.4 percent reduction in 2027 MY in the GEM runs to determine the stringency of the standards.

Table 2-39 GEM Default CI Engine Fuel Maps for Tractors

REGULATORY SUBCATEGORY		ENGINE FUEL MAP
Class 8 Combination	Sleeper Cab - High Roof	15L - 455 HP
Class 8 Combination	Sleeper Cab - Mid Roof	15L - 455 HP
Class 8 Combination	Sleeper Cab - Low Roof	15L - 455 HP
Class 8 Combination	Day Cab - High Roof	15L - 455 HP
Class 8 Combination	Day Cab - Mid Roof	15L - 455 HP
Class 8 Combination	Day Cab - Low Roof	15L - 455 HP
Class 7 Combination	Day Cab - High Roof	11L - 350 HP
Class 7 Combination	Day Cab - Mid Roof	11L - 350 HP
Class 7 Combination	Day Cab - Low Roof	11L - 350 HP
Heavy Haul	Heavy-Haul and Heavy Class 8 Tractors	15L – 600 HP

In vehicle applications, considering that market penetration of WHR would be different between sleeper cab (SC) and day cab (DC) engines due to the nature of their different driving cycles, the emission reductions should be different, and therefore, the engine fuel maps used in GEM can be different as well. In addition, at least one new engine platform would be taken into consideration, which means that more aggressive technology effectiveness is included in the tractor vehicles in addition to higher market penetration of WHR. See Chapter 2.7.5 above.

As discussed in Section III.D(1)(b)(i) of the FRM Preamble, the agencies project that at least one engine manufacturer (and possibly more) will have completed a redesign for tractor engines by 2027. Accordingly, we project that 50 percent of tractor engines in 2027 will be redesigned engines and be 1.6 percent more efficient than required by the engine standards, so the average engine would be 0.8 percent better.[145] However, we could have projected the same overall improvement by projecting 25 percent of engine get 3.2 percent better. Based on the CBI information available to us, we believe projecting a 0.8 percent improvement is somewhat conservative.

Adding this 0.8 percent improvement to the 5.1 reduction *required* by the standards means we project the average 2027 tractor engine would be 5.9 percent better than Phase 1. Because engine improvements for tractors are applied separately for day cabs and sleeper cabs in the vehicle program, we estimated separate improvements for them here. Specifically, we project a 5.4 percent reduction for day cabs and a 6.4 percent reduction in fuel consumption in sleeper cabs beyond Phase 1. It is important to also note that manufacturers that do not achieve this level would be able to make up for the difference by applying one of the many other tractor technologies to a greater extent than we project, or to achieve greater reductions by optimizing technology efficiency further. We are not including the cost of developing these new engines in our cost analysis because we believe these engines are going to be developed due to market forces (i.e., the new platform, already contemplated) rather than due to this rulemaking.

The default fuel maps are created for use in GEM. As just explained, use of different WHR market penetration rates between sleeper cabs and day cabs results in unique fuel maps for each.

Figure 2-30 to Figure 2-38 show all the engine fuel maps used in GEM for years 2021 to 2027, for sleeper cab and day cab vehicles with 455hp rating engines and 350hp rating engines.

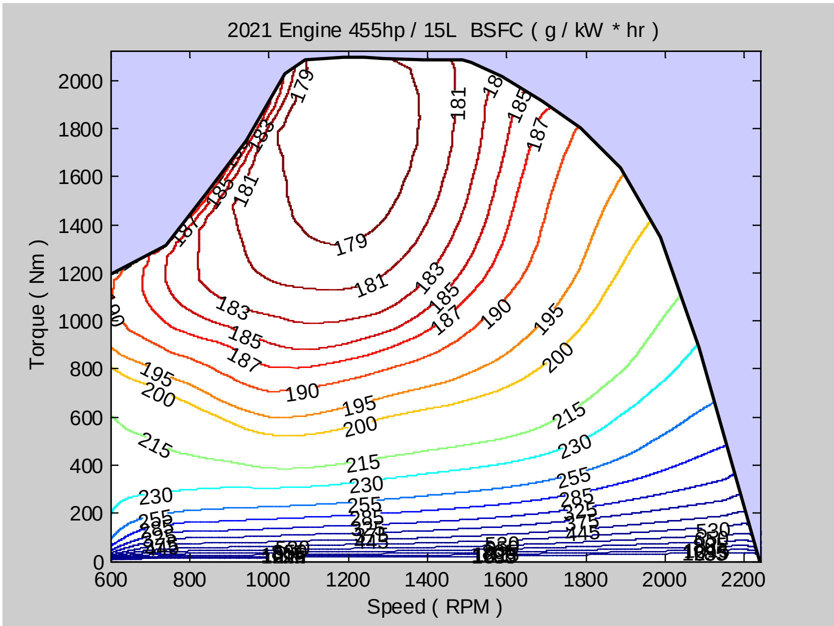


Figure 2-30 2021 Engine Fuel Map with 455hp Rating Used For Sleeper Cab

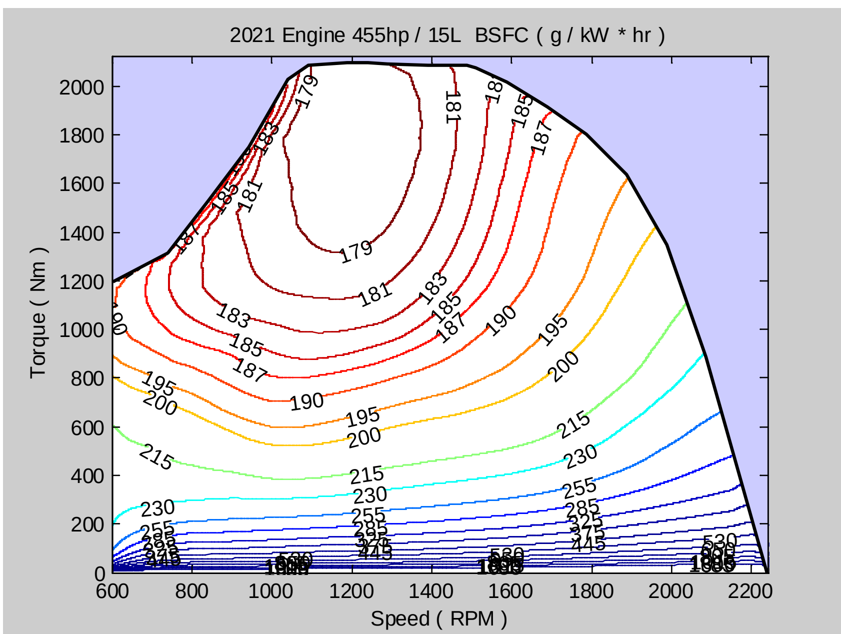


Figure 2-31 2021 Engine Fuel Map with 455hp Rating Used For Day Cab

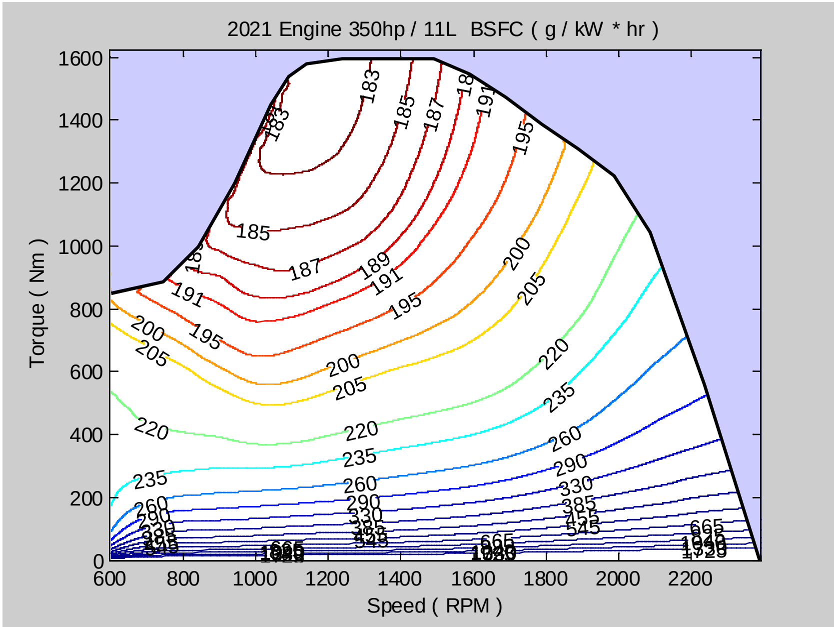


Figure 2-32 2021 Engine Fuel Map with 350hp Rating Used For Class 7 Tractor

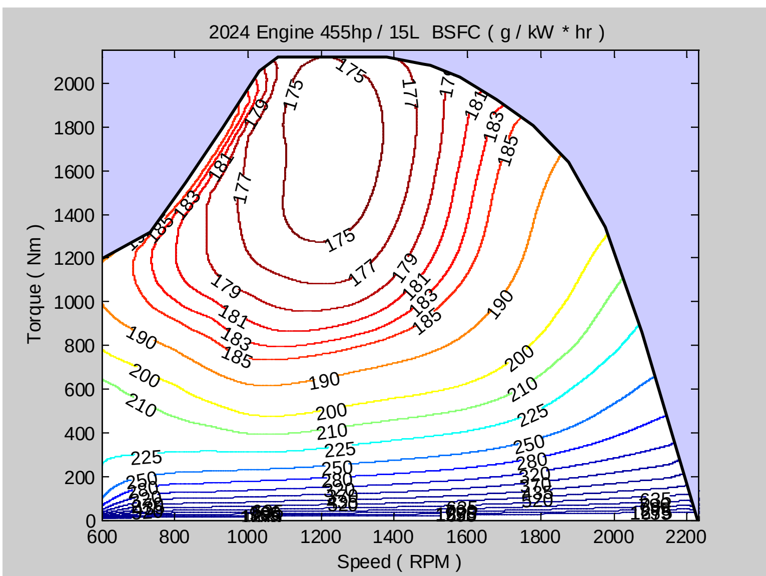


Figure 2-33 2024 Engine Fuel Map with 455hp Rating Used For Sleeper Cab

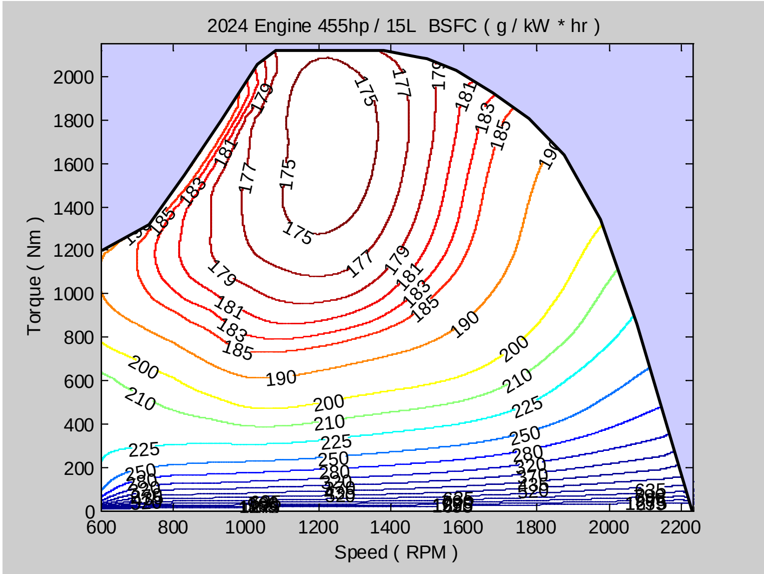


Figure 2-34 2024 Engine Fuel Map with 455hp Rating Used For Day Cab

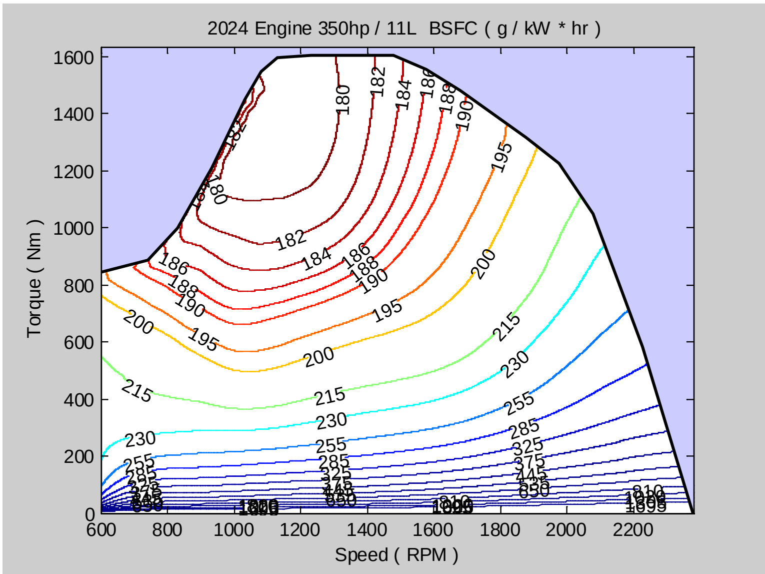


Figure 2-35 2024 Engine Fuel Map with 350hp Rating Used For Class 7 Tractor

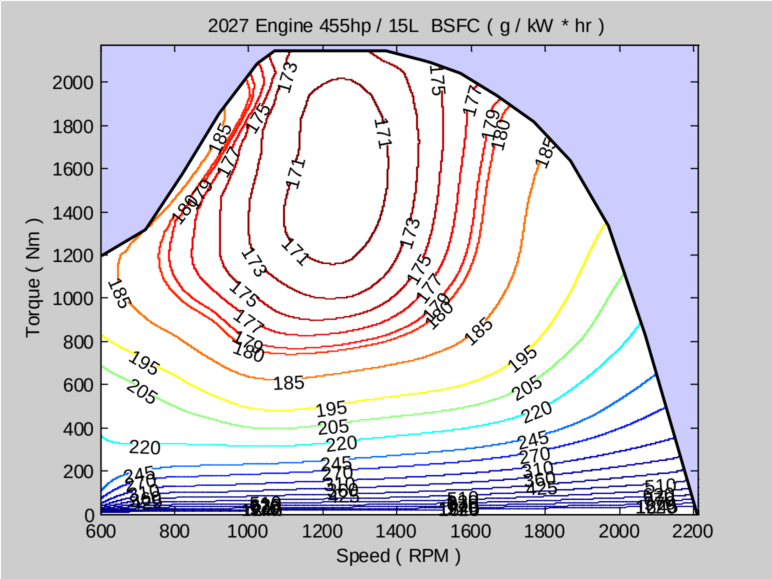


Figure 2-36 2027 Engine Fuel Map with 455hp Rating Used For Sleeper Cab

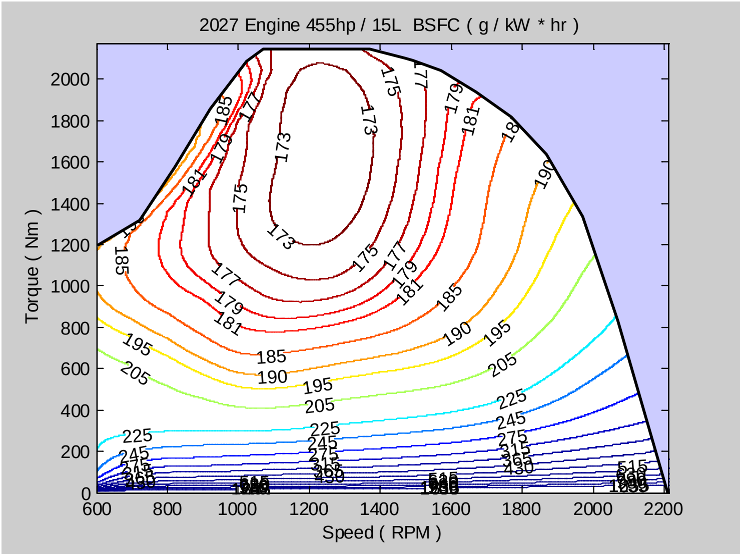


Figure 2-37 2027 Engine Fuel Map with 455hp Rating Used For Day Cab

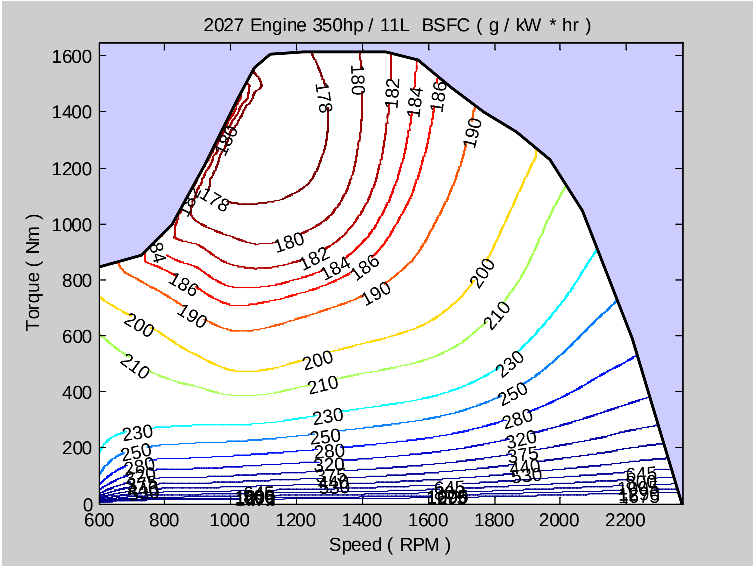


Figure 2-38 2027 Engine Fuel Map with 350hp Rating Used For Class 7 Tractor

2.8.4.2 GEM Inputs Used in Setting the Tractor Standards

As such, the agencies derived a standard for each subcategory by weighting the individual GEM input parameters included in Table 2-30 with the adoption rates in Table 2-34,

Table 2-35, and Table 2-36. For example, the C_dA value for a 2021MY Class 8 Sleeper Cab High Roof scenario case was derived as 60 percent times 5.95 plus 30 percent times 5.40 plus 10 percent times 4.90, which is equal to a C_dA of 5.68 m^2. Similar calculations were made for tire rolling resistance, transmission types, idle reduction, and other technologies. To account for the engine standards and engine technologies, the agencies developed engine fuel maps for GEM, as described in the section above.[J] The agencies then ran GEM with a single set of vehicle inputs, as shown in Table 2-40, to derive the standards for each subcategory.

Table 2-40 GEM Inputs for the 2021MY Class 7 and 8 Tractor Standard Setting

CLASS 7			CLASS 8					
Day Cab			Day Cab			Sleeper Cab		
Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine								
2021MY 11L Engine 350 HP	2021MY 11L Engine 350 HP	2021MY 11L Engine 350 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP	2021MY 15L Engine 455 HP
Aerodynamics (C_dA in m^2)								
5.24	6.33	6.01	5.24	6.33	6.01	5.24	6.33	5.68
Steer Tires (CRR in kg/metric ton)								
6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Drive Tires (CRR in kg/metric ton)								
6.6	6.6	6.3	6.6	6.6	6.3	6.6	6.6	6.3
Extended Idle Reduction Weighted Effectiveness								
N/A	N/A	N/A	N/A	N/A	N/A	2.3%	2.3%	2.3%
Transmission = 10 speed Manual Transmission Gear Ratios = 12.8, 9.25, 6.76, 4.90, 3.58, 2.61, 1.89, 1.38, 1.00, 0.73								
Drive Axle Ratio = 3.36 for day cabs, 3.31 for sleeper cabs								
6x2 Axle Weighted Effectiveness								
N/A	N/A	N/A	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Transmission Type Weighted Effectiveness = 1.1%								
Neutral Idle Weighted Effectiveness								
0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.02%	0.02%	0.02%
Direct Drive Weighted Effectiveness = 0.4%								
Transmission Efficiency Weighted Effectiveness = 0.2%								
Axle Efficiency Improvement = 0.6%								
Air Conditioner Efficiency Improvements = 0.1%								
Accessory Improvements = 0.1%								
Predictive Cruise Control =0.4%								
Automatic Tire Inflation Systems = 0.3%								
Tire Pressure Monitoring System = 0.2%								
Phase 1 Credit Carry-over = 1%								

[J] See RIA Chapter 2.7 explaining the derivation of the engine standards.

Table 2-41 GEM Inputs for the 2024MY Class 7 and 8 Tractor Standard Setting

CLASS 7			CLASS 8					
Day Cab			Day Cab			Sleeper Cab		
Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine								
2024MY 11L Engine 350 HP	2024MY 11L Engine 350 HP	2024MY 11L Engine 350 HP	2024MY 15L Engine 455 HP	2024MY 15L Engine 455 HP	2024MY 15L Engine 455 HP	2024MY 15L Engine 455 HP	2024MY 15L Engine 455 HP	2024MY 15L Engine 455 HP
Aerodynamics (CdA in m^2)								
5.16	6.25	5.82	5.16	6.25	5.82	5.16	6.25	5.52
Steer Tires (CRR in kg/metric ton)								
5.9	5.9	5.8	5.9	5.9	5.8	5.9	5.9	5.8
Drive Tires (CRR in kg/metric ton)								
6.4	6.4	6.0	6.4	6.4	6.0	6.4	6.4	6.0
Extended Idle Reduction Weighted Effectiveness								
N/A	N/A	N/A	N/A	N/A	N/A	2.5%	2.5%	2.5%
Transmission = 10 speed Manual Transmission Gear Ratios = 12.8, 9.25, 6.76, 4.90, 3.58, 2.61, 1.89, 1.38, 1.00, 0.73								
Drive Axle Ratio = 3.31 for day cabs, 3.26 for sleeper cabs								
6x2 Axle Weighted Effectiveness								
N/A	N/A	N/A	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Transmission Type Weighted Effectiveness = 1.6%								
Neutral Idle Weighted Effectiveness								
0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.03%	0.03%	0.03%
Direct Drive Weighted Effectiveness = 1.0%								
Transmission Efficiency Weighted Effectiveness = 0.4%								
Axle Efficiency Improvement = 1.3%								
Air Conditioner Efficiency Improvements = 0.1%								
Accessory Improvements = 0.2%								
Predictive Cruise Control =0.8%								
Automatic Tire Inflation Systems = 0.3%								
Tire Pressure Monitoring System = 0.5%								

Table 2-42 GEM Inputs for the 2027MY Class 7 and 8 Tractor Standard Setting

CLASS 7			CLASS 8					
Day Cab			Day Cab			Sleeper Cab		
Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine								
2027MY 11L Engine 350 HP	2027MY 11L Engine 350 HP	2027MY 11L Engine 350 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP	2027MY 15L Engine 455 HP
Aerodynamics (CdA in m^2)								
5.12	6.21	5.67	5.12	6.21	5.67	5.08	6.21	5.26
Steer Tires (CRR in kg/metric ton)								
5.8	5.8	5.6	5.8	5.8	5.6	5.8	5.8	5.6
Drive Tires (CRR in kg/metric ton)								
6.2	6.2	5.8	6.2	6.2	5.8	6.2	6.2	5.8
Extended Idle Reduction Weighted Effectiveness								
N/A	N/A	N/A	N/A	N/A	N/A	3%	3%	3%
Transmission = 10 speed Manual Transmission Gear Ratios = 12.8, 9.25, 6.76, 4.90, 3.58, 2.61, 1.89, 1.38, 1.00, 0.73								
Drive Axle Ratio = 3.21 for day cabs, 3.16 for sleeper cabs								
6x2 Axle Weighted Effectiveness								
N/A	N/A	N/A	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%
Transmission Type Weighted Effectiveness = 1.6%								
Neutral Idle Weighted Effectiveness								
0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.03%	0.03%	0.03%
Direct Drive Weighted Effectiveness = 1.0%								
Transmission Efficiency Weighted Effectiveness = 0.7%								
Axle Efficiency Improvement = 1.6%								
Air Conditioner Efficiency Improvements = 0.3%								
Accessory Improvements = 0.2%								
Predictive Cruise Control =0.8%								
Automatic Tire Inflation Systems = 0.4%								
Tire Pressure Monitoring System = 0.7%								

Table 2-43 GEM Inputs for the 2021, 2024, and 2027MY Heavy-Haul Tractor Standard Setting

2021MY	2024MY	2027MY
Engine = 2021 MY 15L Engine with 600 HP	Engine = 2024 MY 15L Engine with 600 HP	Engine = 2027 MY 15L Engine with 600 HP
Aerodynamics (CdA in m^2) = 5.00		
Steer Tires (CRR in kg/metric ton) = 6.2	Steer Tires (CRR in kg/metric ton) = 6.0	Steer Tires (CRR in kg/metric ton) = 5.8
Drive Tires (CRR in kg/metric ton) = 6.6	Drive Tires (CRR in kg/metric ton) = 6.4	Drive Tires (CRR in kg/metric ton) = 6.2
Transmission = 18 speed Manual Transmission	Transmission = 18 speed Manual Transmission	Transmission = 18 speed Manual Transmission
Drive axle Ratio = 3.70	Drive axle Ratio = 3.70	Drive axle Ratio = 3.70
6x2 Axle Weighted Effectiveness = 0%	6x2 Axle Weighted Effectiveness = 0%	6x2 Axle Weighted Effectiveness = 0%
Transmission benefit = 1.1%	Transmission benefit = 1.8%	Transmission benefit = 1.8%
Transmission Efficiency=0.2%	Transmission Efficiency=0.4%	Transmission Efficiency=0.7%
Axle Efficiency=0.3%	Axle Efficiency=0.7%	Axle Efficiency=1.6%
Predictive Cruise Control=0.4%	Predictive Cruise Control =0.8%	Predictive Cruise Control =0.8%
Accessory Improvements = 0.1%	Accessory Improvements = 0.2%	Accessory Improvements = 0.3%
Air Conditioner Efficiency Improvements= 0.1%	Air Conditioner Efficiency Improvements = 0.1%	Air Conditioner Efficiency Improvements = 0.2%
Automatic Tire Inflation Systems = 0.3%	Automatic Tire Inflation Systems = 0.3%	Automatic Tire Inflation Systems = 0.4%
Tire Pressure Monitoring System= 0.2%	Tire Pressure Monitoring System= 0.5%	Tire Pressure Monitoring System= 0.7%

The agencies ran GEM with a single set of vehicle inputs, as shown in Table 2-44, to derive the optional standards for each subcategory of the Heavy Class 8 tractors.

Table 2-44 GEM Inputs for 2021 MY Heavy Class 8 Tractor Standards

HEAVY CLASS 8 GEM INPUTS FOR 2021 MY					
Day Cab			Sleeper Cab		
Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
2021MY 15L Engine 600 HP					
Aerodynamics (C_dA in m^2)					
5.2	6.3	6.0	5.2	6.3	5.7
Steer Tires (CRR in kg/metric ton)					
6.1	6.1	6.1	6.1	6.1	6.1
Drive Tires (CRR in kg/metric ton)					
6.8	6.8	6.5	6.8	6.8	6.5
Extended Idle Reduction Weighted Effectiveness					
N/A	N/A	N/A	2.3%	2.3%	2.3%
Transmission = 18 speed Manual Transmission					
Drive Axle Ratio = 3.73					
Transmission Type Weighted Effectiveness = 1.1%					
Neutral Idle Weighted Effectiveness					
0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Direct Drive Weighted Effectiveness = 0.4%					
Transmission Efficiency Weighted Effectiveness = 0.2%					
Axle Efficiency Improvement = 0.6%					
Air Conditioner Efficiency Improvements = 0.1%					
Accessory Improvements = 0.1%					
Predictive Cruise Control =0.4%					
Automatic Tire Inflation Systems = 0.3%					
Tire Pressure Monitoring System = 0.2%					

The levels of the 2021, 2024, and 2027 model year standards for each subcategory are included in Table 2-45.

Table 2-45 2021, 2024, and 2027 Model Year Tractor Standards

2021 MODEL YEAR CO_2 GRAMS PER TON-MILE				
	Day Cab		Sleeper Cab	Heavy-Haul
	Class 7	Class 8	Class 8	Class 8
Low Roof	105.5	80.5	72.3	52.4
Mid Roof	113.2	85.4	78.0	
High Roof	113.5	85.6	75.7	
2021 Model Year Gallons of Fuel per 1,000 Ton-Mile				
	Day Cab		Sleeper Cab	Heavy-Haul
	Class 7	Class 8	Class 8	Class 8
Low Roof	10.36346	7.90766	7.10216	5.14735
Mid Roof	11.11984	8.38900	7.66208	
High Roof	11.14931	8.40864	7.43615	
2024 Model Year CO_2 Grams per Ton-Mile				
	Day Cab		Sleeper Cab	Heavy-Haul
	Class 7	Class 8	Class 8	Class 8
Low Roof	99.8	76.2	68.0	50.2
Mid Roof	107.1	80.9	73.5	
High Roof	106.6	80.4	70.7	
2024 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile				
	Day Cab		Sleeper Cab	Heavy-Haul
	Class 7	Class 8	Class 8	Class 8
Low Roof	9.80354	7.48527	6.67976	4.93124
Mid Roof	10.52063	7.94695	7.22004	
High Roof	10.47151	7.89784	6.94499	
2027 Model Year CO_2 Grams per Ton-Mile[a]				
	Day Cab		Sleeper Cab	Heavy-Haul
	Class 7	Class 8	Class 8	Class 8
Low Roof	96.2	73.4	64.1	48.3
Mid Roof	103.4	78.0	69.6	
High Roof	100.0	75.7	64.3	
2027 Model Year and Later Gallons of Fuel per 1,000 Ton-Mile				
	Day Cab		Sleeper Cab	Heavy-Haul
	Class 7	Class 8	Class 8	Class 8
Low Roof	9.44990	7.21022	6.29666	4.74460
Mid Roof	10.15717	7.66208	6.83694	
High Roof	9.82318	7.43615	6.31631	

The 2027 MY standards for the high roof day cabs and high roof sleeper cab include the 0.3 m^2 reduction in C_dA built into GEM to reflect a change in the standard trailer (see Preamble Section III.E.2.a.viii). This change lowers the numerical value of the standard, but does not impact the stringency (i.e., the effectiveness of the technology packages that need to be installed on a tractor to be compliant with the standards). Therefore, the percent reductions reported throughout the Preamble to the final rule reflect only the effectiveness of the technology package needed to meet the standard and does not include the change in C_dA built into GEM. See Table 2-46 for the percent reduction calculations for high roof tractors in MY 2027.

Table 2-46 Percent Reductions for 2027MY High Roof Tractors

	CLASS 7 HIGH ROOF TRACTOR	CLASS 8 HIGH ROOF DAY CAB	CLASS 8 HIGH ROOF SLEEPER CAB
Baseline GEM Output 2018 MY (g/ton-mile)	129.7	98.2	87.8
2027 MY GEM Output with 0.3 m^2 CdA (g/ton-mile)	100.0	75.7	64.3
2027 MY GEM Output without 0.3 m^2 CdA (g/ton-mile)	102.0	77.0	65.7
% Reduction in Stringency due to Technology Package Only	21%	22%	25%

The level of the Phase 2 2021 model year optional Heavy Class 8 standards for each subcategory is included in Table 2-47.

Table 2-47 Phase 2 Optional Heavy Class 8 Standards

OPTIONAL HEAVY CLASS 8 TRACTOR STANDARDS					
Low Roof Day Cab	**Mid Roof Day Cab**	**High Roof Day Cab**	**Low Roof Sleeper Cab**	**Mid Roof Sleeper Cab**	**High Roof Sleeper Cab**
2021 Model Year CO_2 Standards (Grams per Ton-Mile)					
51.8	54.1	54.1	45.3	47.9	46.9
2021 MY and Later Fuel Consumption (gallons of Fuel per 1,000 Ton-Mile)					
5.08841	5.31434	5.31434	4.44990	4.70530	4.60707

2.8.5 Tractor Package Costs of the Standards

A summary of the technology package costs under the final standard and relative to the flat baseline is included in Table 2-48 through Table 2-51 for MYs 2021, 2024, and 2027, respectively. RIA Chapter 2.11 includes the technology costs for the individual technologies.

Table 2-48 Class 7 and 8 Tractor Technology Incremental Costs in the 2021 Model Year[a,b] Final Standards vs. the Flat Baseline (2013$ per vehicle)

	CLASS 7		CLASS 8				
	Day Cab		Day Cab		Sleeper Cab		
	Low/Mid Roof	High Roof	Low/ Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine[c]	$284	$284	$284	$284	$284	$284	$284
Aerodynamics	$164	$299	$164	$299	$119	$119	$349
Tires	$39	$9	$61	$16	$61	$56	$16
Tire inflation system	$259	$259	$300	$300	$300	$300	$300
Transmission	$4,096	$4,096	$4,096	$4,096	$4,096	$4,096	$4,096
Axle & axle lubes	$71	$71	$101	$101	$101	$101	$101
Idle reduction with APU	$0	$0	$0	$0	$1,998	$1,998	$1,909
Air conditioning	$17	$17	$17	$17	$17	$17	$17
Other vehicle technologies	$204	$204	$204	$204	$204	$204	$204
Total	$5,134	$5,240	$5,228	$5,317	$7,181	$7,175	$7,276

Notes:

[a] Costs shown are for the 2021 model year and are incremental to the costs of a baseline Phase 2 tractor. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the RIA (see RIA 2.11).

[b] Note that values in this table include projected technology penetration rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated tractor classes. To see the actual estimated technology costs exclusive of adoption rates, refer to Chapter 2.11 of this RIA.

[c] Engine costs are for a heavy HD diesel engine meant for a combination tractor (see Table 2-14).

Table 2-49 Class 7 and 8 Tractor Technology Incremental Costs in the 2024 Model Year[a,b] Final Standards vs. the Flat Baseline (2013$ per vehicle)

	CLASS 7		CLASS 8				
	Day Cab		Day Cab		Sleeper Cab		
	Low/Mid Roof	High Roof	Low/ Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine[c]	$712	$712	$712	$712	$712	$712	$712
Aerodynamics	$264	$465	$264	$465	$217	$217	$467
Tires	$40	$12	$65	$20	$65	$65	$20
Tire inflation system	$383	$383	$477	$477	$477	$477	$477
Transmission	$6,092	$6,092	$6,092	$6,092	$6,092	$6,092	$6,092
Axle & axle lubes	$139	$139	$185	$185	$185	$185	$185
Idle reduction with APU	$0	$0	$0	$0	$2,946	$2,946	$2,946
Air conditioning	$32	$32	$32	$32	$32	$32	$32
Other vehicle technologies	$374	$374	$374	$374	$374	$374	$374
Total	$8,037	$8,210	$8,201	$8,358	$11,100	$11,100	$11,306

Notes:

[a] Costs shown are for the 2021 model year and are incremental to the costs of a baseline Phase 2 tractor. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2.11 of this RIA.

[b] Note that values in this table include projected technology penetration rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated tractor classes. To see the actual estimated technology costs exclusive of adoption rates, refer to Chapter 2.11 of this RIA.

[c] Engine costs are for a heavy HD diesel engine meant for a combination tractor (see Table 2-18).

Table 2-50 Class 7 and 8 Tractor Technology Incremental Costs in the 2027 Model Year[a,b] Final Standards vs. the Flat Baseline (2013$ per vehicle)

	CLASS 7		CLASS 8				
	Day Cab		Day Cab		Sleeper Cab		
	Low/Mid Roof	High Roof	Low/ Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Engine[c]	$1,579	$1,579	$1,579	$1,579	$1,579	$1,579	$1,579
Aerodynamics	$453	$547	$453	$547	$415	$415	$639
Tires	$43	$12	$70	$20	$70	$70	$20
Tire inflation system	$469	$469	$594	$594	$594	$594	$594
Transmission	$7,098	$7,098	$7,098	$7,098	$7,098	$7,098	$7,098
Axle & axle lubes	$168	$168	$220	$220	$220	$220	$220
Idle reduction with APU	$0	$0	$0	$0	$3,134	$3,173	$3,173
Air conditioning	$45	$45	$45	$45	$45	$45	$45
Other vehicle technologies	$380	$380	$380	$380	$380	$380	$380
Total	$10,235	$10,298	$10,439	$10,483	$13,535	$13,574	$13,749

Notes:
[a] Costs shown are for the 2021 model year and are incremental to the costs of a baseline Phase 2 tractor. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2.11 of this RIA.
[b] Note that values in this table include projected technology penetration rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated tractor classes. To see the actual estimated technology costs exclusive of adoption rates, refer to Chapter 2.11 of this RIA.
[c] Engine costs are for a heavy HD diesel engine meant for a combination tractor (see Table 2-22).

Table 2-51 Heavy-Haul Tractor Technology Incremental Costs in the 2021, 2024, and 2027 Model Year[a,b] Final Standards vs. the Less Dynamic Baseline (2013$ per vehicle)

	2021 MY	2024 MY	2027 MY
Engine[c]	$284	$712	$1,579
Tires	$61	$65	$70
Tire inflation system	$300	$477	$594
Transmission	$4,096	$6,092	$7,098
Axle Efficiency	$101	$185	$220
Air conditioning	$17	$32	$45
Other vehicle technologies	$204	$374	$380
Total	$5,063	$7,937	$9,986

Notes:
[a] Costs shown are for the specified model year and are incremental to the costs of a baseline Phase 2 tractor. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to Chapter 2 of the RIA (see RIA 2.11).
[b] Note that values in this table include projected technology penetration rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated tractor classes. To see the actual estimated technology costs exclusive of adoption rates, refer to Chapter 2 of the RIA (see RIA 2.11 in particular).
[c] Engine costs are for a heavy HD diesel engine meant for a combination tractor.

2.9 Technology Application and Estimated Costs – Vocational Vehicles

This section describes the technical analysis supporting the derivation of the vocational vehicle standards, including technology effectiveness and adoption rates. For purposes of setting standards, the agencies have established a unique baseline vocational vehicle configuration for each of the vocational vehicle regulatory subcategories, including nine diesel subcategories, nine gasoline subcategories, and seven custom chassis subcategories. For purposes of demonstrating compliance, some of the attributes and parameters are fixed by the agencies and are not available as manufacturer inputs to GEM, while some are available to manufacturers when identifying configurations to certify in the model years of the HD Phase 2 program.

2.9.1 Vocational Engines

This section describes the engines the agencies selected to incorporate into the baseline vehicle configurations for the vocational vehicle subcategories, and how we used the GEM tool to establish performance levels of these baseline vehicles. The agencies have developed models for engines that represent performance of the technologies we expect would be installed in vocational vehicles in the baseline year of 2017. A description of the technologies applied to our 2017 diesel engine models can be found above in Chapter 2.7 of this RIA, and gasoline engine technologies are described in RIA Chapter 2.6. A description of the GEM engine simulation can be found in RIA Chapter 4.

One of the most significant changes in the HD Phase 2 version of GEM is the provision for manufacturers to enter their own engine fuel maps by following the test procedure described in the RIA Chapter 3. The GEM engine fuel map input file consists of information in csv format. It contains a steady-state engine fueling map that includes three columns: engine speed in rpm, engine torque in Nm, and engine fueling rate in g/s. New for the final Phase 2 rules, the input file also includes a cycle average fuel map represented by engine cycle work, the cycle-average engine speed to vehicle speed ratio, and the fuel mass in grams. The input file also contains the engine full torque or lug curve in two columns: engine speed in rpm and torque in NM. The input file also contains the motoring torque and uses the same format and units as the full load torque curve. The idle fuel map is also included.

2.9.1.1 Baseline Vocational Engines

The agencies have developed the vehicle standards using engine fuel maps described in this section for all vocational vehicle sub-categories, utilizing the same format that the OEMs will be required to provide when demonstrating compliance. Four sets of diesel engine maps cover the nine primary diesel vocational vehicle regulatory subcategories and the seven custom chassis subcategories, and one gasoline engine map covers the six gasoline vocational vehicle regulatory subcategories, as summarized in Table 2-52. This means that some of the subcategories share the same engine fuel map (and appropriately so; the agencies anticipate common use of these engine platforms in real world application; see Chapter 2.7.5 above). For example, all MHD diesel subcategories are powered by the same 7L engine with 270 hp rating, as this is a very popular rating for engines in class 6-7 vocational vehicles in the U.S.

The agencies selected the 15L as the primary engine for the Regional HHD subcategory because these vocational vehicles often require a similar level of power as a day cab tractor. Also, the same engine hardware is often used for both tractor and vocational vehicles. It would not be cost effective to develop two complete engines from one manufacturer in order to meet two different market needs. The same principle is applied to 11L engines. We have made changes to this 11L engine since proposal, from a 345hp to a 350hp rating for the HHD subcategories. As proposed, the engine displacements and power ratings for the diesel MHD and LHD vocational subcategories are the same as those simulated in GEM for Phase 1. More details about the comments received on vocational engines and our responses with respect to selection of baseline engines can be found in the Preamble at Section V.C and in the RTC Section 6.

Table 2-52 GEM Engines for Vocational Vehicles

REGULATORY SUBCATEGORY AND DUTY CYCLE		ENGINE FUEL MAP
CI Heavy Heavy-Duty (Class 8)	Regional and Multipurpose Duty Cycles	15L - 455 HP
CI Heavy Heavy-Duty (Class 8)	Regional, Multi-Purpose, and Urban Duty Cycles	11L - 350 HP
CI Medium Heavy-Duty (Class 6-7)	Regional, Multi-Purpose, and Urban Duty Cycles	7L - 270 HP
CI Light Heavy-Duty (Class 2b-5)	Regional, Multi-Purpose, and Urban Duty Cycles	7L - 200 HP
SI Heavy-Duty (Class 2b-8)	Regional, Multi-Purpose, and Urban Duty Cycles	6.8L - 300 HP

Working with SwRI, the agencies have developed a baseline fuel map for an SI engine intended for vocational vehicles. Based on testing at SwRI from a 2015 Ford 6.8L gasoline engine, two key technologies are introduced to develop this baseline engine: cam phasing and cooled EGR through a comprehensive engine modeling using GT-Power. It is recognized that it would be very challenging to develop a map that can exactly match the proposed standards of 627 g/hp-hr numerically with the engine modeling approach taken. Consequently, the small adjustment would have to be taken in order to match 627 g/hp-hr exactly. This can be done by taking the ratio of whatever value obtained from modeling to 627g/hp-hr, and multiplying it to the entire map if the final numerical values derived from GT-Power engine modeling is different from the standards. More detailed process of this map development can be seen in Chapter 5.4 of the SwRI report[146]. It should be pointed out that this technology path is just one of many other potential road maps that can achieve the standards. We believe this reasonably represents a gasoline engine that complies with the applicable MY 2016 engine standard as shown in Figure 2-39.[146]

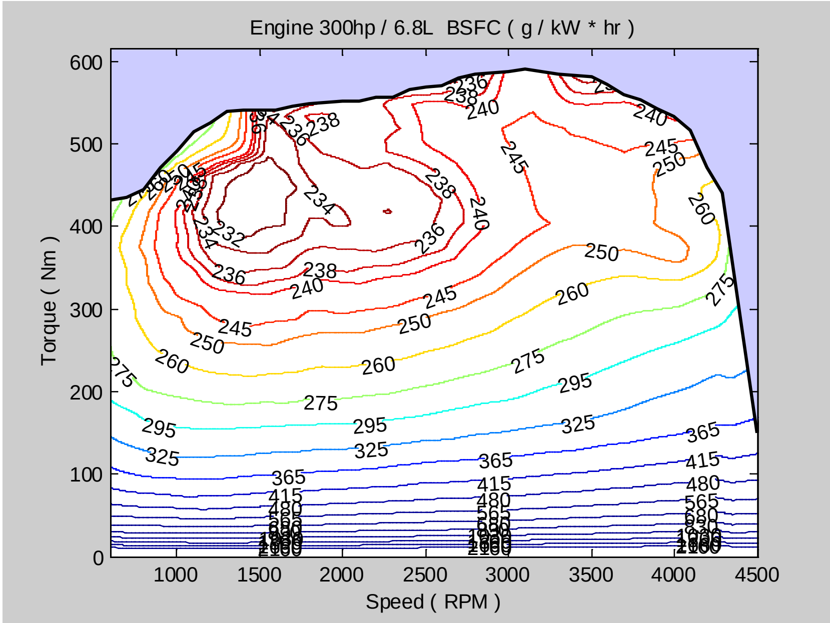


Figure 2-39 Gasoline Engine Fuel Map for 300hp Rating

Vocational diesel baseline engine maps for MY 2018 are presented in Chapter 2.7 above. Specifically, see Figure 2-17 to see the map of the 350 hp engine, Figure 2-18 for a map of the 455 hp engine, Figure 2-20 for a map of the 270 hp engine, and Figure 2-21 for a map of the 200 hp engine.

2.9.1.2 Improved Vocational Engines for Phase 2 Standard-Setting

The agencies developed four model year versions of these engine maps for each of these four diesel engines: one set for MY 2017 as the baseline, a set of maps for MY2021, a set for MY2024, and a set for MY 2027, as improved over the 2017 baseline engine maps.

2.9.1.2.1 Vocational Gasoline Engine Technology for Standard-Setting

Although the agencies will retain the Phase 1 SI separate engine standard for all implementation years of Phase 2, we developed the Phase 2 standards for vocational *vehicles* powered by SI engines, in part, to reflect performance of additional engine technology.[K] When developing improvement levels for the stringency of the MY 2021, MY 2024, and MY 2027 vehicle standards, the agencies analyzed adoption rates, effectiveness, and cost of cylinder deactivation and SI engine technologies that reduce friction. Consistent with our projection of adoption rates of advanced engine friction reduction on HD gasoline pickup trucks, the agencies projected that 44 percent of SI engines intended for vocational vehicles would already have technologies applied that achieve performance equivalent to Level 2 engine friction reduction, enabling a projected adoption rate of 56 percent of SI vocational engines that could upgrade to Level 2. In terms of effectiveness, the agencies relied on the data presented in the Joint Technical Support Document (TSD) published in support of the LD GHG final rulemaking.[147]

[K] The agencies did so in part in response to comments indicating that improvements in SI engine performance over the baseline were feasible.

In Chapter 3 of that document, the agencies present effectiveness values for upgrading from baseline levels of engine friction reduction to Level 2 (EFR2) as ranging from 3.4 percent to 4.8 percent, for a range of LD vehicle types, and with large trucks falling in the middle of this range. The TSD describes example technologies as including low-tension piston rings, piston skirt design, roller cam followers, improved crankshaft design and bearings, material coatings, material substitution, more optimal thermal management, and piston and cylinder surface treatments. For this Phase 2 HD rulemaking, the agencies derived incremental EFR2 effectiveness values from the combined EFR1+EFR2 values that were relative to baseline-level friction reduction. We were able to do this because the TSD also presented incremental improvements for upgrading from EFR1 to EFR2 as ranging from 0.83 to 1.37. Using the same reasoning as explained at proposal, the effectiveness and adoption rate of Level 2 engine friction reduction is estimated to yield a fuel efficiency improvement of 0.6 percent.

Cylinder deactivation is considered as a technology in the HD pickup and van program, and it can be an effective technology for vocational vehicles with high power to vehicle weight ratios in driving conditions that don't demand full load operation. Table VI-6 in Preamble Section VI shows that expected improvements in fuel consumption due to application of cylinder deactivation on HD pickups and vans are on the order of two to three percent over the applicable chassis dynamometer test cycle. The discussion in Section VI.E.8 of the Preamble explains the reasoning behind the agencies' decision to predicate the HD SI pickup standards on 56 percent adoption of cylinder deactivation. Because of differences in offerings between engines sold in complete pickup trucks and those sold in vocational vehicles, we are applying only 30 percent adoption of cylinder deactivation for SI vocational vehicle-level improvements. Because of differences in driving patterns and test procedures between HD pickup trucks and vocational vehicles, we are not applying the same effectiveness as for the pickups, instead we are applying a cycle average effectiveness of one percent. Further, because friction reduction and cylinder deactivation act in some overlapping ways to improve efficiency of engines, we are applying a dis-synergy factor of 0.9. Thus the combination of these technologies results in a calculated package effectiveness value of 0.8 percent, which we apply in each model year of Phase 2 standards. In terms of costs, the agencies have presented the costs of upgrading from EFR1 to EFR2, as shown in Chapter 2.11.2.17 below. The costs of cylinder deactivation are shown in Chapter 2.11.2.18. By applying our market adoption rates and incremental costs of these two technologies, we estimate a vocational vehicle package cost due to improved SI engines of $138 in MY 2021 for this technology.

2.9.1.2.2 Improved Vocational Diesel Engine Technology for Standard-Setting

As pointed out above, we consider that vocational and tractor vehicles share the same engine hardware with 455hp and 350hp rating, since the same engines would likely be applied to both tractor and vocational sectors, consistent with the current market structure. However, moving to 2021, and 2024 and 2027 years, those maps between tractor and vocational vehicles could start to deviate, even though the engine hardware remains the same, because of different technology paths. Since the benefits obtained from WHR would be minimal for vocational applications, we do not expect that WHR would be used in this sector (and the vocational vehicle standards consequently do not reflect any use of engines with WHR). On the other hand, transient control technology is one of the major enabling technologies in the vocational sector.

In addition, the weighting of the composite certification cycles is much higher in the transient cycle than in the 55 mph and 65 mph cruise speed cycles. In the vehicle standard-setting process, we use the steady state map for the 55 and 65 mph cruise speed cycles, while the cycle average maps are used for transient ARB cycle. The technology effectiveness map without WHR and transient control technology is used to develop an engine fuel map for 55 and 65mph cycles, where the same principle of engine fuel map from the tractor vehicle described in Chapter 2.8.4 is used. The second map is for the transient ARB cycle, where the total reduction of technology effectiveness map without WHR but with transient control technology is used for the cycle average map. After two maps are created, a weighting factor derived from three weighting factors of 55mph, 65mph cruise speed cycles and transient ARB cycle is used to determine the final reduction of emissions. For the sake of simplicity, it is noted that engines with 455hp and 350hp are the same ones as the tractor engines largely with the same technology path, and therefore they can be grouped together by using one unique mapping methodology. On the other hand, the engine with 200 hp and 270 hp for Class 2b-7 vehicles can be grouped into a second group by using another set of mapping procedures, since the agencies used a different technology path for these than for tractor engines.

Compared to the tractor engine technology table (Table 2-11) or with potential new engine platform, the SET weighted reductions are identical except WHR setting to zero, and a technology called model based control for transient operations is added. It is also noted that market penetrations are different from Table 2-12. This is because new engine calibrations must be developed without the WHR device, and portions of new engine platform may be less likely applied to vocational sectors as opposed to the tractor market. Again, this is just one of the technology paths proposed, and there could be many other ways to achieve the same goal. It is also noted that the total reduction from each table is different, with more reductions predicted from transient control than for control under steady state conditions. This reflects a different technology path for each, and, specifically, that model based control for the transient operation can play a significant role in reducing vehicle CO_2 emissions.

The maps reflect that certain additional benefits from engine improvements can appropriately be included in the vehicle standard, specifically, improvements based on will total and more optimal integration between engine and transmission during transient operation. (As explained in 2.8 above, the same approach is reflected with respect to engine improvements in the tractor standard).

We next used these steady state and transient technology maps to translate the reductions into the engine fuel maps used for GEM during the stringency standard runs. Figure 2-40 highlights the principle of the final mapping procedure. In this figure, SS stands for steady state. Starting with the 2018 baseline engine fuel map (the top of this figure), the baseline cycle average map is created with a 1.05 transient correction factor, which is used to multiply the fuel rate obtained from a normal GEM simulation with a steady state engine fuel map. How the cycle average map is created can be seen in Chapter 3 of the RIA. The transient factor of 1.05 is derived from a large experimental data set to account for transient behavior. Next, 2018 baseline technology maps, such as Figure 2-20 and Figure 2-21, are used to generate steady state engine fuel maps for 2021, 2024, and 2027, following the exactly same procedure for HHD engines as the tractor engine fuel maps, and the same procedure for Class 2b-7 as vocational engines (i.e., engines used in vocational vehicles). The cycle average maps for 2021, 2024, and 2027 will be generated based on the new derived cycle average multiplier as shown in Table 2-53 and Table 2-54.

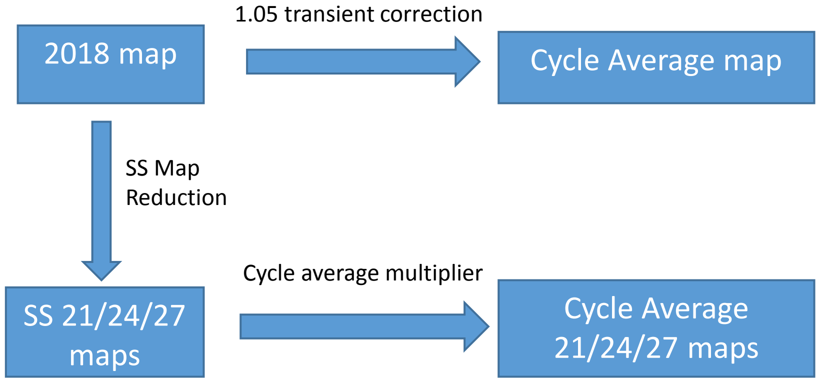


Figure 2-40 Vocational engine fuel map for GEM run

The cycle average multipliers are shown in the table below, which are calculated by subtracting the difference between the transient technology map reduction and the SS technology map reduction from 1.05.

Table 2-53 Cycle Average Multiplier for HHD Engines

YEARS	SS TECHNOLOGY MAP REDUCTION USED IN GEM	TRANSIENT TECHNOLOGY MAP REDUCTION USED IN CYCLE AVERAGE MAP	CYCLE AVERAGE MULTIPLIER
2021	2.0%	2.8%	1.042
2024	3.4%	4.8%	1.036
2027	3.9%	5.5%	1.034

Table 2-54 Cycle Average Multiplier for LHD and MHD Engines

YEARS	SS TECHNOLOGY MAP REDUCTION USED IN GEM	TRANSIENT TECHNOLOGY MAP REDUCTION USED IN CYCLE AVERAGE MAP	CYCLE AVERAGE MULTIPLIER
2021	1.8%	2.6%	1.043
2024	3.4%	4.4%	1.036
2027	3.5%	5.2%	1.033

The overall reduction over the composite cycles differ as a result of combining steady state mapping with transient mapping for the final vehicle stringency standard runs using GEM. It should be between the total reduction shown in the steady state technology map and transient technology maps. Since more aggressive model based control for transient operation is used in the vehicle standards than for the engine standards, it can be expected that overall reduction would be more than engine standards, which vehicle standard is in the range of 4.8 percent on average over all vocational vehicles.

With the engine fuel map procedure developed, all vocational engine fuel maps can be created. Figures shown below are the engine fuel maps used for vocational vehicles from 2021 to 2027, including 455hp, 350hp, 270hp, and 200hp engines.

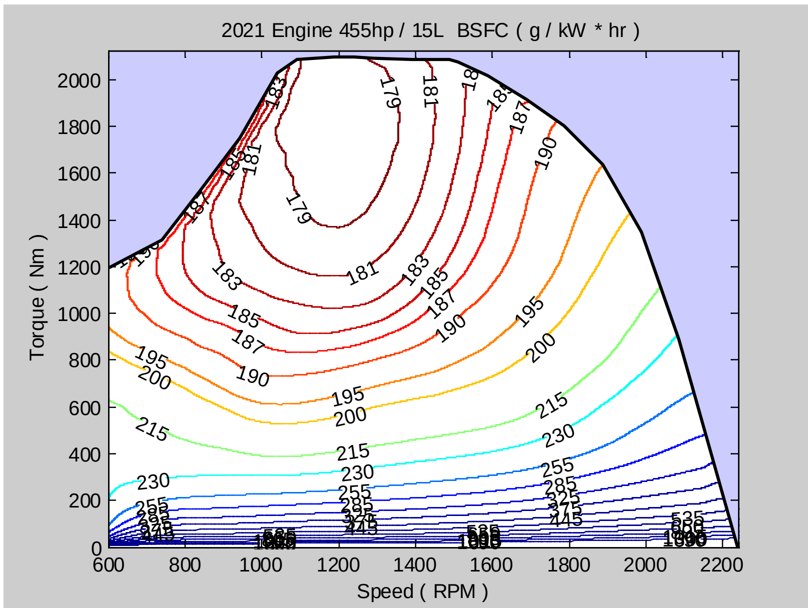


Figure 2-41 2021 Vocational Engine Fuel Map with 455hp Rating

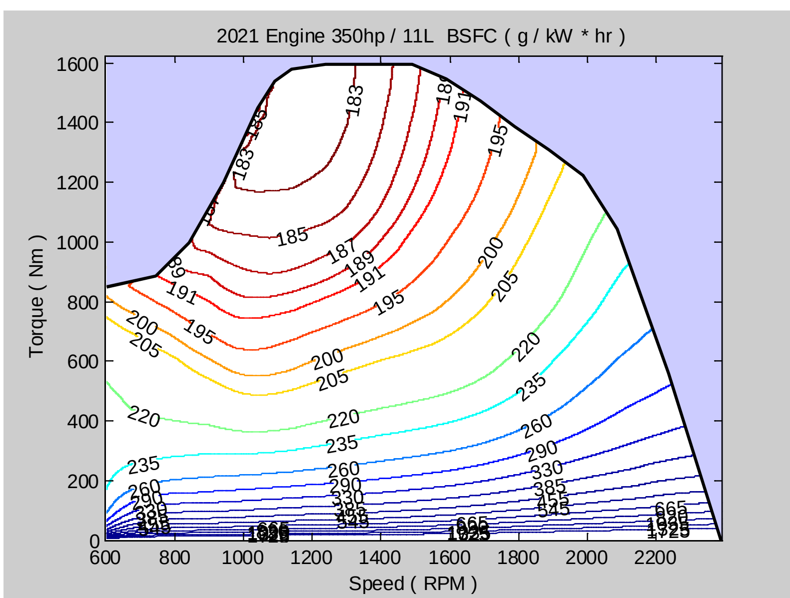


Figure 2-42 2021 Vocational Engine Fuel Map with 350hp Rating

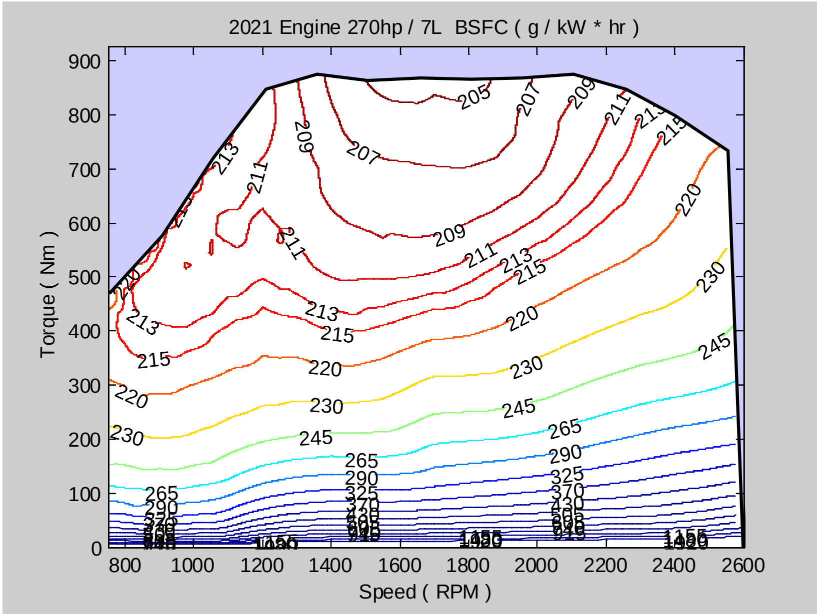


Figure 2-43 2021 Vocational Engine Fuel Map with 270hp Rating

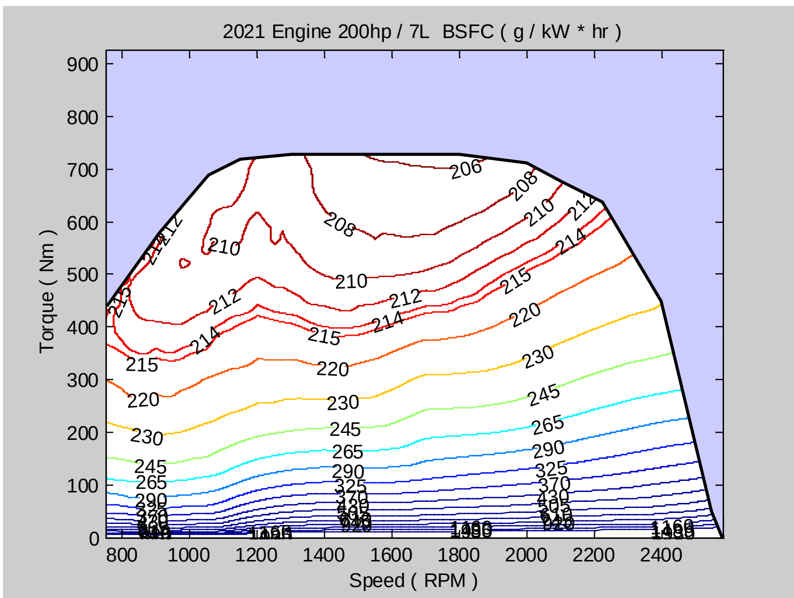


Figure 2-44 2021 Vocational Engine Fuel Map with 200hp Rating

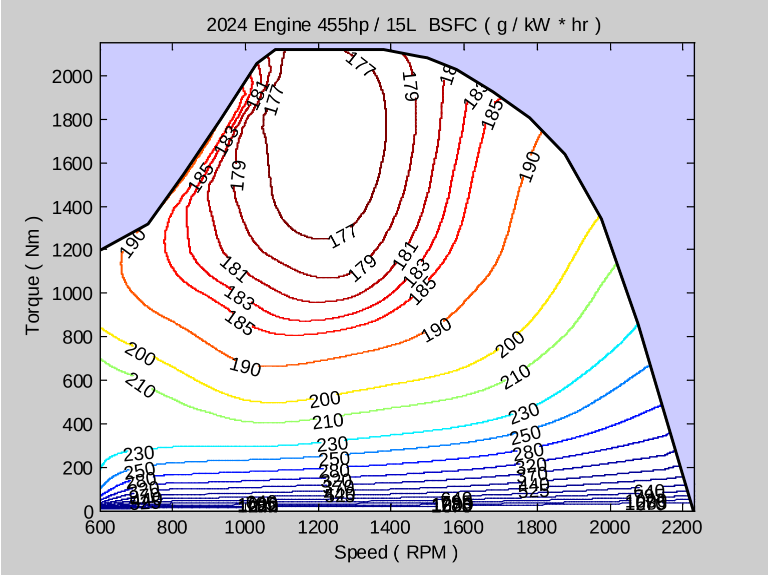


Figure 2-45 2024 Vocational Engine Fuel Map with 455hp Rating

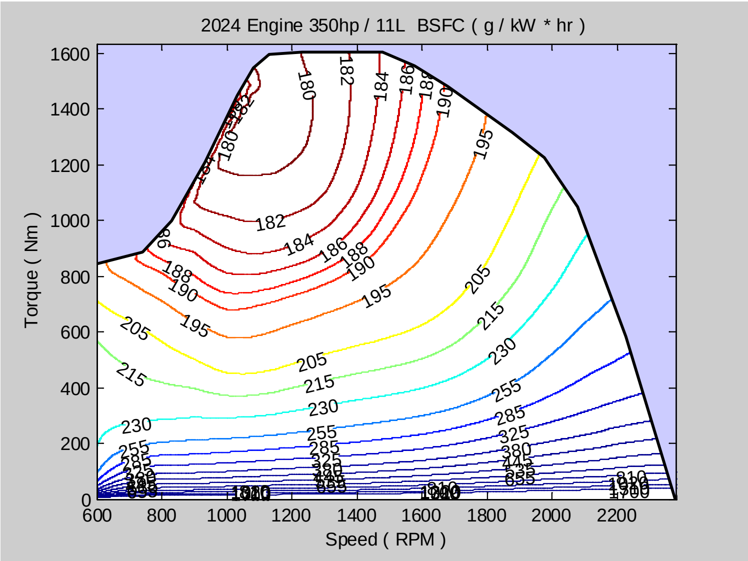


Figure 2-46 2024 Vocational Engine Fuel Map with 350hp Rating

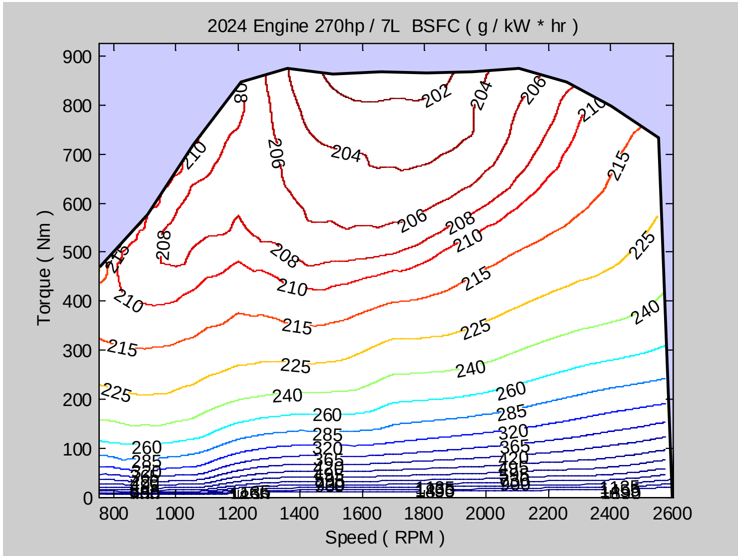


Figure 2-47 2024 Vocational Engine Fuel Map with 270hp Rating

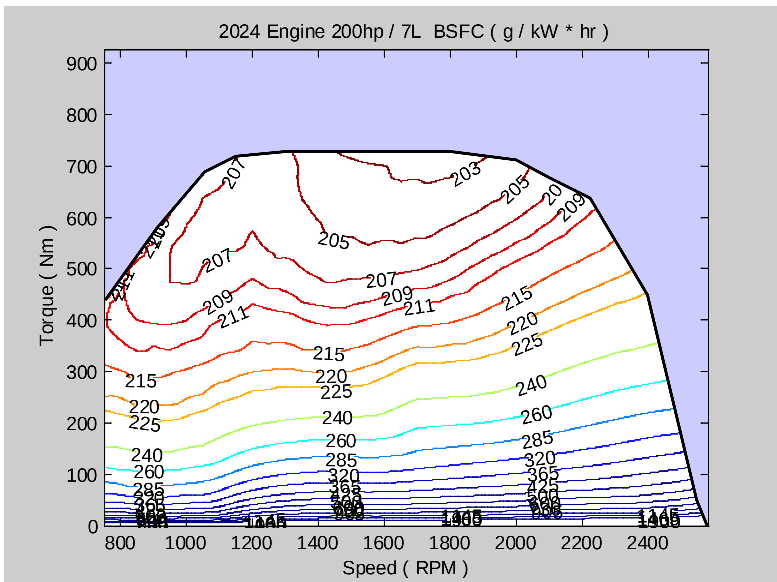


Figure 2-48 2024 Vocational Engine Fuel Map with 200hp Rating

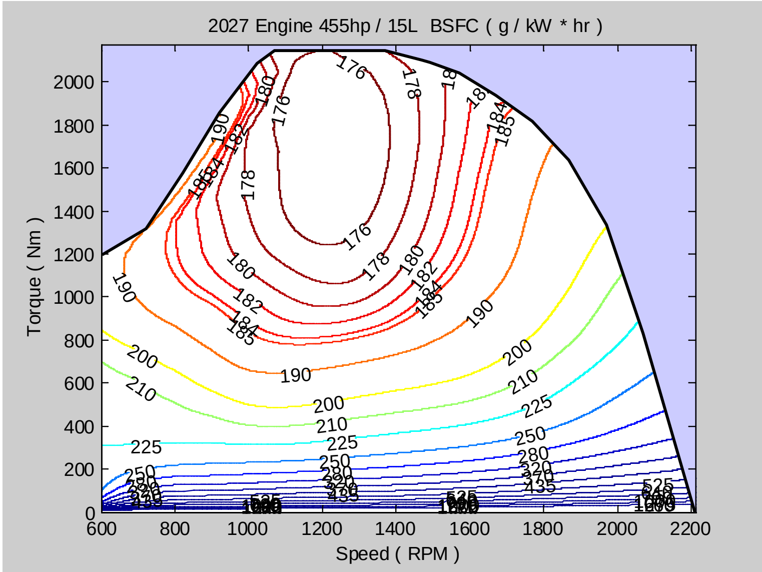


Figure 2-49 2027 Vocational Engine Fuel Map with 455hp Rating

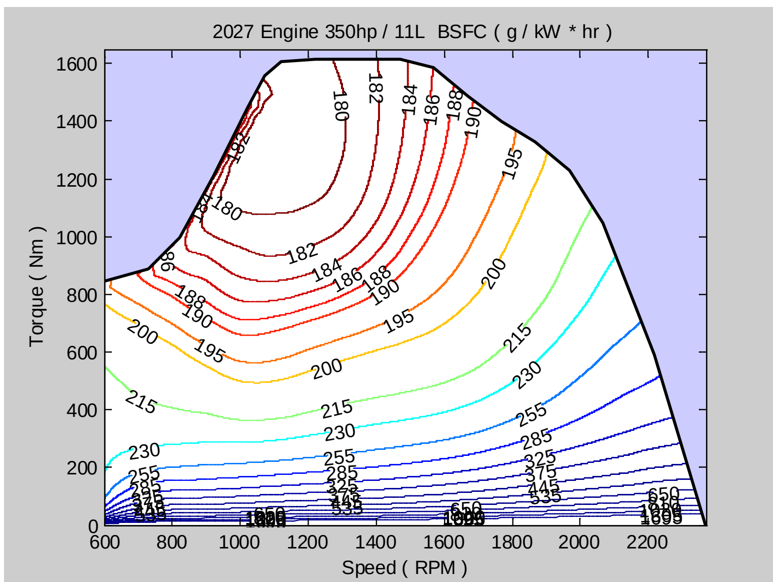


Figure 2-50 2027 Vocational Engine Fuel Map with 350hp Rating

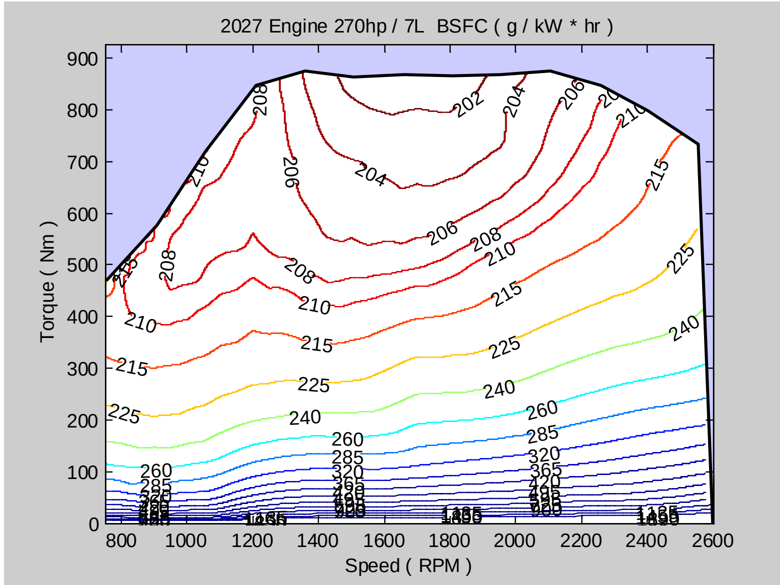


Figure 2-51 2027 Vocational Engine Fuel Map with 270hp Rating

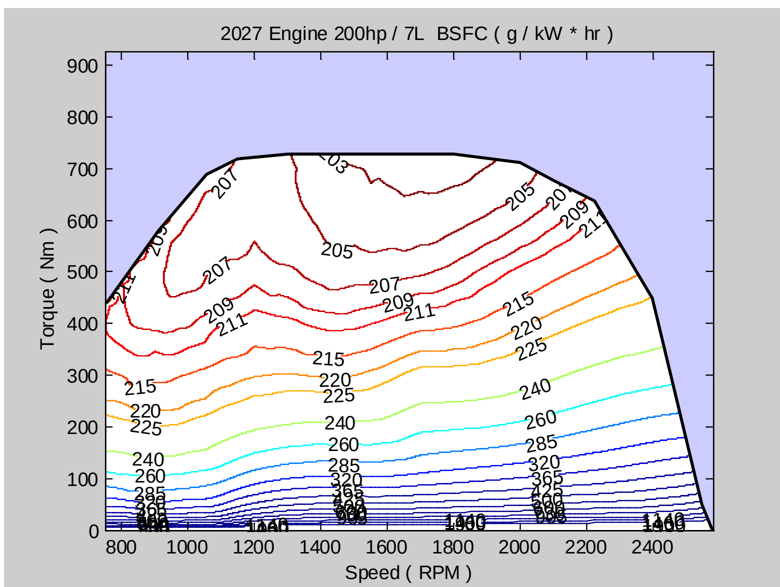


Figure 2-52 2027 Vocational Engine Fuel Map with 200hp Rating

2.9.2 Defining Baseline Vocational Vehicles

As at proposal, the agencies are subcategorizing the vocational vehicle sector by use of three gross vehicle weight classes and three distinct test cycles. Also as proposed, these duty cycles are termed Regional, Multipurpose, and Urban. However, the agencies have made significant changes to these duty cycles as well as changes to the specifications of vehicles that are considered as part of the baseline for each of these subcategories. For the establishment of three duty cycle-based subcategories, the agencies are relying on work conducted by the U.S. Department of Energy at the National Renewable Energy Laboratory (NREL) that grouped vehicles with similarities of key driving statistics into three clusters of operation. NREL's methodology and findings are described in a report in the docket for this rulemaking.[148]

For development and refinement of the certification test cycles, the agencies have considered NREL's work as well as public comment and engineering judgment. Details on how the agencies established weightings of the different test cycles for each subcategory are presented in the RIA Chapter 3.4.3. Figure 2-53 illustrates vehicles in NREL's fleet DNA database plotted according to similarities in their driving statistics. In this image, the two clusters identified in a prior exercise are joined by a middle cluster that contains vehicle traces that do not clearly fall into either the left (slower) or right (faster) cluster. Each point represents one day of driving in the entire data set. Points are colored according to their optimized cluster placement.

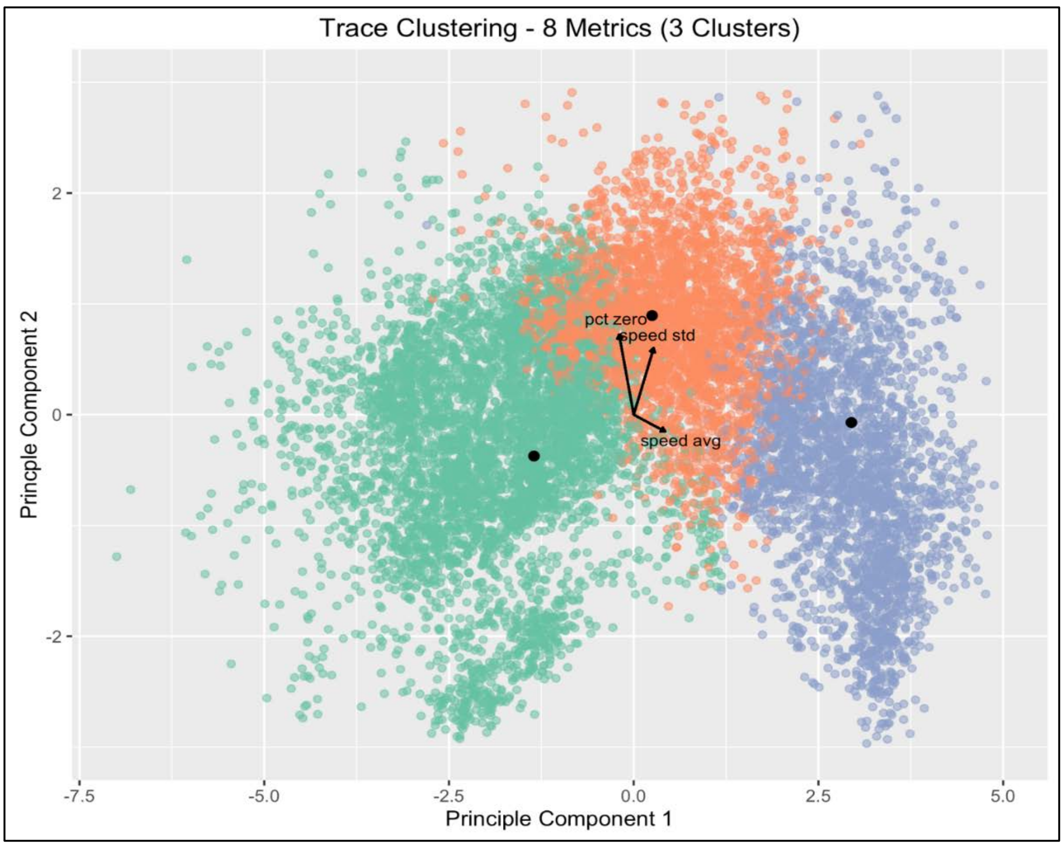


Figure 2-53 Three operational clusters observed by NREL

Consistent with the number of Phase 2 subcategories, nine baseline vocational vehicle configurations have been developed for those powered by CI engines, plus six configurations for vocational vehicle powered by SI engines, plus seven custom chassis baseline configurations. Vocational vehicle attributes set by the agencies in both the baseline and in the executable version of the GEM include: transmission gear efficiencies, transmission inertia, engine inertia, axle efficiency, number of axles, axle inertia, axle efficiency, electrical and mechanical accessory power demand, vehicle mass and payload, and aerodynamic cross-section and drag coefficient. Other vehicle attributes that are available as user inputs for compliance purposes and for which we have established baseline values include: engine power and displacement (and multi-point fuel map), axle ratio, transmission type and gear ratios, and tire revs/mile.

In each of our defined baseline configurations, the agencies have not applied any vehicle-level fuel saving or emission reduction technology beyond what is required to meet the Phase 1 standards. NHTSA and EPA reviewed available information regarding the likelihood that manufacturers of vocational vehicles would apply technology beyond what is required for Phase 1, and we concluded that the best approach was to analyze a reference case that maintains technology performance at the Phase 1 level. Thus, the GEM-simulated baseline vocational vehicle configurations as well as the programmatic vocational vehicle reference case analyzed in this rule represent what is referred to as a nominally flat baseline.

Tables 4-8, 4-9, and 4-10 in the RIA Chapter 4 present the non-user-adjustable modeling parameters for HHD, MHD and LHD vocational vehicles, respectively. In addition to those parameters, to completely define the baseline vehicles, the agencies also selected parameters shown in Table 2-55 to Table 2-61. These attributes and parameters were selected to represent a range of performance across this diverse segment, and are intended to represent a reasonable range of vocational chassis configurations likely to be manufactured in the implementation years of the Phase 2 program. The tire sizes and axle ratios were selected based on market research of publically available manufacturer product specifications, as well as some manufacturer-supplied information about configurations sold in prior model years. The transmission gear ratios were selected based on the transmissions for which models have been validated in GEM, plus public comments from transmission suppliers. We received public comments from Allison recommending close transmission gear ratios for use in coach and transit buses, which we have programmed as the default GEM transmission for these custom chassis. Considering all of the above information, the agencies have significantly better defined vocational baselines than at proposal. A summary of information on which we based these baselines is available in the docket.[149] In general, the trend is that vehicles with higher final drive ratios have been selected for the subcategories with less weighting of the highway test cycles.

Table 2-55 Heavy Heavy-Duty Diesel Modeling Parameters for Vocational Vehicle Baseline

GEM PARAMETER	REGIONAL (95%)	REGIONAL (5%)	MULTI-PURPOSE (80%)	MULTI-PURPOSE (10%)	MULTI-PURPOSE (10%)	URBAN
CI Engine	2018 MY 15L 455hp Engine	2018 MY 11L 350 hp engine	2018 MY 11L 350 hp Engine	2018 MY 15L 455hp Engine	2018 MY 11L 350 hp Engine	2018 MY 11L 350 hp Engine
Transmission Type	10-speed MT	6-speed AT	6-speed AT	10-speed MT	10-speed MT	5-speed AT
Transmission Gears	12.8, 9.25, 6.76, 4.9, 3.58, 2.61, 1.89, 1.38, 1.0, 0.73	3.51, 1.91, 1.43, 1.0, 0.74, 0.64	4.6957, 2.213, 1.5291, 1.0, 0.7643, 0.6716	12.8, 9.25, 6.76, 4.9, 3.58, 2.61, 1.89, 1.38, 1.0, 0.73	12.8, 9.25, 6.76, 4.9, 3.58, 2.61, 1.89, 1.38, 1.0, 0.73	4.6957, 2.213, 1.5291, 1.0, 0.7643
Torque converter lockup gear	3	3	3	3	3	3
Drive Axle Gear Ratio	3.76	3.8	4.33	4.33	4.33	5.29
Axle Configuration	6x4	6x4	6x4	6x4	6x4	6x4
Tire Revs/mile	496	515	496	496	496	496
Steer Tires (CRR kg/metric ton)	7.7	7.7	7.7	7.7	7.7	7.7
Drive Tires (CRR kg/metric ton)	7.7	7.7	7.7	7.7	7.7	7.7
Electrified Accessories	0	0	0	0	0	0
Tire Pressure System	0	0	0	0	0	0
Idle Reduction	N	N	N	N	N	N
Weight Reduction (lb)	0	0	0	0	0	0

Table 2-56 Vocational MHD SI Baseline Modeling Parameters

GEM PARAMETER	REGIONAL	MULTI-PURPOSE	URBAN
SI Engine	2018 MY 6.8L, 300 hp engine		
Transmission Type	6-speed AT	6-speed AT	5-speed AT
Transmission Gears	3.102, 1.8107, 1.4063, 1.0, 0.7117, 0.61		3.102, 1.8107, 1.4063, 1.0, 0.7117
Transmission efficiency	GEM Default		
Torque converter lockup gear	3	3	3
Axle efficiency	GEM Default		
Drive Axle Gear Ratio	5.5	5.1	5.1
Axle Configuration	4x2	4x2	4x2
Idle Reduction	No		
Tire Revs/mile	517	557	557
Steer Tires (CRR kg/metric ton)	7.7	7.7	7.7
Drive Tires (CRR kg/metric ton)	7.7	7.7	7.7
Aerodynamic Improvement	0	0	0
Electrified Accessories	0	0	0
Tire Pressure System	0	0	0
PTO Improvement	0	0	0
Weight Reduction (lb)	0	0	0

Table 2-57 Vocational MHD Diesel Baseline Modeling Parameters

GEM PARAMETER	REGIONAL	MULTI-PURPOSE	URBAN
CI Engine	2018 MY 7L, 270 hp Engine		
Transmission Type	6-speed AT	6-speed AT	5-speed AT
Transmission Gears	3.102, 1.8107, 1.4063, 1.0, 0.7117, 0.61		3.102, 1.8107, 1.4063, 1.0, 0.7117
Transmission efficiency	GEM Default		
Torque converter lockup gear	3	3	3
Axle efficiency	GEM Default		
Drive Axle Gear Ratio	5.5	5.29	5.29
Axle Configuration	4x2	4x2	4x2
Idle Reduction	No		
Tire Revs/mile	517	557	557
Steer Tires (CRR kg/metric ton)	7.7	7.7	7.7
Drive Tires (CRR kg/metric ton)	7.7	7.7	7.7
Aerodynamic Improvement	0	0	0
Electrified Accessories	0	0	0
Tire Pressure System	0	0	0
PTO Improvement	0	0	0
Weight Reduction (lb)	0	0	0

Table 2-58 SI Light Heavy-Duty Modeling Parameters for Vocational Baseline

GEM PARAMETER	REGIONAL	MULTI-PURPOSE	URBAN
SI Engine	2018 MY 6.8L, 300 hp engine		
Transmission Type	6-speed AT	6-speed AT	5-speed AT
Transmission Gears	3.102, 1.8107, 1.4063, 1.0, 0.7117, 0.61		3.102, 1.8107, 1.4063, 1.0, 0.7117
Transmission efficiency	GEM Default		
Torque converter lockup gear	3	3	3
Axle efficiency	GEM Default		
Drive Axle Gear Ratio	4.33	4.88	4.88
Axle Configuration	4x2	4x2	4x2
Idle Reduction	No		
Tire Revs/mile	680	680	660
Steer Tires (CRR kg/metric ton)	7.7	7.7	7.7
Drive Tires (CRR kg/metric ton)	7.7	7.7	7.7
Aerodynamic Improvement	0	0	0
Electrified Accessories	0	0	0
Tire Pressure System	0	0	0
PTO Improvement	0	0	0
Weight Reduction (lb)	0	0	0

Table 2-59 Vocational LHD Diesel Baseline Modeling Parameters

GEM PARAMETER	REGIONAL	MULTI-PURPOSE	URBAN
CI Engine	2018 MY 7L, 200 hp Engine		
Transmission Type	6-speed AT	6-speed AT	5-speed AT
Transmission Gears	3.102, 1.8107, 1.4063, 1.0, 0.7117, 0.61		3.102, 1.8107, 1.4063, 1.0, 0.7117
Torque converter lockup gear	3	3	3
Drive Axle Gear Ratio	4.33	4.56	4.56
Axle Configuration	4x2	4x2	4x2
Idle Reduction	No		
Tire Revs/mile	670	670	660
Steer Tires (CRR kg/metric ton)	7.7	7.7	7.7
Drive Tires (CRR kg/metric ton)	7.7	7.7	7.7
Aerodynamic Improvement	0	0	0
Electrified Accessories	0	0	0
Tire Pressure System	0	0	0
PTO Improvement	0	0	0
Weight Reduction (lb)	0	0	0

The final baseline configurations for buses shown in Table 2-60 reflect comments from Allison about close ratio transmission gear spreads that are common for these applications. The transmission gear ratios for the other three types of HHD custom chassis use the same transmission as in the HHD Urban primary subcategory. The final baseline configurations for motor homes and school buses shown in Table 2-61 are identical to the respective baseline configurations for MHD Regional and MHD Urban vehicles in the primary program.

Table 2-60 Custom Chassis HHD Baseline Modeling Parameters

GEM Parameter	Coach Bus (Regional)	Refuse, Mixer, Emergency (Urban)	Transit (urban)
CI Engine	2018 MY 11L, 350 hp Engine		
Transmission Type	6-speed AT	5-speed AT	5-speed AT
Transmission Gears	3.51, 1.91, 1.43, 1.0, 0.74, 0.64	4.69, 2.213, 1.5291, 1.0, 0.7643	3.51, 1.91, 1.43, 1.0, 0.74
Torque converter lockup gear	3	3	3
Drive Axle Gear Ratio	4.33	5.29	5.29
Axle Configuration	6x2	6x4	4x2
Idle Reduction	No	No	No
Tire Revs/mile	496	496	517
Steer Tires (CRR kg/metric ton)	7.7	7.7	7.7
Drive Tires (CRR kg/metric ton)	7.7	7.7	7.7
Aerodynamic Improvement	0	0	0
Electrified Accessories	0	0	0
Tire Pressure System	0	0	0
PTO Improvement	0	0	0
Weight Reduction (lb)	0	0	0

Table 2-61 Custom Chassis MHD Baseline Modeling Parameters

GEM Parameter	Motor Homes (Regional)	School Bus (Urban)
CI Engine	2018 MY 7L, 270 hp Engine	
Transmission Type	6-speed AT	5-speed AT
Transmission Gears	3.102, 1.8107, 1.4063, 1.0, 0.7117, 0.61	3.102, 1.8107, 1.4063, 1.0, 0.7117
Torque converter lockup gear	3	3
Drive Axle Gear Ratio	5.5	5.29
Axle Configuration	4x2	4x2
Idle Reduction	No	No
Tire Revs/mile	517	557
Steer Tires (CRR kg/metric ton)	7.7	7.7
Drive Tires (CRR kg/metric ton)	7.7	7.7
Aerodynamic Improvement	0	0
Electrified Accessories	0	0
Tire Pressure System	0	0
PTO Improvement	0	0
Weight Reduction (lb)	0	0

2.9.2.1 Setting Vocational Vehicle Baselines

The baseline performance of vocational vehicles powered by CI engines as described above is shown in Table 2-62.

Table 2-62 Baseline Vocational Vehicle Performance with CI Engines

BASELINE EMISSIONS PERFORMANCE IN CO_2 GRAM/TON-MILE			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	482	332	338
Multi-Purpose	420	294	287
Regional	334	249	220
Baseline Fuel Efficiency Performance in gallon per 1,000 ton-mile			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	47.3477	32.6130	33.2024
Multi-Purpose	41.2574	28.8802	28.1925
Regional	32.8094	24.4597	21.6110

The baseline performance of vocational vehicles powered by SI engines as described above is shown in Table 2-63.

Table 2-63 Baseline Vocational Vehicle Performance with SI Engines

BASELINE EMISSIONS PERFORMANCE IN CO_2 GRAM/TON-MILE		
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7 (and C8 Gasoline)
Urban	502	354
Multi-Purpose	441	314
Regional	357	275
Baseline Fuel Efficiency Performance in gallon per 1,000 ton-mile		
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7 (and C8 Gasoline)
Urban	56.4870	39.8335
Multi-Purpose	49.6230	35.3325
Regional	40.1710	30.9441

The baseline performance of the custom chassis configurations described above is shown in Table 2-64.

Table 2-64 Baseline Performance of Custom Chassis

VEHICLE TYPE	EPA	NHTSA
Coach Bus	231	22.6916
Motor Home	249	24.4597
School Bus	332	32.6130
Transit	332	32.6130
Refuse	338	33.2024
Mixer	338	33.2024
Emergency	338	33.2024

2.9.2.2 Assigning Vocational Vehicles to Subcategories

In the NPRM, the agencies proposed criteria by which a vehicle manufacturer would know in which vocational subcategory – Regional, Urban, or Multipurpose – the vehicle should be certified. These cut-points were defined using calculations relating engine speed to vehicle speed. Specifically, we proposed a cutpoint for the Urban duty cycle where a vehicle at 55 mph would have an engine working above 90 percent of maximum engine test speed for vocational vehicles powered by diesel engines and above 50 percent for vocational vehicles powered by gasoline engines. Similarly we proposed a cutpoint for the Regional duty cycle where a vehicle at 65 mph would have an engine working below 75 percent of maximum engine test speed for vocational vehicles powered by diesel engines and below 45 percent for vocational vehicles powered by gasoline engines. We received several comments that identified weaknesses in that approach. Specifically, Allison explained that vehicles with two shift schedules would need clarification which top gear to use when calculating the applicable cut-point. Also, Daimler noted that, to the extent that downspeeding occurs in this sector over the next decade or more, cutpoints based on today's fleet may not be valid for a future fleet. Allison noted that the presence of additional top gears could strongly influence the subcategory placement of vocational vehicles. These comments highlight the possibility of misclassification, and the potential pitfalls in a mandated classification scheme. Furthermore, the agencies are concerned that even if cutpoints were set that were viewed as valid in future years, manufacturers would be able to satisfy the criteria to qualify for the regional subcategory by modifying driveline designs slightly while maintaining customer satisfaction.

In a regulatory structure where standards for vehicles in different subcategories have different stringencies, the agencies are inclined to prefer assigning subcategorization based on regulatory criteria rather than allowing the manufacturers unconstrained choice. The approach to setting of the final standards is explained in Preamble Section V.C.2.d. Below in Table 2-65 we present our estimate of the distribution of vocational vehicles we predict will be certified in each subcategory, as used only for estimating overall programmatic costs and benefits, not as part of standard-setting. This estimate includes refined population distributions by weight class that have been adjusted in part in response to comments on the draft NREL report in the NODA as well as new analysis of telematics data from Ryder lease vehicles.

Table 2-65 Vocational Vehicle Types and Population Allocation

VEHICLE TYPE	REGIONAL	MULTI-PURPOSE	URBAN
C4-5 Short Haul Straight Truck	9%	41%	50%
C6-7 Short Haul Straight Truck	15%	50%	35%
C8 Short Haul Straight Truck	20%	60%	20%
Long Haul Straight Truck, Motor Home, Intercity Bus	100%	0%	0%
School Bus	0%	10%	90%
Transit Bus	0%	0%	100%
Refuse	0%	10%	90%
All Class 4-5	11%	15%	18%
All Class 6-7	10%	11%	16%
All Class 8	5%	8%	6%

2.9.3 Costs and Effectiveness of Vocational Vehicle Technologies

The following paragraphs describe the vehicle-level technologies on which the vocational vehicle standards are predicated, and their projected effectiveness over the test cycles. The methodology for estimating costs, including indirect cost estimates and learning effects, is described in RIA Chapter 2.11.1. Certain elements of the cost estimating methodology are the same as for the Phase 1 program, but certain elements are different including how the agencies apply the markups, how the markups change with time, and which cost elements are influenced by learning effects. As a result of different technology complexities, learning effects, and different short-term and long-term warranty and non-warranty-related indirect costs, some technology costs identified below may appear higher in MY 2021 than in MY 2027. These differences are not due to changes in adoption rates, since the costs in Chapter 2.11 and below in Chapter 2.9.3 to 2.9.4 are for applying a given technology to a single vehicle. Throughout this chapter, where a dollar cost is given for a technology, note that these are adjusted to be valued as year 2013 dollars. Average costs for vocational vehicle technology packages, including adoption rates, are presented below in Chapter 2.9.5. Detailed descriptions of technology packages for SI engines can be found in the RIA Chapter 2.6. Detailed descriptions of technology packages and costs for CI engines can be found in the RIA Chapter 2.7.

2.9.3.1 Transmissions

Transmission improvements present a significant opportunity for reducing fuel consumption and CO_2 emissions from vocational vehicles. Transmission efficiency is important for many vocational vehicles as their duty cycles involve high percentages of driving under transient operation. The types of transmission improvements the agencies considered for Phase 2 are advanced shift strategy, gear efficiency, torque converter lockup, architectural improvements, and hybrid powertrain systems.

Of the technologies described above in Chapter 2.4, the agencies are predicating the vocational vehicle standards in part on performance improvements achieved by use of advanced transmissions as described in Table 2-66, below. The projected market adoption rates that inform the technology packages are described in Chapter 2.9.5.

Table 2-66 Projected Vocational Transmission Improvements over GEM Baseline

TRANSMISSION TECHNOLOGY	PROJECTED IMPROVEMENT OVER TEST CYCLE[a]		REGIONAL COMPOSITE CYCLE	MULTI-PURPOSE COMPOSITE CYCLE	URBAN COMPOSITE CYCLE
Two More Gears	ARB Transient	1.0%	1.7	1.2	0.9
	55 mph Cruise	2.0%			
	65 mph Cruise	2.0%			
Torque Converter Lockup in 1st Gear (vs 3rd)	ARB Transient	1-5%	0.7 to 0.9	0.9 to 2.2	0.8 to 3.2
	55 mph Cruise	0%			
	65 mph Cruise	0%			
Non-Integrated Mild Hybrid	ARB Transient	14%	3	8	11-12
	55 mph Cruise	0%			
	65 mph Cruise	0%			
Integrated Mild Hybrid with Stop-Start	ARB Transient	23-26%	4-5	14-19	19-25
	55 mph Cruise	0%			
	65 mph Cruise	0%			
Advanced Shift Strategy	ARB Transient	7%	3	4-5	5-6
	55 mph Cruise	2%			
	65 mph Cruise	2%			

Note:
[a] Technology improvements modeled in GEM are TC lockup and gear number. Hybrids and shift strategy require separate testing.

2.9.3.1.1 Advanced Shift Strategy

The technology we described at proposal as driveline integration, 80 FR 40296, is now defined as use of an advanced shift strategy. At proposal the agencies included shift strategy, aggressive torque converter lockup, and a high efficiency gearbox among the technologies defined as driveline integration that would only be recognized by use of powertrain testing. The agencies continue to believe that an effective way to derive efficiency improvements from a transmission is by optimizing it with the engine and other driveline components to balance both performance needs and fuel savings. One example of an engine manufacturer partnering with a transmission manufacturer to achieve an optimized driveline is the SmartAdvantage powertrain.[150] Using engineering calculations to estimate the benefits that can be demonstrated over the powertrain test, the agencies project that transmission shift strategies, including those that make use of enhanced communication between engine and driveline, can yield efficiency improvements ranging from three percent for Regional vehicles to nearly six percent for Urban vehicles. The calculation is an energy-weighted and cycle-weighted average improvement using cycle-specific CO_2 emissions reported in the GEM output file for baseline vehicles. For the idle cycles, the development version of GEM provides emissions in grams per hour. For the driving cycles, GEM provides emissions in grams per ton-mile. By multiplying those values by the average speed of each cycle and the default payload, all values are converted to grams per hour, and these are surrogates for the energy expended over those cycles. For example, in the medium heavy-duty Multipurpose subcategory with a payload of 5.6 tons, the baseline vehicle configuration has cycle-specific results of 28,000 g CO_2/hr for the transient cycle, 59,000 for the

55 cycle, 85,000 for the 65 cycle, 8,500 for drive idle, and 3,700 for parked idle. By summing the products of the percent improvement expected over each cycle, the CO_2 emitted while completing the cycle, and the associated composite weighting of the cycle, and dividing by the sum of the products of the CO_2 emitted and cycle weightings, we obtain results shown in Table 2-66. See the RIA Chapter 3.6 for a discussion of the powertrain test procedure.

The agencies have revised the GEM simulation tool to recognize additional transmission technologies beyond what was possible at proposal. We are adopting a transmission efficiency test to recognize improved mechanical gear efficiency and reduced transmission friction, where the test results can be submitted as GEM inputs to override the default efficiency values. The agencies project that vehicle fuel efficiency can be improved by up to one percent from improved transmission gear efficiency, which we are projecting to be the same during each of the driving cycles and (necessarily) zero while idling. Actual test results are likely to show that some gears have more room for improvement than others, especially where a direct drive gear is already highly efficient. Using the energy-weighted calculation method described above, the transmission gear efficiency improvement used in our stringency calculations ranges from 0.82 to 0.97 percent. Final GEM also accepts an input field for torque converter lockup gear. As a default, GEM simulates automatic transmissions using lockup in third gear. Using the library of agency transmission files, GEM gives a different effectiveness value in every vocational vehicle subcategory, because this is influenced by the gear ratios, drive cycle, and torque converter specifications. Manufacturers will obtain slightly different results with their own driveline specifications. The observed range of cycle-weighted effectiveness of torque converter lockup is from less than one percent to three percent, as shown in Table 2-66 above.

Based on use of a sensor, the agencies estimate the total cost to apply an advanced shift strategy for driveline integration is $87 in MY 2021 and $73 in MY 2027, as described in RIA 2.11.3.7. The agencies have also estimated capital and operational costs associated with building test cells and conducting testing, as well as research and development costs associated with designing shift strategies and integrating drivelines. These costs are presented in the RIA Chapter 7.1.1.2 and 7.1.1.3, respectively. The agencies estimate the total cost to apply a high efficiency gearbox is $315 in MY 2021 and $267 in MY 2027, as described in RIA 2.11.3.5. The agencies estimate the total cost to apply early torque converter lockup to a vocational vehicle at $31 in MY 2021 and $26 in MY 2027, as described in RIA 2.11.3.6.

2.9.3.1.2 Architectural Transmission Improvements

One type of architectural improvement the agencies project can reasonably be developed by manufacturers of all transmission architectures is increased number of gears. The benefit of adding more gears varies depending on whether the gears are added in the range where most operation occurs. In some cases additional gears in the low end of the range enhances driving performance without improving fuel efficiency. The TIAX 2009 report projected that 8-speed transmissions could incrementally reduce fuel consumption by 2 to 3 percent over a 6-speed automatic transmission, for Class 3-6 box and bucket trucks, refuse haulers, and transit buses.[151] We have run GEM simulations comparing 5-speed, 6-speed, 7-speed, and 8-speed automatic transmissions where some cases hold the total spread constant, some hold the high end ratio constant, and some hold the low-end ratio constant, where all cases use a third gear lockup and axle ratios are held constant. We have observed mixed results, with some improvements over the highway cruise cycles as high as six percent, and some cases where additional gears increased fuel consumption. As proposed, we are allowing GEM to determine the improvement, where manufacturers will enter the number of gears and gear ratios and the model will simulate the efficiency over the applicable test cycle. The agencies have revised GEM based on comment, and we are confident that it fairly represents the fuel efficiency of transmissions with different gear ratios. Consistent with literature values, we are using engineering calculations to estimate that two extra gears has an effectiveness of one percent improvement during transient driving and two percent improvement during highway driving. Weighting these improvements using our final composite duty cycles (zero improvement at idle) and the energy-weighting method described above, this technology is estimated to improve vocational vehicle efficiency between 0.9 and 1.7 percent. The agencies estimate the total cost to add two gears to a vocational vehicle transmission at $504 in MY 2021 and $465 in MY 2027, as described in RIA 2.11.3.1.

Most vocational vehicles currently use torque converter automatic transmissions (AT), especially in Classes 2b-6. Automatic transmissions offer acceleration benefits over drive cycles with frequent stops, which can enhance productivity. With the diversity of vocational vehicles and drive cycles, other kinds of transmission architectures can meet customer needs, including automated manual transmissions (AMT), dual clutch transmissions (DCT), as well as manual transmissions (MT).[152] As at proposal, dual clutch transmissions may be simulated as AMT's in GEM. A manufacturer may elect to conduct powertrain testing to obtain specific improvements for use of a DCT. The RIA Chapter 4.2.2.3 explains the EPA default shift strategy and the losses associated with each transmission type, and discusses changes that have been made since proposal. Although the representation of transmissions has improved since proposal, the differences between AT and AMT are too difficult to isolate for purposes of figuring them into our stringency calculations. Although we expect manufacturers to have a reasonable model of transmission behavior for certification purposes, we could not estimate relative improvement values between AT and AMT for vocational vehicles using any defensible estimation method. The agencies have not been able to obtain conclusive data that could support a final vocational vehicle standard, in any subcategory, predicated on adoption of an AMT or DCT with a predictable level of improvement over an AT. As a result, the only architectural changes on which the final vocational vehicle standards are based are increasing number of gears and automation compared with a manual transmission. The final Phase 2 GEM has been calibrated to reflect a fixed two percent difference between manual transmissions and automated transmissions during the driving cycles (zero at idle). As in the HHD Regional subcategory baseline, manual transmissions simulated in GEM perform two percent worse than similarly-geared AMT. This fixed improvement is discussed further in RIA Chapter 2.4. The agencies have estimated the cost of upgrading from HHD manual transmissions to AMT at $4,540 in MY 2021 and $3853 in MY 2027, as described in RIA 2.11.3.2.

2.9.3.1.3 Hybrid Drivelines

Hybrid drivelines are included under transmission technologies because, depending on the design and degree of hybridization, they may either replace a conventional transmission or be deeply integrated with a conventional transmission. Further, these systems are often manufactured by companies that also manufacture conventional transmissions.

The agencies are including hybrid powertrains as a technology on which some of the vocational vehicle standards are predicated, in part.

After considering comments, the agencies are projecting adoption of two types of mild hybrids, defined using system parameters based on actual systems commercially available in the market today.[153] Some mild hybrid systems will be integrated with an engine sufficient to enable use of an engine stop-start feature, while some mild hybrids will not be integrated and will only provide transient benefits related to regenerative braking. We also have reconsidered our effectiveness estimation method as a result of comments. Instead of relying on previously published road tests over varying drive cycles, we are applying engineering calculations to account for defined hybrid system capacities and inefficiencies over our certification test cycle. We are using a spreadsheet model that calculates the recovered energy of a hybrid system using road loads of the default baseline GEM vehicles over the ARB Transient test cycle.[154]

The inputs to this spreadsheet model include maximum hybrid system power, battery capacity, allowable swing in the battery state of charge, system efficiencies, as well as vehicle road loads such as tire rolling resistance, vehicle mass and aerodynamic drag area. For stringency purposes, the system inputs used were 75 kW motor, 8 kWh battery, and 10 percent swing in SOC. The system efficiencies included 90 percent, 90 percent, 90 percent, 92 percent and 85 percent, for the battery, power electronics, electric motor, axle and transmission, respectively. The vehicle road loads were identical to those in the baseline GEM vehicle configurations. Within the system constraints the algorithm stores and releases the available kinetic energy from the vehicle without any information of engine efficiency through the cycle. The calculations also take into account the energy that is needed to drive the accessories through the drivetrain when the vehicle is decelerating. The algorithm is iterative, and the calculations continue until the battery net energy change is at a value less than one percent of the total fuel energy which is approximated by 3 times the total tractive work of the cycle.

One simplification in the spreadsheet model is that the effectiveness is assumed to be zero for the highway cruise cycles. In the real world there are driving conditions on highways that may present opportunities to capture and re-use energy, including conditions related to road grade and congestion. However, for this simplified method we are not counting the benefits of systems that make use of such opportunities. We are not projecting substantially less effectiveness for heavier vehicles than for lighter vehicles, even though the same systems were assessed for all weight classes (not scaled up for heavier vehicles). This is due in part to the assumptions about the fraction of brake energy that enters the hybrid system vs the fraction that goes entirely to friction braking.

Using this spreadsheet model and system inputs described above, for the non-integrated mild hybrids, we are estimating a one to 12 percent fuel efficiency improvement over the powertrain test, depending on the duty cycle (i.e. Regional, Urban, or Multi-purpose) in GEM for the applicable subcategory. For the integrated mild hybrids, we have projected that the systems are scaled up for heavier vehicles, and we have combined the effectiveness calculated using the hybrid spreadsheet model with the GEM effectiveness of stop-start, described below. These combined effectiveness values range from four to 25 percent for the mild hybrids with stop-start. Even though the actual improvement from hybrids in Phase 2 will be evaluated using the powertrain test, because the model uses the same vehicle test cycle and conservative estimates of realistic configurations, the agencies have concluded it is reasonable to use these spreadsheet-based estimates as a basis for setting stringency in the final rules.

The industry is currently developing many variations of hybrid powertrain systems. There are a few hybrid systems in the heavy-duty market today and several more under development, as evidenced by several public comments on this rulemaking. See also Chapter 6.3.3 of the Response to Comments document. In addition, energy storage systems are getting better.[155] Heavy-duty customers are getting used to these systems with the number of demonstration products on the road. A list of hybrid manufacturers and their products intended for the vocational market is provided in Table 2-67.

Table 2-67 Examples of Hybrid Manufacturers

MANUFACTURER	PRODUCT	EXAMPLE APPLICATION
Hino	Class 5 cab-over-engine battery-electric hybrid	Delivery Trucks
Allison	HHD parallel hybrid	Transit Bus
BAE	HHD series or parallel hybrid	Transit Bus
XL	Class 3-4 mild electric hybrid	Shuttle Bus
Crosspoint Kinetics	Class 3-7 mild electric hybrid	Delivery trucks, shuttle buses
Lightning Hybrids	Class 2-5 hydraulic hybrid	Delivery trucks
Parker Hannifin	MHD hydraulic hybrid	Delivery trucks
Freightliner Custom Chassis	MHD hydraulic hybrid	Delivery trucks
Morgan Olson	MHD hydraulic hybrid	Delivery trucks
Autocar-Parker	Runwise hydraulic hybrid	Refuse Trucks
Eaton[a]	HHD parallel electric hybrid	Trucks and Buses
Odyne	Plug-in electric hybrid, E-PTO	Utility Trucks

Note:
[a] Currently selling in markets outside the U.S.

The agencies estimate the total cost of a bolt-on, non-integrated mild hybrid system for any size vocational vehicle at $8,906 in MY 2021 and $6,906 in MY 2027. The agencies estimate the total cost of an integrated mild hybrid system with stop-start for a LHD vocational vehicle is $6,320 in MY 2021 and $5,082 in MY 2027. For a MHD vocational vehicle, the total cost of an integrated system is estimated at $9,934 in MY 2021 and $7,989 in MY 2027. For a HHD vocational vehicle, the total cost of an integrated system is estimated at $16,590 in MY 2021 and $13,341 in MY 2027, as described in RIA 2.11.7. The estimated higher costs for heavier vehicles are related to higher power demands and greater energy storage needs. These estimates assume no engine downsizing in the design of hybrid packages. This is in part to be conservative in our cost estimates, and in part because in some applications a smaller engine may not be acceptable if it would risk that performance could be sacrificed during some portion of a work day.

2.9.3.2 Axles

The agencies are predicating part of the stringency of the final vocational vehicle standards on performance of two types of axle technologies. The first is advanced low friction axle lubricants and efficiency as demonstrated using the separate axle test procedure described in the RIA Chapter 3.8 and 40 CFR 1037.560. The agencies received many adverse comments on the proposal to assign a fixed 0.5 percent improvement for this technology. In consideration of comments, the agencies are assigning default axle efficiencies to all vocational vehicles. Manufacturers may submit test data to over-ride these default axle efficiency values in GEM. Based on comments from axle suppliers as well as other available data, we project the effectiveness of technologies to improve axle efficiency can achieve between two and three percent improvement.[156] Our cost analysis for the final rulemaking includes maintenance costs of replacing axle lubricants on a periodic basis. Based on supplier information, some advanced lubricants have a longer drain interval than traditional lubricants. We are estimating the axle efficiency & lubricating costs for HHD to be the same as for HHD tractors since those vehicles likewise typically have three axles. For HHD vocational vehicles (with 3 axles), the agencies estimate the cost at $200 in MY 2021 and $174 in MY 2027, as described in RIA 2.11.5.4. However, for LHD and MHD vocational vehicles, we scaled down the cost of this technology to reflect the presence of a single rear axle. The agencies estimate the total cost of improved axle efficiency on a LHD or MHD vocational vehicle (with 2 axles) at $134 in MY 2021 and $116 in MY 2027.

The second axle technology applies only for HHD vocational vehicles, which typically are built with two rear axles. Part time 6x2 configuration or axle disconnect is a design that enables one of the rear axles to temporarily disconnect or otherwise behave as if it's a non-driven axle. The agencies proposed to base the HHD vocational vehicle standard on some use of both part time and full time 6x2 axles. The agencies received compelling adverse comment on the application of the permanent 6x2 configuration for vocational vehicles, and in response we are not basing the final vocational vehicle standards on any adoption of full time 6x2 axles. The disconnect configuration is one that keeps both drive axles engaged only during some types of vehicle operation, such as when operating at construction sites or in transient driving where traction especially for acceleration is vital. Instead of calculating a fixed improvement as at proposal, the agencies have refined GEM to recognize this configuration as an input, and the benefit will be actively simulated over the applicable drive cycle. Effectiveness based on simulations with EPA axle files is projected to be as much as 1.2 percent for HHD Regional vehicles. Further information about this technology is provided in RIA Chapter 2.4.

The agencies estimate the total cost of part time 6x2 on a vocational vehicle at $121 in MY 2021 and $117 in MY 2027, as described in RIA 2.11.5.2.

2.9.3.3 Lower Rolling Resistance Tires

Tires are the second largest contributor to energy losses of vocational vehicles, as found in the energy audit conducted by Argonne National Lab.[157] The two most helpful sources of data in establishing the projected vocational vehicle tire rolling resistance levels for the final Phase 2 standards are the comments from RMA and actual certification data for model year 2014. At proposal, we projected that all vocational vehicle subcategories could achieve average steer tire coefficient of rolling resistance (CRR) of 6.4 kg/ton and drive tire CRR of 7.0 kg/ton by MY 2027. These new data have informed our analysis to enable us to differentiate the technology projections by subcategory. The RMA comments included CRR values for a wide range of vocational vehicle tires, for rim sizes from 17.5 inches to 24.5 inches, for steer/all position tires as well as drive tires. The RMA data, while illustrating a range of available tires, are not sales weighted. The 2014 certification data include actual production volumes for each vehicle type, thus both steer and drive tire population-weighted data are available for emergency vehicles, cement mixers, school buses, motor homes, coach buses, transit buses, and other chassis cabs. The certification data are consistent with the RMA assessment of the range of tire CRR currently available. We also agree with RMA's suggestion to set a future CRR level where a certain percent of current products can meet future GEM targets. We disagree with RMA that the MY 2027 target should be a level that 50 percent of today's product can meet. With programmatic averaging, such a level would mean essentially no improvements overall from tire rolling resistance, because today when manufacturers comply on average, half their tires are above the target and half are below. Further, with Phase 2 GEM requiring many more vehicle inputs than tire CRR, manufacturers have many more degrees of freedom (i.e. other available compliance pathways) to meet the performance standard than they do in Phase 1. In these final rules, the agencies are generally projecting adoption of LRR tires in MY 2027 at levels currently met by 25 to 40 percent of today's vocational products, on a sales-weighted basis.[158] Figure 2-54 and Figure 2-55 present a summary of the CRR levels of tires fitted on vocational vehicles certified in the 2014 model year.

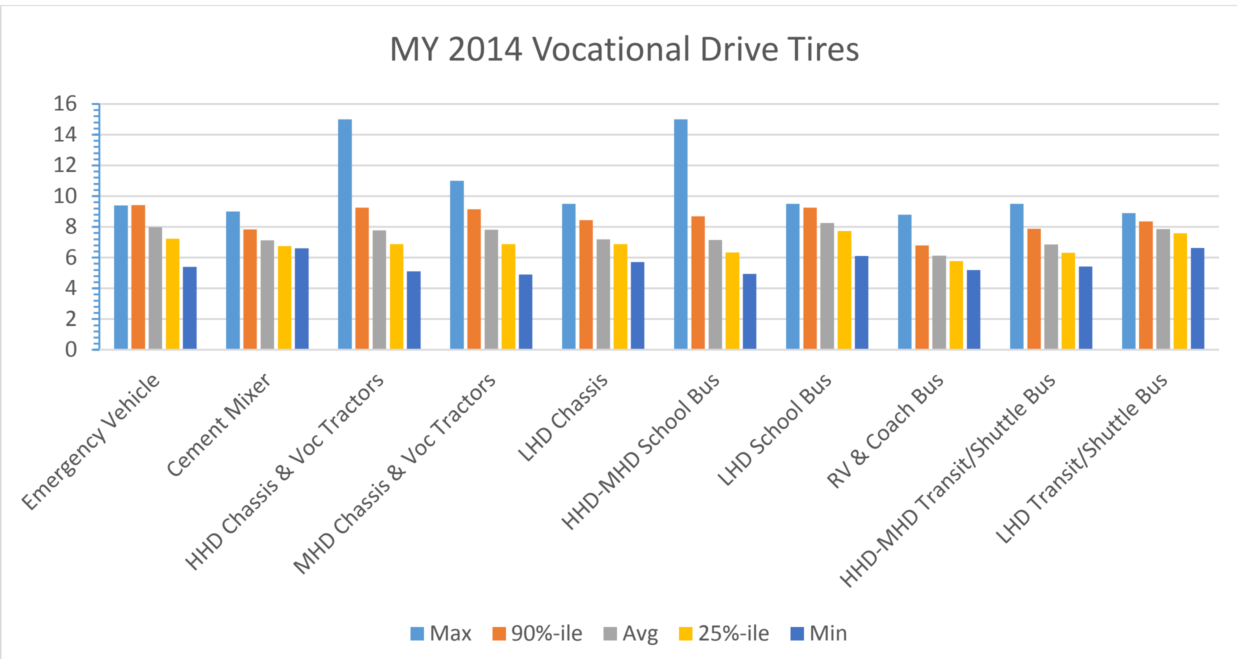


Figure 2-54 Vocational Drive Tire CRR Data Summary

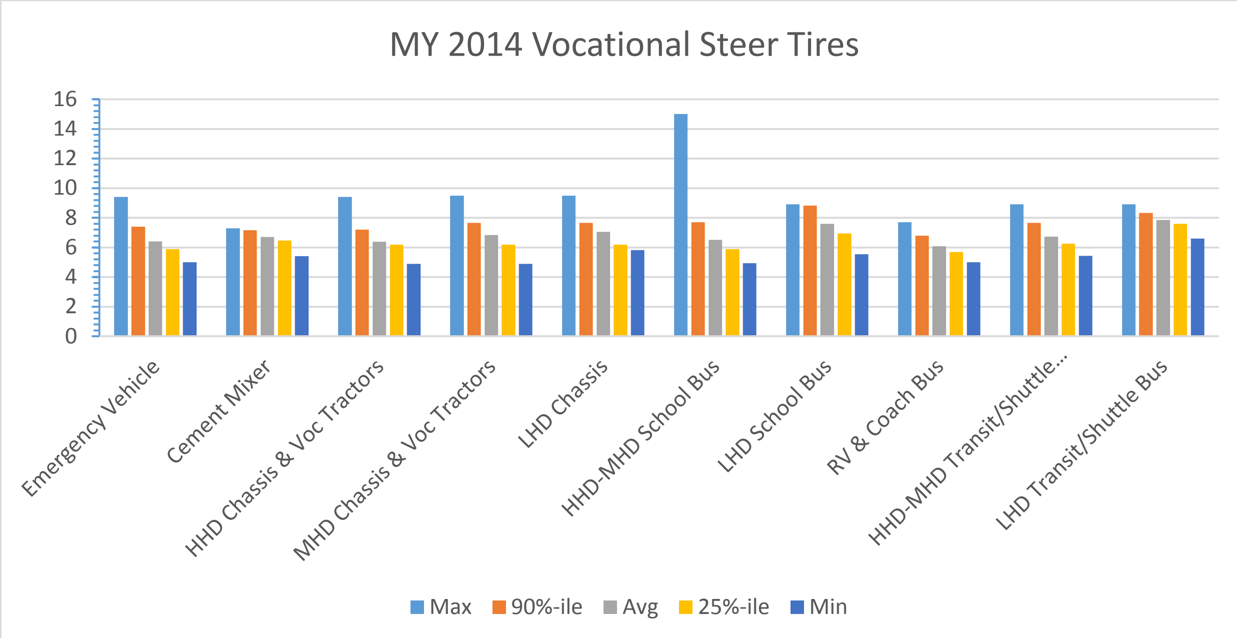


Figure 2-55 Vocational Steer Tire CRR Data Summary

The agencies acknowledge there can be tradeoffs when designing a tire for reduced rolling resistance. These tradeoffs can include characteristics such as wear resistance, cost and scuff resistance. NHTSA, EPA, and ARB met with stakeholders from the tire industry (Bridgestone, Continental, Cooper, Goodyear, and Michelin) to discuss the next generation of lower rolling resistance (LRR) tires for the Phase 2 timeframe for all segments of Class 2b-8 vehicles, including trailers. Manufacturers discussed forecasts for rolling resistance levels and production availability in the Phase 2 timeframe, as well as their plans for improving rolling resistance performance while maintaining other performance parameters such as traction, handling, wear, mass reduction, retreadability, and structural durability.

The meetings included specific discussions of the impacts of the current generation of LRR tires on vehicle stopping distance and handling. Manufacturers indicated no known safety detriment in the current on-road fleet from use of LRR tires. While the next generation of tires may require some tradeoffs in wear performance and costs over the next 10 years to achieve better tire rolling resistance performance, manufacturers said they will not trade off safety for performance. They also emphasized that keeping tires inflated (through proper maintenance or automatic systems) was the best way to assure long term fuel efficiency and safety during vehicle operation.

In these final rules, we are differentiating the improvement level by weight class and duty cycle, recognizing that heavier vehicles designed for highway use can generally apply tires with lower rolling resistance than other vehicle types, and will see a greater benefit during use. In the Preamble at Section V.C.1, Table V-14, the agencies define five levels of CRR for purposes of estimating the manufacturing costs associated with applying improved tire rolling resistance to vocational vehicles. None of the rolling resistance levels projected for adoption in MY 2027 are lower than the 25^{th} percentile of tire CRR on actual vocational vehicles sold in MY 2014. Thus, we believe the improvements will be achievable without need to develop new tires not yet available.

As an example of the total vehicle costs to apply LRR tires, the agencies estimate the total cost to fit a LHD or MHD vocational vehicle with two LRR level 5v steer tires ($57) and four level 3v drive tires ($107) to be $164 in MY 2021. Detailed tables of LRR tire costs in each year are provided in RIA Chapter 2.11.8.

As proposed, the agencies will continue the light truck (LT) tire CRR adjustment factor that was adopted in Phase 1. 80 FR 40299; see generally 76 FR 57172-57174. In Phase 1, the agencies developed this adjustment factor by dividing the overall vocational test average CRR of 7.7 by the LT vocational average CRR of 8.9. This yielded an adjustment factor of 0.87. Because the MY 2014 certification data for LHD vocational vehicles may have included some CRR levels to which this adjustment factor may have already been applied, and because we did not receive adverse comment on our proposal to continue this, the agencies have concluded that we do not have a basis to discontinue allowing the measured CRR values for LT tires to be multiplied by a 0.87 adjustment factor before entering the values in the GEM for compliance.

2.9.3.4 Workday Idle Reduction

The Phase 2 idle reduction technologies considered for vocational vehicles are those that reduce workday idling, unlike the overnight or driver rest period idling of sleeper cab tractors. Idle reduction technology is one type of technology that is particularly duty-cycle dependent. In light of new information, the agencies have learned that our proposal had mischaracterized the idling operation of vocational vehicles, significantly underestimating the extent of this mode of operation, and incorrectly calculating it using a drive idle cycle when significant idling also occurs while parked. As described in Preamble Section V.B.1, in these final rules we have revised our test cycles to better reflect real world idle operation, including both parked idle and drive idle test conditions. The RIA Chapter 3.4.2 describes these certification test cycles.

The Phase 1 composite test cycle for vocational vehicles includes a 42 percent weighting on the ARB Transient test cycle, which comprises nearly 16 percent of idle time. However, no single idle event in this test cycle is longer than 36 seconds, which is not enough time to adequately recognize the benefits of idle reduction technologies.[L] In the Phase 2 proposal, we applied composite test cycle weightings of 10, 20, and 30 percent of a drive idle cycle to the Regional, Multipurpose and Urban duty cycles, respectively. These weightings were an initial estimate because the interagency agreement between EPA and DOE-NREL to collaborate to characterize workday idle among vocational vehicles was not yet complete. As shown in Table 2-68, the average total amount of daily total idle operation per vehicle identified by NREL is 25 percent for vehicles observed in the high speed cluster, 47 percent for vehicles observed in the slow speed cluster, and 52 percent for vehicles straddling those two clusters. This work was shared as part of the NODA and supported by commenters. Although some comments indicated individual fleets log different idle times than those in our test cycles, the final test cycles are

[L] However, as noted above, emission improvements due to workday idle technology can be recognized under Phase 1 as an innovative credit under 40 CFR 1037.610 and 49 CFR 535.7.

representative of the range of operation and adequately capture vocational vehicle idle behavior for purposes of recognizing workday idle reduction technology.

Table 2-68 Summary of Out-of-Gear Idle Behavior

NREL Cluster	Operating Mode	NREL Percent of Workday	Percent Accounted for in Final Transient Cycle	Final Weighting of Parked Idle Cycle	Final Weighting of Drive Idle Cycle	Sum Of All Regulatory Idle Test Weighings
1	Out of Gear Idle	28		25		
1	In Gear (Drive Idle)		10		15	
1	Zero Speed (both in gear and out of gear)	47				50
2	Out of Gear Idle	22		25		
2	In Gear (Drive Idle)		8		17	
2	Zero Speed (both in gear and out of gear)	52				50
3	Out of Gear Idle	25		25		
3	In Gear (Drive Idle)		6		0	
3	Zero Speed (both in gear and out of gear)	25				25

The separate drive idle cycle supplements the drive idle that occurs during the transient cycle. The time fraction of drive idle represented in the transient cycle is a complex iterative equation because that is a distance-based cycle. By setting a total target zero-speed time of 50 percent for Multipurpose and Urban vehicles consistent with the recommendations of NREL, the agencies were able to assign appropriate cycle weightings to the drive idle and parked idle test cycles for each subcategory. In the final rules, the Regional duty cycle has 25 percent composite test cycle weighting of parked idle and zero drive idle. The Multi-purpose cycle has 25 percent of drive and 17 percent parked idle, and the Urban cycle has 15 percent drive idle and 25 percent parked idle. The final cycle weightings are derived from data summarizing miles accumulated within 2 mph speed bins for representative vehicles in each cluster. Details on development of the cycle weightings are found in the RIA Chapter 3.4.3.1 and in the vocational vehicle duty cycle report by NREL, which is available in the docket.[159]

At proposal, we identified two types of idle reduction technologies to reduce workday idle emissions and fuel consumption for vocational vehicles: neutral idle and stop-start. After considering the new duty cycle information and the many comments received, we are basing our final vocational vehicle standards in part on the performance of three types of workday idle reduction technologies: neutral idle, stop-start, and automatic engine shutdown. We believe that these technologies are effective, feasible, and cost-effective, as discussed further in this section.

Neutral idle is essentially a transmission technology, but it also requires a compatible engine calibration. Torque converter automatic transmissions traditionally place a load on engines when a vehicle applies the brake while in drive, which we call curb idle transmission torque (CITT). When an engine is paired with a manual or automated manual transmission, the CITT is naturally lower than when paired with an automatic, as a clutch disengagement must occur for the vehicle to stop without stalling the engine. We did not receive adverse comment on our proposal to include this technology in our standard-setting for vocational vehicles. The engineering required to program sensors to detect the brake position and vehicle speed, and enable a smooth re-engagement when the brake pedal is released makes this a relatively low complexity technology that can be deployed broadly. Navistar commented that idle reduction strategies must have sufficient engine, aftertreatment and occupant protections in place such that any fuel cost savings are a net benefit for the owner/operator without compromising safety. We agree, and for neutral idle we believe an example of an allowable override is if a vehicle is stopped on a hill. Skilled drivers operating manual transmissions can safely engage a forward gear from neutral when stopped on upslopes with minimal roll-back. With an AT, the vehicle's computer would need to handle such situations automatically. In the Phase 2 certification process, transmission suppliers will attest whether the transmission has this feature present and active, and certifying entities will be able to enter Yes or No as a GEM input for the applicable field. The effectiveness of this technology will be calculated using data points collected during the engine test, and the appropriate fueling over the drive idle cycle and the transient cycle will be used. Based on GEM simulations using the final vocational vehicle test cycles, the agencies project neutral idle to provide fuel efficiency improvements ranging from one to seven percent, depending on the regulatory subcategory. Details are in the docket for this rulemaking.[160]

Automatic engine shutdown (AES) is an engine technology that is widely available in the market today, but has seen more adoption in the tractor market than for vocational vehicles. Although we did not propose to include this technology, we received many comments suggesting this would be appropriate. Some commenters may have conflated the concept of stop-start with AES, such as a comment on stop-start asking us to consider the on-board need to power accessories while the vehicle is in stationary mode. We believe that automatic engine shutdown is effective and feasible for many different types of vehicles, depending on how significant a portion of the work day is spent while parked. Most truck operators are aware of the cost of fuel consumed while idling, and importantly, the wear on the engine due to idling. Engine manufacturers caution owners to monitor the extent of idling that occurs for each work truck and to reduce the oil change interval if the idle time exceeds ten percent of the work day.[161] Accordingly, many utility truck operators track their oil change intervals in engine hours rather than in miles.

NTEA provided the agencies with a report with survey results on which work truck fleets are adopting AES with backup power, and their reasons for doing so.[162] The most common reason given in the survey is to allow an engine to shut down and still have vehicle power available to run flashing safety lights. Some vocational vehicles also need to conduct work using a power take-off (PTO) while stationary for hours, such as on a boom truck. The agencies are adopting an allowable AES over-ride for PTO use. Technologies that can reduce fuel consumption during this type of high-load idle are discussed below and in the Preamble at V.C.1.c. We are also adopting an allowable AES over-ride if the battery state of charge drops below a safe threshold. This would ensure there is sufficient power to operate any engine-off accessories up to a point where the battery capacity has reached a critical point. Where a vocational vehicle has such extensive stationary accessory demands that an auxiliary power source is impractical or that an over-ride condition would be experienced frequently, we would not consider AES to be feasible. In the Phase 2 certification process, engine suppliers will attest whether this feature is present and tamper-proof, and certifying entities will be able to enter Yes or No as a GEM input for the applicable field.[M] As with neutral idle described above, the effectiveness of AES will be calculated in GEM using data obtained through engine testing. The appropriate data points over the parked idle cycle will be used for calculating the fueling. Based on GEM simulations using the final vocational vehicle test cycles, the agencies project AES to provide fuel efficiency improvements ranging from less than one to seven percent for diesel vehicles, and from three to eight percent for gasoline vehicles, depending on the regulatory subcategory. Other overrides are listed in the regulations at 40 CFR 1037.660.

While the primary program does not simulate vocational vehicles over a test cycle that includes PTO operation, the agencies will continue, with revisions, the hybrid-PTO test option that was in Phase 1. See 40 CFR 1037.540 and 76 FR 57247. Recall that we will regulate vocational vehicles at the incomplete stage when a chassis manufacturer may not know at the time of certification whether a PTO will be installed or how the vehicle will be used. Although chassis manufacturers will certainly know whether a vehicle's transmission is PTO-enabled, that is very different from knowing whether a PTO will actually be installed and how it will be used. Chassis manufacturers may rarely know whether the PTO-enabled vehicle will use this capability to maneuver a lift gate on a delivery vehicle, to operate a utility boom, or merely as a reserve item to add value in the secondary market. In cases where a manufacturer can certify that a PTO with an idle-reduction technology will be installed either by the chassis manufacturer or by a second stage manufacturer, the hybrid-PTO test cycle may be utilized by the certifying manufacturer to measure an improvement factor over the GEM duty cycle that would otherwise apply to that vehicle. In addition, the delegated assembly provisions would apply. See Preamble Section I.F.2 for a description of the delegated assembly provisions. See RIA Chapter 3.7.4 for a discussion of the revisions to the hybrid PTO test cycle. In cases where a chassis manufacturer does not know whether a powertrain that is PTO-enabled will actually have a PTO-using tool installed, and whether there will be an energy storage system installed to save fuel during PTO operation, then the agencies do not see a way for the Phase 2 program to recognize hybrid PTO technology.

Our estimates are that applying neutral idle to a vocational vehicle with an automatic transmission would cost $118 in MY 2021, decreasing to $114 in MT 2027, as shown in RIA 2.11.6.5. These costs are increased from proposal, based on comments from Allison indicating hardware may be needed, such as a sensor to detect brake position or road grade. Our estimates are that applying AES to a vocational vehicle would cost $30 in MY 2021, decreasing to $25 in MT 2027, as shown in RIA 2.11.6.7. This cost does not include the cost of an auxiliary power source while the engine is off.

Based on GEM simulations using the final vocational vehicle test cycles, the agencies project stop-start to provide fuel efficiency improvements ranging from less than one to 14 percent for diesel vehicles, and from one to ten percent for gasoline vehicles, depending on the regulatory subcategory. Our estimates are that the cost of applying stop-start to a vocational vehicle will vary by vehicle weight class, because varying amounts of engine and vehicle

[M] We will consider non-tamper-proof AES as off-cycle technologies for a lesser credit.

upgrades will be needed. For LHD vocational vehicles, we estimate the total cost would range from $871 in MY 2021 to $722 in MY 2027. For MHD vocational vehicles, we estimate the total cost would range from $917 in MY 2021 to $760 in MY 2027. For HHD vocational vehicles, we estimate the total cost would range from $1,683 in MY 2021 to $1,395 in MY 2027. These costs, presented in RIA Chapter 2.11.6.6, are derived from costs reported by Tetra Tech for stop-start, plus costs for electrified accessories derived from values used in the light-duty GHG program, and scaled up for heavier vehicles.

With either a stop-start engine feature or with a neutral idle transmission calibration, less fuel is burned at idle. Furthermore, it is expected that SCR catalyst function could be better managed when an engine shuts off than when it idles. SCR systems are well insulated and can maintain temperature when an engine is shut off, whereas idling causes relatively cool air to flow through a catalyst. Therefore, the agencies have reason to believe there may be a NO_X co-benefit to stop-start idle reduction technologies, and possibly also to neutral idle. This would be true if the NO_X reductions from reduced fuel consumption and retained aftertreatment temperature were greater than any excess NO_X emissions due to engine re-starts.

2.9.3.5 Weight Reduction

The agencies are predicating the final vocational vehicle standards in part on use of material substitution for weight reduction. The method of recognizing this technology is similar to the method used for tractors. The agencies have created a menu of vocational chassis components with fixed reductions in pounds that may be entered in GEM when substituting a component made of a more lightweight material than the base component made of mild steel. According to the 2009 TIAX report, there are freight-efficiency benefits to reducing weight on vocational vehicles that carry heavy cargo, and tax savings potentially available to vocational vehicles that remain below excise tax weight thresholds. This report also estimates that the cost effectiveness of weight reduction over urban drive cycles is potentially greater than the cost effectiveness of weight reduction for long haul tractors and trailers. We are adopting as proposed a GEM allocation of half the weight reduction to payload and half to reduced chassis weight. We did not receive comment suggesting a different weight allocation. The menu of components available for a vocational vehicle weight credit in GEM is presented in Table 2-70 and can be found in the regulations at 40 CFR 1037.520. It includes fewer options than proposed, due to comments from Allison that aluminum transmission cases and clutch housings are standard for automatic transmissions. The agencies believe there are a number of other feasible material substitution choices at the chassis level, which could add up to weight savings of hundreds of pounds. The stringency of the final vocational vehicle standards for custom chassis transit buses and vehicles in the primary program is based in part on use of aluminum wheels in 10 positions on 3-axle vocational vehicles (250 lbs) and in 6 wheel positions on 2-axle vocational vehicles (150 lbs). This is a change from proposal, where we believed application of lightweight components would be adopted more narrowly. Our projected adoption rate is revised upward based on the determination that the technology package is smaller (fewer pounds removed than at proposal) and that aluminum wheels are widely feasible. Based on the default payloads in GEM, and depending on the vocational vehicle subcategory, the agencies estimate a reduction of 250 lbs would offer a fuel efficiency improvement of up to one percent for HHD vehicles, and a reduction of 150 pounds would offer a fuel efficiency improvement up to 0.8 percent for MHD vehicles, and up to 1.5 percent for LHD vehicles, as shown in Table 2-69. The agencies estimate the total cost to apply aluminum wheels to LHD and MHD vocational vehicles (about 150 pounds) to be $693 in MY 2021 and $587 in MY 2027, as described in RIA 2.11.10.3. We estimate the total cost to apply aluminum wheels to 3-axle vocational vehicles (about 250 pounds) to be $2495 in MY 2021 and $2204 in MY 2027, as described in RIA 2.11.10.3. This is in the range of $3 to $10 per pound, as reported by TIAX 2009.[163]

Table 2-69 Estimated Effectiveness of Vocational Weight Reduction

	HHD		MHD		LHD	
Weight Reduction	250	0	150	0	150	0
Static Test Weight (kg)	18,994	19,051	11,374	11,408	7,223	7,257
Dynamic Test Weight (kg)	19,561	19,618	11,714	11,748	7,563	7,597
Payload (ton)	7.5625	7.5	5.6375	5.6	2.8875	2.85
Effectiveness over Transient	1.0%		0.8%		1.5%	
Effectiveness over 55 mph	0.9%		0.7%		1.4%	
Effectiveness over 65 mph	0.9%		0.7%		1.4%	
Urban Cycle Effectiveness	1.0%		0.8%		1.5%	
Multi-Purpose Cycle Effectiveness	0.9%		0.8%		1.4%	
Regional Cycle Effectiveness	0.9%		0.7%		1.4%	

Table 2-70 Vocational Weight Reduction Technologies

COMPONENT	MATERIAL	VOCATIONAL VEHICLE CLASS		
		Class 2b-5	Class 6-7	Class 8
Axle Hubs - Non-Drive	Aluminum	40		40
Axle Hubs - Non-Drive	High Strength Steel	5		5
Axle - Non-Drive	Aluminum	60		60
Axle - Non-Drive	High Strength Steel	15		15
Brake Drums - Non-Drive	Aluminum	60		60
Brake Drums - Non-Drive	High Strength Steel	42		42
Axle Hubs – Drive	Aluminum	40		80
Axle Hubs – Drive	High Strength Steel	10		20
Brake Drums – Drive	Aluminum	70		140
Brake Drums – Drive	High Strength Steel	37		74
Suspension Brackets, Hangers	Aluminum	67		100
Suspension Brackets, Hangers	High Strength Steel	20		30
Crossmember – Cab	Aluminum	10	15	15
Crossmember – Cab	High Strength Steel	2	5	5
Crossmember - Non-Suspension	Aluminum	15	15	15
Crossmember - Non-Suspension	High Strength Steel	5	5	5
Crossmember -Suspension	Aluminum	15	25	25
Crossmember -Suspension	High Strength Steel	6	6	6
Driveshaft	Aluminum	12	40	50
Driveshaft	High Strength Steel	5	10	12
Frame Rails	Aluminum	120	300	440
Frame Rails	High Strength Steel	40	40	87
Wheels – Dual	Aluminum	150	150	250
Wheels – Dual	High Strength Steel	48	48	80
Wheels - Wide Base Single[a]	Aluminum	294	294	588
Wheels - Wide Base Single[a]	High Strength Steel	168	168	336
Permanent 6x2 Axle Configuration	Multi	N/A	N/A	300

Note:
[a] Based on values from Table 6 of 40 CFR 1027.520 and use of four wide base singles on Class 8 vocational vehicles and two on vehicles with one drive axle.

2.9.3.6 Electrified Accessories

Reducing the mechanical and electrical loads of accessories reduces the power requirement of the engine and in turn reduces the fuel consumption and CO_2 emissions. Modeling in GEM, as shown in Table 2-71, demonstrates there is a measurable effect of reducing 1 kW of accessory load for each vocational subcategory.

Table 2-71 Effect of Accessory Load Reduction on Vocational CO_2 Emissions

VOCATIONAL SUBCATEGORY	DIESEL (CI) PERCENT CO_2 PER KW	GASOLINE (SI) PERCENT CO_2 PER KW
HHD_R	0.95%	-
HHD_M	1.62%	-
HHD_U	1.82%	-
MHD_R	1.39%	1.28%
MHD_M	2.62%	2.14%
MHD_U	3.15%	2.48%
LHD_R	2.00%	1.87%
LHD_M	3.38%	2.91%
LHD_U	3.95%	3.44%

Optimization and improved pressure regulation may significantly reduce the parasitic load of the water, air and fuel pumps. Electrification may result in a reduction in power demand, because electrically-powered accessories (such as the air compressor or power steering) operate only when needed if they are electrically powered, but they impose a parasitic demand all the time if they are engine-driven. In other cases, such as cooling fans or an engine's water pump, electric power allows the accessory to run at speeds independent of engine speed, which can reduce power consumption.

Some vocational vehicle applications have much higher accessory loads than is assumed in the default GEM configurations. In the real world, there may be some vehicles for which there is a much larger potential improvement available than those listed above, as well as some for which electrification is not cost-effective. To date, accessory electrification has been associated only with hybrids, although CalStart commented they are optimistic that accessory electrification will become more widespread among conventional vehicles in the time frame of Phase 2.

Electric power steering (EPS) or Electrohydraulic power steering (EHPS) provides a potential reduction in CO_2 emissions and fuel consumption over hydraulic power steering because of reduced overall accessory loads. This eliminates the parasitic losses associated with belt-driven power steering pumps which consistently draw load from the engine to pump hydraulic fluid through the steering actuation systems even when the wheels are not being turned. EPS is an enabler for all vehicle hybridization technologies since it provides power steering when the engine is off. EPS is feasible for most vehicles with a standard 12V system. Some heavier vehicles may require a higher voltage system which may add cost and complexity.

Although we did not propose to allow pre-defined credit for electrified accessories as was proposed for tractors, we received comment requesting that this be allowed for vocational vehicles. As discussed in 2.9.3.1 above, the agencies are projecting that some electrified accessories will be necessary as part of the development of stop-start idle reduction systems for vocational vehicles. The technology package for vocational stop-start includes costs for high-efficiency alternator, electric water pump, electric cooling fan, and electric oil pump. However, because the GEM algorithm for determining the fuel benefit of stop-start does not account for any e-accessories, vehicles certified with stop-start are also eligible to be certified using an improvement value in the e-accessories column.

Daimler, ICCT, Bendix, Gentherm, Navistar, Odyne, and CARB asked the agencies to consider electric cooling fans, variable speed water pumps, clutched air compressors, electric air compressors, electric power steering, electric alternators, and electric A/C compressors. ICCT cautioned that certain accessories would be recognized over an engine test and credit should not be duplicated at the vehicle level. Bosch suggested that high-efficiency alternators be considered, and suggested use of a standard component-level test for alternators to determine their efficiency, and establishment of a minimum efficiency level that must be attained. Although there are industry-accepted test procedures for measuring the performance of alternators, we do not have sufficient information about the baseline level performance of alternators to define an improved level that would qualify for a benefit at certification. We are not able to set a fixed improvement for electric cooling fans or clutched accessories due to similar challenges related to baselines and defining the qualifying technology. In consideration of ICCT's comment, we are not including water pumps and oil pumps among the components eligible for a fixed improvement because we believe that our engine test procedure will recognize improvements that would be seen in the real world from electrifying these parts. Thus, we believe it is appropriate to offer fixed technology improvements for use of electric power steering and an electric A/C compressor, as inputs to GEM.

The agencies have combined the GEM results shown in Table 2-71 with information from comments provided by ICCT, the TIAX 2009 technology report, CARB's Driveline Optimization report, the 2010 NAS report, and a 2014 article published in IET Electrical Systems in Transportation to assign fixed improvement values for the defined technologies shown in Table 2-72.[164] These values are consistent with the TIAX study that used 2 to 4 percent fuel consumption improvement for accessory electrification, with the understanding that electrification of accessories will have more effect in short haul/urban applications and less benefit in line-haul applications.[165]

Table 2-72 Effectiveness of Vocational E-Accessories

TECHNOLOGY	EFFECTIVENESS	SUBCATEGORIES
Electric A/C Compressor	0.5%	HHD
	1.0%	MHD & LHD
Electric Power Steering	0.5%	Regional
	1.0%	Multipurpose & Urban

The improvement value for electric A/C compressors was estimated using a value of 4.7 kW demand from Table 5-11 of the 2010 NAS report, along with an assumption that it runs on average 40 percent of the time, and that electrification reduces the total load to the engine by 40 percent. Combining these values with the GEM-derived values of percent CO_2 per kW reduced from Table 2-71, the improvement is estimated to be in the range of 0.5 to three percent depending on the subcategory. The improvement value for electric power steering was estimated using an average value of 2 kW demand from Table 5-11 of the 2010 NAS report, along with an assumption that it runs on average 60 percent of the time, and that electrification reduces the total load to the engine by 40 percent. Combining these values with the GEM-derived values of percent CO_2 per kW reduced from Table 2-71, the improvement is estimated to be in the range of 0.5 to 1.5 percent depending on the subcategory. We have selected conservative values from these results as fixed technology improvements.

The agencies estimate the total cost to electrify accessories as described above on a LHD vocational vehicle to be $425 in MY 2021 and $369 in MY 2027. Scaling up, the costs for a MHD vocational vehicle are estimated at $801 in MY 2021 and $697 in MY 2027, and the costs for a HHD vocational vehicle are estimated at $1,603 in MY 2021 and $1,393 in MY 2027, as described in RIA 2.11.10.2.

Manufacturers wishing to obtain credit for technologies that are more effective than we have projected, or technologies beyond the scope of this defined technology improvement, may apply for off-cycle credits.

2.9.3.7 Tire Pressure Systems

2.9.3.7.1 TPMS

The agencies did not propose to base the vocational vehicle standards on the performance of tire pressure monitoring systems (TPMS). However, we received comment that we should consider this technology. See discussion in Preamble Section III.D.1.b. In addition to comments related to tractors and trailers, RMA commented that TPMS can also apply to the class 2b – 6 vehicles, and if the agencies add TPMS to the list of recognized technologies, that this choice should also be made available to class 2b-6 vehicles. Bendix commented that TPMS is a proven product, readily available from a number of truck, bus, and motorcoach OEMs. Autocar commented that TPMS is useful for refuse truck applications. Tirestamp said that TPMS is ideal for trucks and buses that are unable to apply ATIS due to difficulties plumbing air lines externally of the axles. The agencies find these comments to be persuasive. As a result, we are finalizing vocational vehicle standards that are predicated on the performance of TPMS in all subcategories, including all custom chassis except emergency vehicles and concrete mixers. Available information indicates that it is feasible to utilize TPMS on all vocational vehicles, though systems for heavy vehicles in duty cycles where the air in the tires becomes very hot must be ruggedized so that the sensors are protected from this heat. Such devices are commercially available, though they cost more. To account for this in our analysis, we have projected a lower adoption rate for TPMS in Urban vehicles than for Regional or Multipurpose vehicles, rather than by increasing the cost and applying an equal adoption rate. We are assigning a fixed improvement value in GEM for use of this technology in vocational vehicles of one percent for Regional vehicles including motor coaches and RV's (the same as for tractors and trailers) and 0.9 percent for Multipurpose, Urban, and other custom chassis vocational vehicles, recognizing that the higher amount of idle is likely to reduce the effectiveness for these vehicles. These values will be specified as GEM inputs in the column designated for tire pressure systems. For HHD vocational vehicles (with 3 axles), the agencies estimate the cost of TPMS at $583 in MY 2021 and $507 in MY 2027, as described in RIA 2.11.8.9. For LHD and MHD vocational vehicles, we scaled down the cost of this technology to reflect the presence of a single rear axle. The agencies estimate the total cost of TPMS on a LHD or MHD vocational vehicle (with 2 axles) at $307 in MY 2021 and $267 in MY 2027.

2.9.3.7.1.1 *ATIS*

The agencies did not propose to base the vocational vehicle standards on the performance of automatic tire inflation systems (ATIS), otherwise known as central tire inflation (CTI). However, we did receive comment indicating that it is feasible on some vocational vehicles, specifically those which could choose to be certified as custom chassis. Air CTI commented that central tire inflation is not only feasible but enhances safety on vehicles such as dump trucks and heavy haul vehicles that need higher tire pressures under certain driving conditions, such as when loaded, but need lower tire pressures when running empty or operating off-road. Tirestamp commented that ATIS can be plumbed externally for trucks and buses, but such systems have a propensity for damage and Autocar has provided information about how much extra weight this plumbing adds to the chassis. ATA commented that some onboard air pressure systems may not be able to pressurize tires sufficiently for very heavy vehicles. The primary vocational vehicle standards are not predicated on any adoption of ATIS because the agencies do not have sufficient information about which chassis will have an onboard air supply for purposes of an air suspension or air brakes. ATIS would logically only be adopted for vehicles that already need an onboard air supply for other reasons. Comments received for custom chassis were supportive of standards predicated on ATIS for buses with air suspensions. These comments are again persuasive. As a result, we are basing the optional standards for refuse trucks, school buses, coach buses, and transit buses in part on the adoption of ATIS. Although many motor homes have onboard air supply for other reasons making ATIS technically feasible, it is sufficiently costly that it is not practically feasible. Furthermore, for the same reasons stated above about the disadvantages of installing external plumbing for ATIS on some trucks and buses, we have determined it is not feasible for emergency vehicles or concrete mixers. Nonetheless, we are allowing any vocational vehicle to obtain credit for the performance of ATIS through a GEM input with a fixed improvement value in GEM for use of this technology in vocational vehicles of 1.2 percent for Regional vehicles including motor coaches and RV's (the same as for tractors and trailers) and 1.1 percent for Multipurpose, Urban, and other custom chassis vocational vehicles, recognizing that the higher amount of idle is likely to reduce the effectiveness for these vehicles. These values will be specified as GEM inputs in the column designated for tire pressure systems. See discussion in Preamble Section III.D.1.b for our reasoning behind this effectiveness value. Because ATIS is not projected as a technology in the basis for the mandatory vocational vehicle standards, we have not estimated detailed costs for applying this technology on these vehicles. Even so, in RIA 2.11.8.8 (see Table 2-130), the agencies estimate the cost of ATIS on 3-axle tractors to be $916 in MY 2021 and $796 in MY2027. We would expect the cost to apply ATIS on a 3-axle vocational vehicle to be comparable to these costs. Table 2-133 in RIA 2.11.8.8 presents costs the agencies have estimated to apply ATIS on short van trailers; $481 in MY 2021 and $418 in MY 2027. We would expect the cost to apply ATIS on a 2-axle vocational vehicle to be comparable to these costs.

2.9.3.8 HFC Leakage

Emissions due to direct refrigerant leakage are significant in all vehicle types. Since the proposal, EPA has learned that the capacities of vocational vehicle air conditioning systems range from those that are similar to those of other HD vehicles to some that are much larger. Even considering these differences, we believe it is appropriate to apply a similar leakage standard as was applied in the HD Phase 1 program for tractors and HD pickup trucks and vans. EPA is adopting a 1.50 percent refrigerant leakage per year standard for each air conditioning system with a refrigerant capacity greater than 733 grams, to assure that high-quality, low-leakage components are used in the design of these systems. Since refrigerant leakage past the compressor shaft seal is the dominant source of leakage in belt-driven air conditioning systems, the agency recognizes that this 1.50 percent leakage standard is not feasible for systems with a refrigerant capacity of 733 grams or lower, as the minimum feasible leakage rate does not continue to drop as the capacity or size of the air conditioning system is reduced. The fixed leakage from the compressor seal and other system devices results in a minimum feasible yearly leakage rate. EPA does not believe that leakage reducing technologies will be available in MY 2021 to enable lower capacity systems to meet the percent per year standard, so we are adopting a maximum gram per year leakage standard of 11.0 grams per year for vocational vehicle air conditioning systems with a refrigerant capacity of 733 grams or lower, as was adopted in the HD Phase 1 program for tractors and HD pickup trucks and vans.

The standard is derived from the vehicles with the largest system refrigerant capacity based on the Minnesota GHG Reporting database.[166] These are the same data on which the HD Phase 1 HFC leakage standard was based.[167]

By requiring that all vocational vehicles achieve the leakage level of 1.50 percent per year, roughly half of the vehicles in the 2010 data sample would need to reduce their leakage rates, and an emissions reduction roughly comparable to that necessary to generate direct emission credits under the light-duty vehicle program would result. See 75 FR at 25426-247. However, no credits or trading flexibilities are available under this standard for heavy-duty vocational vehicles. We believe that a yearly system leakage approach assures that high-quality, low-leakage, components are used in each A/C system design, and we expect that manufacturers will reduce A/C leakage emissions by utilizing improved, leak-tight components. Some of the improved components available to manufacturers are low-permeation flexible hoses, multiple o-ring or seal washer connections, and multiple-lip compressor shaft seals. The availability of low leakage components in the market is being driven by the air conditioning credit program in the light-duty GHG rulemaking (which applies to 2012 model year and later vehicles). EPA believes that reducing A/C system leakage is both highly cost-effective and technologically feasible. The cooperative industry and government Improved Mobile Air Conditioning (IMAC) program has demonstrated that new-vehicle leakage emissions can be reduced by 50 percent by reducing the number and improving the quality of the components, fittings, seals, and hoses of the A/C system.[168] All of these technologies are already in commercial use and exist on some of today's A/C systems in other heavy-duty vehicles.

EPA is adopting the same compliance method for control of leakage from A/C systems in vocational vehicles as was adopted for the HD Phase 1 HFC leakage standard. Under this approach, manufacturers will choose from a menu of A/C equipment and components used in their vehicles in order to establish leakage scores, which characterizes their A/C system leakage performance and calculates the percent leakage per year as this score divided by the system refrigerant capacity. The agencies estimate the total cost to apply low leakage A/C components to a vocational vehicle to be $22 in MY 2021 and $20 in MY 2027, as described in RIA 2.11.4.1.

Consistent with the Light-Duty Vehicle Greenhouse Gas Emissions rulemaking, the components of vocational vehicle A/C systems are being compared to a set of leakage reduction technologies that is based closely on that being developed through IMAC and the Society of Automotive Engineers (as SAE Surface Vehicle Standard J2727, August 2008 version).[169] See generally 75 FR at 25426. The SAE J2727 approach was developed from laboratory testing of a variety of A/C related components, and EPA believes that the J2727 leakage scoring system generally represents a reasonable correlation with average real-world leakage in new vehicles. Like the IMAC approach, our approach associates each component with a specific leakage rate in grams per year identical to the values in J2727 and then sums together the component leakage values to develop the total A/C system leakage. As is currently done for other HD vehicles, for vocational vehicles, the total A/C leakage score will then be divided by the total refrigerant system capacity to develop a percent leakage per year value.

2.9.4 Other Vocational Vehicle Technologies the Agencies Considered

2.9.4.1 Vocational Aerodynamics

The agencies did not propose to include aerodynamic improvements as a basis for the Phase 2 vocational vehicle standards. However, we did request comment on an option to allow credits for use of aerodynamic devices such as fairings on a very limited basis. We received public comments from AAPC in support of offering this as an optional credit, with a suggestion to allow this option for a wide range of vehicle sizes, and suggesting that the grams per ton-mile benefit could be scaled down for larger vehicles. CARB commented in support of a Phase 2 program that would include use of aerodynamic improvements as a basis for the stringency, suggesting that a large fraction of the vocational vehicle fleet could see real world benefits from use of aerodynamic devices. Because we do not have sufficient fleet information to establish a projected application rate for this technology, we are not basing any of the final standards for vocational vehicles on use of aerodynamic improvements. In consideration of comments, we are adopting provisions for vocational vehicles to optionally receive an improved GEM result by certifying use of a pre-approved aerodynamic device.

Based on testing supported by CARB, the agencies have developed a list of specific aerodynamic devices with pre-defined improvement values (in delta C_DA units), as well as criteria regarding which vehicles are eligible to earn credit in this manner. Manufacturers wishing to receive credit for other aerodynamic technologies or on other vehicle configurations may apply for credits using the test procedures at 40 CFR 1037.527.

Table 2-73 shows the vocational aerodynamic technologies that we are adopting as pre-approved, for which the credit listed is available through GEM. In response to comments, we are allowing a wide range of vehicles to be eligible to use this option. Vocational vehicles in any weight class over the Regional duty cycle may use this option, subject to restrictions on the size of the cargo box (see 40 CFR 1037.520). The agencies have not estimated manufacturing costs for these technologies on vocational vehicles. We project that a manufacturer would only apply these where it was found to be cost-effective for the specific application. For a description of the costs estimated for applying aerodynamic technologies to tractors, see the RIA at Chapter 2.11.9.1, where the estimated cost for a Bin2 package on a low roof day cab tractor is shown to be roughly $1,000.

Table 2-73 Pre-approved Vocational Aerodynamic Technologies

VEHICLE	SKIRT	FRONT FAIRING (NOSE CONE)	REAR FAIRING (TAIL)	BOTH FRONT FAIRING AND SKIRT
Total chassis length at least 36 ft and frontal area at least 9 m^2	0.3	0.3		0.5
Total chassis length at least 23 ft and frontal area at least 8 m^2			0.2	

A description of the testing that was conducted in support of the assigned GEM improvements due to these technologies is presented in the draft report from NREL to CARB.[170] The degree of change in C_dA for each pre-approved device has been set at conservative values due to the small number of configurations tested and the large uncertainty inherent in those results. As an example of the degree of uncertainty, the change in C_dA on the class 6 box truck due to applying a chassis skirt was reported by NREL in Table 8 as being approximately -0.6 m^2 with a 95 percent confidence interval of plus or minus -0.6 m^2. Manufacturers using this credit provision may enter the pre-defined delta C_dA as an input to GEM, and the simulation will determine the effectiveness over the applicable duty cycle. Using this approach, we do not need to set a scaled benefit for different sizes of vehicles. When the vehicle weight class and duty cycle are specified, a default chassis mass and payload are simulated in GEM. When the pre-defined delta C_dA is entered, the simulation returns a resulting improved performance with respect to the specified chassis configuration. GEM will logically return a smaller improvement for heavier vehicles.

The final Regional composite duty cycle in GEM for vocational vehicles has a weighted average speed of 41.9 mph, increased from the average speed at proposal due to a heftier 56 percent composite weighting of the 65 mph drive cycle. The agencies have learned from the NREL duty cycle analysis that vocational vehicles with operational behavior of a regional nature accumulate more miles at highway speeds than previously assumed.

Using GEM simulation results, the agencies estimate the fuel efficiency benefit of improving the C_dA of a Class 6 box truck by 11 percent (0.6 m^2 delta C_dA off of a default of 5.4 m^2) at approximately five percent over the Regional composite test cycle. This same delta C_dA simulated in GEM on a class 8 Regional vocational vehicle results in an overall improvement of less than four percent because the default C_dA in GEM for class 8 vocational vehicles is 6.86 m^2 so the change in C_dA is only nine percent. Although in actual operation the added weight of aerodynamic fairings may reduce the operational benefits of these technologies when driving at low speeds, the agencies are not applying any weight penalty as part of the certification process for vocational aerodynamic devices.

As described in the NPRM, we are requiring chassis manufacturers employing this option to provide assurances to the agencies that these devices will be installed as part of the certified configuration, even if the installation is completed by another entity. We received many comments on the requirements for secondary manufacturers as they apply for vocational aerodynamics as well as other technologies that may be specified by a chassis manufacturer but installed later. See Preamble Section I.F.2 and Section V.D.2 for further discussion of delegated assembly issues.

2.9.4.2 E-PTO

Although the primary program does not simulate vocational vehicles over a test cycle that includes PTO operation, the agencies are adopting a revised hybrid-PTO test procedure. See 76 FR 57247 and 40 CFR 1037.540. Recall that we regulate vocational vehicles at the incomplete stage when a chassis manufacturer may not know at the time of certification whether a PTO will be installed or how the vehicle will be used. Chassis manufacturers may rarely know whether the PTO-enabled vehicle will use this capability to maneuver a lift gate on a delivery vehicle, to operate a utility boom, or merely to keep it as a reserve item to add value in the secondary market. For these reasons, it would not be fair to require every vocational vehicle to certify to a standard test procedure with a PTO cycle in it. Thus, we are not basing the final standards on use of technology that reduces emissions in PTO mode.

There are products available today that can provide auxiliary power, usually electric, to a vehicle that needs to work in PTO mode for an extended time, to avoid idling the main engine. There are different designs of electrified PTO systems on the market today. Some designs have auxiliary power sources, typically batteries, with sufficient energy storage to power an onboard tool or device for a short period of time, and are intended to be recharged during the workday by operating the main engine, either while driving between work sites, or by idling the engine until a sufficient state of charge is reached that the engine may shut off. Other designs have sufficient energy storage to power an onboard tool or device for many hours, and are intended to be recharged as a plug-in hybrid at a home garage. In cases where a manufacturer can certify that a PTO with an idle-reduction technology will be installed either by the chassis manufacturer or by a second stage manufacturer, the hybrid-PTO test cycle may be utilized by the certifying manufacturer to measure an improvement factor over the GEM duty cycle that otherwise applies to that vehicle. In addition, the delegated assembly provisions will apply (see Section I.F.2). See RIA Chapter 3.7.4 for a discussion of the revisions to the PTO test cycle.

The agencies will continue the hybrid-PTO test option that was available in Phase 1, with a few revisions. See the regulations at 40 CFR 1037.540. The calculations recognize fuel savings over a portion of the test that is determined to be charge-sustaining as well as a portion that is determined to be charge-depleting for systems that are designed to power a work truck during the day and return to the garage where recharging from an external source occurs during off-hours. The agencies requested comment on this idea, and received comment from Odyne relating to the population and energy storage capacity of plug-in e-PTO systems, for which a charge-depleting test cycle may be more appropriate. We also partnered with DOE-NREL to characterize the PTO operation of many vocational vehicles. NREL has characterized the PTO operation using telematics data from Odyne on over 80 utility trucks with over 1,500 total operating days, plus telematics data on ten utility trucks from PG&E with hundreds of operating days. Our final regulations include a utility factor table based on these data for use in determining the effectiveness of a hybrid PTO system. A description of the analysis underlying the development of this utility factor curve is available in the docket.[171] Manufacturers wishing to conduct testing as specified may apply for off-cycle credits derived from e-PTO or hybrid PTO technologies.

2.9.4.3 Electric Vehicles

Some heavy-duty vehicles can be powered exclusively by electric motors. Electric motors are efficient and able to produce high torque, giving e-trucks strong driving characteristics, particularly in stop-and-go or urban driving situations, and are well-suited for moving heavy loads. Electric motors also offer the ability to operate with very low noise, an advantage in certain applications. Currently, e-trucks have some disadvantages over conventional vehicles, primarily in up-front cost, weight and range. Components are relatively expensive, and storing electricity using currently available technology is expensive, bulky, and heavy. However commenters provided information on total cost of ownership for electric trucks, and some applications may see attractive long term cost scenarios for electric trucks or buses, considering maintenance savings.

The West Coast Collaborative, a public-private partnership, has estimated the incremental costs for electric Class 3-6 trucks in the Los Angeles, CA, area.[172] Compared to a conventional diesel, the WCC estimates a battery-electric vehicle system would cost between $70,000 and $90,000 more than a conventional diesel system. The CalHEAT Technology Roadmap includes an estimate that the incremental cost for a fully-electric medium- or heavy- duty vehicle would be between $50,000 and $100,000. In the Draft RIA Chapter 2.12.7.6, the agencies estimated the cost of a full electric LHD or MHD vocational vehicle at $55,216 in MY 2021 and $52,128 in MY 2024. The CalHEAT roadmap report also presents several actions that must be taken by manufacturers and others, before heavy-duty e-trucks can reach what they call Stage 3 Deployment.[173]

Early adopters of electric drivetrain technology are medium-heavy-duty vocational vehicles that are not weight-limited and have drive cycles where they don't need to go far from a central garage. According to CALSTART's report to the NAFA 2014 Institute and Expo, there is an emerging market of MHD all-electric vocational vehicles, including models from Smith, EVI, Boulder, AMP, and others. It is a significant stepping stone that we are seeing these emerging markets, where prototype and demonstration vehicles can be tested and observed in real world conditions. CalHEAT has published results of a comprehensive performance evaluation of three battery electric truck models using information and data from in-use data collection, on road testing and chassis dynamometer testing.[174]

Given the high costs and the developing nature of this technology, the agencies do not project fully electric vocational vehicles to be widely commercially available in the time frame of the final Phase 2 rules. For this reason, the agencies have not based the Phase 2 standards on adoption of full-electric vocational vehicles. EEI provided information on the total cost of ownership for electric trucks, where under certain conditions some vehicle applications may see attractive long term cost scenarios for electric trucks or buses, when considering maintenance savings. To the extent this technology is able to be brought to market in the time frame of the

Phase 2 program, there is currently a certification path for these chassis from Phase 1, as described in the Preamble Section V and in the regulations at 40 CFR 1037.150 and 49 CFR 535.8.

2.9.5 Derivation of the Vocational Vehicle Technology Packages

The final standards for vocational vehicles are predicated on the same suite of technologies in all implementation years of the Phase 2 program. The change in stringency between those years is a result of different adoption rates of those technologies. Package costs for each model year are presented following each respective adoption rate discussion.

2.9.5.1 Projected Technology Adoption Rates for Vocational Vehicles

The agencies describe below the extent to which technologies may be adopted by manufacturers to meet each set of vocational vehicle standards.

2.9.5.1.1 Transmissions

Because we expect that transmission suppliers will be able to conduct a modest amount of testing that can be valid for a large sales volume of transmissions, the agencies project an adoption rate of 50 percent in MY 2021, 60 percent in MY 2024, and nearly 70 percent in MY 2027 of transmissions with improved gear efficiencies, with inputs over-riding the GEM defaults obtained over the separate transmission efficiency test. In response to comments regarding the diversity of drivelines and the narrow range of products for which powertrain testing is likely to be conducted, we are projecting an adoption rate of 10 percent in MY 2021, 20 percent in MY 2024, and nearly 30 percent in MY 2027 of advanced shift strategies, with demonstration of improvements recognized over the separate powertrain test. With additional time and research, we expect that the adoption of this strategy for improving fuel efficiency will grow.

We are predicating the Phase 2 standards on zero adoption of added gears in the HHD Regional subcategory, because it is modeled with a 10-speed transmission, and vehicles already using that number of gears are not expected to see any real world improvement by increasing the number of available gears. For the Multipurpose and Urban HHD subcategories, the MY 2021 projected adoption of adding gears is 5 percent, increasing to 10 percent for MY 2024 and MY 2027. We are projecting 10 percent of adding two gears in each of the other six subcategories for MY 2021, increasing to 20 percent for MY 2024 and MY2027. Commenters supported the inclusion of this technology as part of the basis for the standards. Allison commented that they have configured an 8-speed vocational transmission. Eaton's new MHD dual clutch transmission has seven forward gears. There is also a likelihood that suppliers of 8-speed transmissions for HD pickups and vans may sell some into the LHD vocational vehicle market.

We are also predicating the optional custom chassis standards for school and coach buses in part on adoption of transmissions with additional gears. In MY 2021, this adoption rate is five percent, increasing to 10 percent in MY 2024 and 15 percent in MY 2027. Manufacturers who certify these vehicles to the primary standards will use GEM to model the actual gears and gear ratios. Manufacturers opting into the custom chassis program will not have this flexibility. The agencies have estimated the cycle-average benefit of adding an extra gear for school buses (modeled as MHD Urban vehicles) at 0.9 percent and coach buses (with 6 gears in the baseline) at 1.7 percent, therefore manufacturers using the custom chassis regulatory subcategory identifiers for these vehicles will be permitted to enter these pre-defined improvement values at the time of certification.

Based on comment regarding our regulatory baselines, both the HHD Regional and HHD Multipurpose subcategories now have manual transmissions in the baseline configuration. For these vehicles, the agencies project upgrades to automated transmissions such as either AMT, DCT, or automatic, at an adoption rate of 30 percent in MY 2021, 60 percent in MY 2024, and 90 percent in MY 2027 for Regional vehicles. For Multipurpose, beginning with 20 percent manuals in the baseline, the adoption rate of automated transmissions is five percent in MY 2021 and 20 percent in MY 2024. Consistent with our projections of technology adoption, the regulations require that any vocational vehicles with manual transmissions must be certified as Regional in MY 2024 and beyond. This progression of transmission automation is consistent with the agencies' projection of 10 percent manuals and 90 percent automated transmissions in the day cab tractor subcategories in MY 2027. See Table III-13 of the Preamble. HHD vocational vehicles in regional service have many things in common with day cab tractors, including the same assumed engine size and typical transmission type, and a similar duty cycle. Thus, it is reasonable for the agencies to make similar projections about the fraction of automated vs manual transmissions adopted over the next decade among these sectors.

In the seven subcategories (i.e. all of the remaining subcategories) in which automatic transmissions are the base technology, the agencies project that ten percent of the HHD vehicles will apply an aggressive torque converter lockup strategy in MY 2021, and 30 percent in the LHD and MHD subcategories. These adoption rates are projected to increase to 20 percent for HHD and 40 percent for LHD and MHD in MY 2024. We project adoption of aggressive torque converter lockup for HHD automatics of 30 percent in MY 2027, and 50 percent for LHD and MHD. We project these adoption rates to be greater than that of the fully integrated shift strategy and less than that of the transmission gear efficiency technologies because this is less complex to apply and may be entered as a GEM input rather than requiring separate test procedures.

In setting the standard stringency, we have projected that non-integrated (bolt-on) mild hybrids will not have the function to turn off the engine at stop, while the integrated mild hybrids will have this function. The agencies have estimated the effectiveness of non-integrated mild hybrids for vehicles certified in the Urban subcategories will achieve as much as 12 percent improvement, and integrated systems that turn off at stop will see up to 25 percent improvement in the Urban subcategories. We have also projected zero hybrid adoption rate (mild or otherwise) by vehicles in the Regional subcategories, expecting that the benefit of hybrids for those vehicles will be too low to merit use of that type of technology.

There is no fixed hybrid value assigned in GEM. Consequently, any vehicles utilizing hybrid technology will determine the actual improvement by conducting powertrain testing.

By the full implementation year of MY 2027, the agencies are projecting an overall vocational vehicle adoption rate of 12 percent mild hybrids, which we estimate will be 14 percent of vehicles certified in the Multi-Purpose and Urban subcategories (six percent integrated and eight percent non-integrated). We are projecting a low adoption rate in the early years of the

Phase 2 program, zero integrated hybrid systems and two percent of the bolt-on systems in these subcategories in MY 2021, and three percent integrated mild hybrids in MY 2024 for vehicles certified in the Multi-Purpose and Urban subcategories, plus 5 percent non-integrated mild hybrids in MY 2024. Based on our assumptions about the populations of vehicles in different subcategories, these hybrid adoption rates are about two percent overall in MY 2021 and six percent overall in MY 2024. With the revised projection of lower cost mild hybrids instead of strong hybrids and more robust assessment of effectiveness than at proposal, we are confident that we can project a slightly higher overall adoption rate than we had at proposal.

Navistar commented with concerns that the agencies may be double counting some of the improvements of deep integration. For example, the addition of a gear to a transmission may reduce the added benefit of deep integration, as the transmission may already achieve a more optimal operation state more often due to the greater number of gears. The agencies have been careful to project adoption rates and effectiveness of transmission technologies in a way that that avoids over-estimating the achievable reductions. For example, as we developed the packages, we reduced the adoption rate of advanced shift strategy by the adoption rate of integrated hybrids, and we reduced the adoption rate of transmission gear efficiency by the amount of non-integrated hybrids. This means that in the HHD Multipurpose category in MY 2027, the sum of adoption rates of hybrids, advanced shift strategy, and transmission gear efficiency is 100 percent. Further, instead of summing the combined efficiencies, we combine multiplicatively as described in Equation 2-2, below. Transmission improvements are central to the Phase 2 vocational vehicle program, second only to idle reduction. We are projecting that many vehicles will apply more than one technology that improves vehicle performance with respect to the transmission, which necessarily means that the adoption rate of transmission technologies in some subcategories sums to greater than 100 percent. For example, with a 50 percent adoption of torque converter lockup and a 70 percent adoption of high efficiency gearbox for Regional vehicles in MY 2027, some vehicles may need to - and could reasonably - apply both. However, we believe we have fairly accounted for dis-synergies of effectiveness where technologies are applied to a similar vehicle system.

Custom chassis manufacturers have provided compelling comment that the absence of recognition in the certification process of improved transmission technology will not deter them from its adoption. Therefore, although some types of improved transmissions are feasible for some custom chassis, the fact that these vehicles are typically assembled from off-the-shelf parts in low production volumes makes them much less likely to have access to the most advanced transmission technologies. Further, for the reasons described above about non-representative drivelines in the baseline configurations, we believe that allowing these to be certified with a default driveline is a reasonable program structure. For school buses and others, if a manufacturer wishes to be recognized beyond the levels described for adopting improved transmissions, it may optionally certify to the primary standards.

2.9.5.1.2 Axles

The agencies project that 10 percent of vocational vehicles in all subcategories will adopt high efficiency axles in MY 2021, 20 percent in MY 2024, and 30 percent in MY 2027, and the standards are predicated on these penetration rates for high efficiency axles. Fuel efficient lubricant formulations are widespread across the heavy-duty market, though advanced synthetic formulations are currently less popular.[N] Axle lubricants with improved viscosity and efficiency-enhancing performance are projected to be widely adopted by manufacturers in the time frame of Phase 2. Such formulations are commercially available and the agencies see no reason why they could not be feasible for most vehicles. Nonetheless, we have refrained from projecting full adoption of this technology. The agencies do not have specific information regarding reasons why axle manufacturers may specify a specific type of lubricant over another, and whether advanced lubricant formulations may not be recommended in all cases. The agencies received adverse comment on allowing fixed credit for use of high efficiency axles, whether from lubrication or other mechanical designs. In response, we are adopting a separate axle efficiency test, which can be used as an input to GEM to over-ride default axle efficiency values. The low overall adoption rate indicates that we expect axle suppliers to only offer high-efficiency axles for their most high production volume products, especially those that can serve both the tractor and vocational market. Therefore, we believe it is unlikely that high-efficiency axles will be adopted in custom chassis applications. Because we are no longer offering a fixed improvement for this technology as at proposal, this is only available for vocational vehicles that are certified to the primary program.

The agencies estimate that 10 percent of HHD Regional vocational vehicles and five percent of HHD Multipurpose vehicles will adopt part time 6x2 axle technology in MY 2021. This technology is most likely to be applied to Class 8 vocational vehicles (with 2 rear axles) that are designed for frequent highway trips. The agencies project a 20 percent for HHD Regional and 15 percent adoption rate for HHD Multipurpose for part time 6x2 axle technologies in MY 2024. In MY 2027, we project 30 percent adoption of part time 6x2 for HHD Regional and 25 percent for HHD Multipurpose. We are establishing a baseline configuration for coach buses with a 6x2 axle. If a HHD coach bus is sold with a 6x4 or part time 6x2 axle, the manufacturer must enter the as-built axle configuration as a GEM input. This is true whether the vehicle is in the primary program or if it is certified to the custom chassis standard.

2.9.5.1.3 Lower Rolling Resistance Tires

The agencies estimate that the per-vehicle average level of rolling resistance from vocational vehicle tires could be reduced by up to 13 percent for many vehicles by full implementation of the Phase 2 program in MY 2027, based on broader adoption of vocational vehicle tires currently available. We estimate this will yield reductions in fuel use and CO_2 emissions of up to 3.3 percent for these vehicles. As proposed, the Phase 2 weighting of steer tire CRR and drive tire CRR is 0.3 times the steer tire CRR and 0.7 times the drive tire CRR, representing an average weight distribution of the rear axle(s) carrying 2.3 times the weight of the front axle. The projected adoption rates of tires with improved CRR for chassis in the primary program are presented in Table 2-74. The levels 1v through 5v noted in the table are defined in Section V.C.1.a.iv of the Preamble. By applying the assumed axle load distribution, the estimated vehicle CRR improvement projected as part of the MY 2021 standards ranges from 5 to 8 percent, which we project will achieve up to 1.9 percent reduction in fuel use and CO_2 emissions, depending on the vehicle subcategory. The agencies estimate the vehicle CRR

[N] April 2014 meeting with Dana.

improvement in MY 2024 will range from 5 to 13 percent, yielding reductions in fuel use and CO_2 emissions up to 3.2 percent, depending on the vehicle subcategory.

The agencies believe that these tire packages recognize the variety of tire purposes and performance levels in the vocational vehicle market, and maintain choices for manufacturers to use the most efficient tires (i.e. those with lowest rolling resistance) only where it makes sense given these vehicles' differing purposes and applications.

Table 2-74 Projected LRR Tire Adoption Rates

	REGIONAL		MULTIPURPOSE		URBAN	
	Steer	Drive	Steer	Drive	Steer	Drive
2021 HHD	100% LRR 5v	100% LRR 2v	100% LRR 5v	100% LRR 2v	100% LRR 4v	100% LRR 1v
2021 MHD	100% LRR 3v	100% LRR 1v	100% LRR 3v	100% LRR 1v	100% LRR 3v	100% LRR 1v
2021 LHD	100% LRR 3v	100% LRR 3v	100% LRR 3v	100% LRR 3v	100% LRR 2v	100% LRR 2v
2024 HHD	100% LRR 5v	100% LRR 3v	100% LRR 5v	100% LRR 2v	100% LRR 4v	100% LRR 1v
2024 MHD	100% LRR 5v	100% LRR 3v	100% LRR 3v	50% LRR 1v, 50% LRR 2v	100% LRR 3v	100% LRR 1v
2024 LHD	100% LRR 5v	100% LRR 3v	100% LRR 3v	100% LRR 3v	100% LRR 2v	100% LRR 2v
2027 HHD	100% LRR 5v	100% LRR 3v	100% LRR 5v	100% LRR 3v	100% LRR 5v	100% LRR 2v
2027 MHD	100% LRR 5v	100% LRR 3v	100% LRR 5v	100% LRR 3v	100% LRR 3v	50% LRR 1v, 50% LRR 2v
2027 LHD	100% LRR 5v	100% LRR 3v	100% LRR 5v	100% LRR 3v	100% LRR 3v	50% LRR 2v, 50% LRR 3v

Table 2-75 presents the projected adoption rates of LRR tires for custom chassis. As noted in Section V.C.1.a of the Preamble, the adoption rates generally represent improvements in the range of the 25th to 40th percentile using data from actual vehicles in each application that were certified in MY 2014. A summary of these data is provided in a memorandum to the docket.[175] An exception to this is emergency vehicles. The final emergency vehicle standards reflect adoption of tires that progress to the 50th percentile by MY 2027, using steer and drive tire data for certified emergency vehicles. At these adoption rates, manufacturers need not change any of the tires they are currently fitting on emergency vehicles, and they will comply on average.

Table 2-75 Projected LRR Tire Adoption Rates for Custom Chassis

	MY 2021		MY 2024		MY 2027	
	Steer	Drive	Steer	Drive	Steer	Drive
Coach	100% LRR 4v	100% LRR 4v	100% LRR 5v	100% LRR 5v	100% LRR 5v	100% LRR 5v
RV	100% LRR 5v	100% LRR 5v	100% LRR 5v	100% LRR 5v	100% LRR 5v	100% LRR 5v
School	100% LRR 4v	100% LRR 2v	100% LRR 5v	100% LRR 3v	100% LRR 5v	100% LRR 4v
Transit	100% LRR 1v	100% LRR 1v	100% LRR 1v	100% LRR 1v	100% LRR 3v	100% LRR 3v
Refuse	100% LRR 1v	100% LRR 1v	100% LRR 1v	100% LRR 1v	100% LRR 3v	100% LRR 3v
Mixer	100% LRR 2v	100% LRR 1v	100% LRR 3v	100% LRR 1v	100% LRR 3v	100% LRR 2v
Emergency	100% LRR 2v	100% LRR 1v	100% LRR 3v	100% LRR 1v	100% LRR 4v	100% LRR 1v

2.9.5.1.4 Workday Idle Reduction

In these rules, the adoption rate of AES for HHD Regional vehicles is 40 percent in MY 2021, 80 percent in MY 2024, and 90 percent in MY 2027. This is because these vehicles have driving patterns with a significant amount of parked idle, and the vast majority have relatively modest accessory demands such that only a few would have such large demands for backup power that turning the engine off while parked would not be feasible. For all weight classes of Regional vehicles except coach buses, the neutral idle and stop start adoption rates remain zero in all model years because these vehicles have driving patterns with such a small amount of transient driving that this drive-idle technology would not provide real world benefits. The LHD and MHD weight class Regional vehicles carry a 30 percent, 60 percent, and 70 percent adoption rate of AES in MYs 2021, 2024, and 2027 respectively. The adoption rates of idle reduction technologies for vocational vehicles in MY 2027 are presented in Table 2-76.

Table 2-76 MY 2027 Adoption Rates of Idle Reduction Technologies

	Heavy Heavy-Duty			Medium Heavy-Duty			Light Heavy-Duty		
Technology	Regional	Multi-purpose	Urban	Regional	Multi-purpose	Urban	Regional	Multi-purpose	Urban
Neutral Idle	0	70	70	0	60	60	0	60	60
Stop-Start	0	20	20	0	30	30	0	30	30
AES	90	70	70	90	70	70	90	70	70

Although it is possible that a vehicle could have both neutral idle and stop-start, our stringency calculations only consider emissions reductions where a vehicle either has one or the other of these technologies. The final GEM input file allows users to apply multiple idle reduction technologies within a single vehicle configuration.

Because we have included costs to maintain engine protection during periods of shut-off, as well as over-rides to recognize instances where it may not be safe to shut off an engine, we believe stop-start can safely be applied at the rates described above in the time frames described. Also, because we have defined two idle cycles where the automatic engine shutoff technology addresses the condition of being parked with the service brake off, we believe this alleviates many of the concerns expressed by commenters about stop-start. We believe many commenters were (erroneously) imagining that stop-start systems would be required to function during periods of extended parking.

We agree with commenters that stop-start is not feasible for emergency vehicles and concrete mixers. We further believe that stop-start would not provide any real world benefit for coach buses or motor homes. However, for school buses, transit buses, and refuse trucks, we believe stop-start is feasible and likely to result in real world benefits. The only custom chassis standards reflecting adoption of AES is school buses, because for the others, we believe the simple shutdown timer would be likely to trigger an over-ride condition frequently enough to yield a very small benefit from this technology. To make AES practical for a coach or transit bus, for example, a much larger auxiliary power source would be needed than the one projected as part of this rulemaking. We have based the school bus standards in part on adoption of AES, however. Although many school buses have voluntarily adopted idle reduction strategies for other reasons, we do not believe many have tamper-proof automatic shutdown systems. The adoption rates of idle reduction technologies for custom chassis are presented in Table 2-77.

Table 2-77 Custom Chassis Workday Idle Adoption Rates

Technology	MY	AES	NI	Stop-Start
Coach	2021	-	40	-
	2027	-	70	-
School	2021	30	60	5
	2027	70	60	30
Transit	2021	-	60	10
	2027	-	70	30
Refuse	2021	-	30	0
	2027	-	50	20

As described above, refuse trucks that do not compact waste are ineligible for the optional custom chassis vocational vehicle standards. We believe trucks that do not compact waste have sufficiently low PTO operation (usually only while parked) to make application of drive idle reduction technologies quite feasible. Front-loading refuse collection vehicles tend to have a relatively low number of stops per day as they tend to collect waste from central locations such as commercial buildings and apartment complexes. Because these have a relatively low amount of PTO operation, we expect stop-start will be reasonably effective for these vehicles. Rear-loading and side-loading neighborhood waste and recycling collection trucks are the refuse trucks where the largest number of stop-start and neutral idle over-ride conditions are likely to be encountered. Because chassis manufacturers, even those with small production volumes and close customer relationships, do not always know whether a refuse truck chassis will be fitted with a body designed for front loading, rear loading, or side loading, we are applying an adoption rate of 20 percent stop-start in 2027 to refuse trucks certified as custom chassis. Chassis manufacturers certifying refuse trucks to the optional custom chassis standards may enter Yes in the input field in GEM for stop-start and the effectiveness will be computed based on the default 350 hp engine with 5-speed HHD automatic transmission. In the case where a chassis manufacturer certifies a refuse truck to the primary standards under the HHD Urban subcategory, the MY 2027 adoption rate is also 20 percent, and the stringency assumes a sufficiently capable stop-start system to not require an excessive use of over-rides. Manufacturers opting to certify refuse trucks to the primary standards will have an option to be recognized for enhanced stop-start systems through the powertrain test.

It may take some minor development effort to apply neutral idle to high-torque automatic transmissions designed for the largest vocational vehicles. Based on stakeholder input, the designs needed to avoid an uncomfortable re-engagement bump when returning to drive from neutral may require some engineering refinement as well as some work to enable two-way communication between engines and transmissions. Nonetheless, this technology should be available in the near term for many vehicles and is low cost compared to many other technologies we considered. Commenters asked for over-rides such as when on a steep hill, and we agree and are adopting this provision.

We see the above idle reduction technologies being technically feasible on the majority of vocational vehicles, and especially effective on those with the most time in drive-idle in their workday operation. Although we are not prepared to predict what fraction of vehicles will adopt stop-start in the absence of Phase 2, the agencies are confident that this technology, which is on the entry-level side of the hybrid and electrification spectrum, will be widely available in the Phase 2 time frame.

Based on these projected adoption rates and the effectiveness values described above in this section, we expect overall GHG and fuel consumption reductions from workday idle on vocational vehicles to range from one to 13 percent in MY 2027.

2.9.5.1.5 Weight Reduction

As described in the RIA Chapter 2.11.10.3, weight reduction is a relatively costly technology, at approximately $3 to $10 per pound for a 200-lb package. Even so, for vehicles in service classes where dense, heavy loads are frequently carried, weight reduction can translate directly to additional payload. The agencies project that modest weight reduction is feasible for all vocational vehicles. The agencies are predicating the final standards on adoption of weight reduction comparable to what can be achieved through use of aluminum wheels. This package is estimated at 150 pounds for LHD and MHD vehicles, and 250 pounds for HHD vehicles, based on six and 10 wheels, respectively. In MY 2021, we project an adoption rate of 10 percent, 30 percent in MY 2024, and 50 percent in MY 2027.

The agencies project that manufacturers will have sufficient options of other components eligible for material substitution so that this level of weight reduction will be feasible even where aluminum wheels are not selected by customers. Based on comments, we have removed aluminum transmission cases and aluminum clutch housings from the vocational lookup table in the regulations at 40 CFR 1037.520.

The only custom chassis standards on which we are predicating the standard on use of weight reduction is transit buses. In addition to compelling comment from UCS, we considered information from a 2014 study conducted by the APTA, where researchers found that fewer than half of all transit bus models comply with a 20,000 pound single axle weight limit when empty (i.e., at curb weight) and nearly all rear axles on transit buses longer than 35 feet exceed 24,000 pounds. According to APTA, the transit bus manufacturing industry has undertaken significant research and development activities directed at decreasing the curb weight of transit buses, and future opportunities to reduce transit bus curb weight include the use of lighter weight materials and alternative manufacturing techniques, but any weight reductions are expected to be costly for the manufacturing industry.[176] Because overloaded axles is a significant issue for transit buses, we believe it is appropriate for these rules to recognize it and provide a regulatory driver for lightweighting in this sector.

We have learned that manufacturers of concrete mixers, refuse trucks, and some high end buses have already made extensive use of lightweighting technologies in the baseline fleet. We also received persuasive comment cautioning us not to base the school bus standards on weight reduction due to potential conflicts with safety standards. In considering this information, we are allowing all vehicles certified using custom chassis regulatory subcategory identifiers to make use of weight reduction as a compliance flexibility, but only predicating standard stringency for transit buses on use of aluminum wheels at the same adoption rate as for the primary program.

2.9.5.1.6 Electrified Accessories

The agencies are predicating the final vocational vehicle standards in part on an adoption rate of five percent in MY 2021 of an electrified accessory package that achieves one percent fuel efficiency improvement. The previous discussion in Chapter 2.9.3.6 describes some pre-defined e-accessory improvements that are available in GEM for all vocational vehicles. In MY 2024 we increase this adoption rate to ten percent, and in MY 2027 the projected adoption rate is 15 percent, applicable in all subcategories excluding custom chassis. Although we believe some components could be electrified for some custom chassis, we do not have sufficient information to estimate an incremental cost associated with electrifying the more complex systems on custom chassis such as buses, or to project a specific adoption rate for this type of improvement.

2.9.5.1.7 Tire Pressure Systems

The agencies are predicating the vocational vehicle standards in part on widespread adoption of tire pressure monitoring systems. These are readily accepted by fleets as a cost-effective safety and fuel-saving measure. Because there may be some minor challenges in applying this technology to some vehicles where the payload and duty cycle lead to very high tire temperatures and pressures (as described above), we are applying a lower adoption rate to Urban and Multi-purpose vehicles than to Regional vehicles, as shown in Table 2-78. We are applying similarly lower adoption rates for refuse trucks and transit buses. We are not predicating the emergency vehicle or cement mixer standards on adoption of TPMS.

We are predicating the optional school bus, coach bus, transit bus, and refuse truck standards in part on limited adoption of automatic tire inflation systems (ATIS), as shown in

Table 2-78. These are more costly than TPMS, and require an onboard air supply and sometimes extensive plumbing of air lines.

Table 2-78 Vocational Tire Pressure System Adoption Rates

Technology	TPMS			ATIS		
	MY 2021	MY 2024	MY 2027	MY 2021	MY 2024	MY 2027
Regional	60	75	90	-	-	-
Multi-Purpose	50	65	80	-	-	-
Urban	40	55	70	-	-	-
School	70		80	-		20
Coach	50		75	10		25
Transit	40		50	10		20
Refuse	40		50	10		15
Motor Home	60		90	-		-

2.9.5.1.8 HFC Leakage

We project 100 percent adoption rate in all implementation years of the Phase 2 program for use of low leakage air conditioning system components to reduce direct emissions of HFC compounds from vocational vehicles.

2.9.6 Vocational Vehicle Standards

The derivation of the vocational vehicle standards incorporates several methods because some GEM inputs lend themselves to fleet-average values, some are vehicle specific (either on or off) and some improvements are not directly modeled in GEM. For each model year of standards, the agencies derived a scenario vehicle for each subcategory using the future model year engine map with fleet average input values for tire rolling resistance and weight reduction. For example, the MY 2021 HHD weight reduction input value was derived as follows: 210 pounds times 10 percent adoption yields 21 pounds. Those scenario vehicle performance results were combined in a post-process method with subcategory-specific improvements from idle reduction, axle disconnect, torque converter lockup, and transmission automation, using directly modeled GEM improvements comparing results with these technologies on or off the scenario vehicle. Subsequently, these performance values were combined with estimated improvement values of technologies not modeled in GEM, including TPMS, hybrids, and transmission gear efficiency.

The set of fleet-average inputs for tire CRR and weight reduction for MY 2021, as modeled in GEM is shown in Table 2-79, along with the respective adoption rates for idle reduction, axle disconnect, and torque converter lockup. The agencies derived the level of the MY 2024 standards by using the GEM inputs and adoption rates shown in Table 2-80 below. The agencies derived the level of the MY 2027 standards by using the GEM inputs and adoption rates shown in Table 2-81, below. Post-processing improvements for technologies not directly modeled, including TPMS, e-accessories, hybrids, and axle and transmission improvements are presented as a combined driveline improvement factor in Table 2-82 below. The values in this table for SI-powered vocational vehicles include improvements due to adoption of SI engine technology.

After obtaining individual GEM performance values for each of the subcategories, the agencies conducted fleet-mix averaging described in the Preamble in Section V.C. The resulting final vocational vehicle standards are presented in Table 2-83 through Table 2-88.

Table 2-79 GEM Inputs Used to Derive MY 2021 Vocational Vehicle Standards

CLASS 2B-5			CLASS 6-7			CLASS 8		
Urban	Multi-Purpose	Regional	Urban	Multi-Purpose	Regional	Urban	Multi-Purpose	Regional
SI Engine								
2018 MY 6.8L, 300 hp engine								
CI Engine								
2021 MY 7L, 200 hp Engine			2021 MY 7L, 270 hp Engine			2021 MY 11L, 350 hp Engine	2021 MY 11L, 350 hp Engine and 2021 MY 15L 455hp Engine[a]	
Torque Converter Lockup in 1st (adoption rate)								
30%	30%	30%	30%	30%	30%	10%	10%	0%
6x2 Disconnect Axle (adoption rate)								
0%	0%	0%	0%	0%	0%	0%	5%	10%
AES (adoption rate)								
30%	30%	40%	30%	30%	40%	30%	30%	40%
Stop-Start (adoption rate)								
10%	10%	0%	10%	10%	0%	0%	0%	0%
Neutral Idle (adoption rate)								
50%	50%	0%	50%	50%	0%	50%	50%	0%
Steer Tires (CRR kg/metric ton)								
7	6.8	6.8	6.8	6.7	6.7	6.4	6.2	6.2
Drive Tires (CRR kg/metric ton)								
7.2	6.9	6.9	7.8	7.5	7.5	7.8	7.5	7.5
Weight Reduction (lb)								
15	15	15	15	15	15	25	25	25

Note:
[a] The Multipurpose and Regional HHD standards are established using averages of configurations with different engines as described in Table 2-55.

Table 2-80 GEM Inputs Used to Derive MY 2024 Vocational Vehicle Standards

CLASS 2B-5			CLASS 6-7			CLASS 8		
Urban	Multi-Purpose	Regional	Urban	Multi-Purpose	Regional	Urban	Multi-Purpose	Regional
SI Engine								
2018 MY 6.8L, 300 hp engine								
CI Engine								
2024 MY 7L, 200 hp Engine			2024 MY 7L, 270 hp Engine			2024 MY 11L, 350 hp Engine	2024 MY 11L, 350 hp Engine and 2024 MY 15L 455hp Engine[a]	
Torque Converter Lockup in 1st (adoption rate)								
40%	40%	40%	40%	40%	40%	20%	20%	0%
6x2 Disconnect Axle (adoption rate)								
0%	0%	0%	0%	0%	0%	0%	15%	20%
AES (adoption rate)								
60%	60%	80%	60%	60%	80%	60%	60%	80%
Stop-Start (adoption rate)								
20%	20%	0%	20%	20%	0%	10%	10%	0%
Neutral Idle (adoption rate)								
70%	70%	0%	70%	70%	0%	70%	70%	0%
Steer Tires (CRR kg/metric ton)								
7.0	6.8	6.2	6.8	6.7	6.2	6.4	6.2	6.2
Drive Tires (CRR kg/metric ton)								
7.2	6.9	6.9	7.8	7.5	6.9	7.8	7.5	6.9
Weight Reduction (lb)								
45	45	45	45	45	45	75	75	75

Note:
[a] The Multipurpose and Regional HHD standards are established using averages of configurations with different engines as described in Table 2-55.

Table 2-81 GEM Inputs Used to Derive MY 2027 Vocational Vehicle Standards

CLASS 2B-5			CLASS 6-7			CLASS 8		
Urban	Multi-Purpose	Regional	Urban	Multi-Purpose	Regional	Urban	Multi-Purpose	Regional
SI Engine								
2018 MY 6.8L, 300 hp engine								
CI Engine								
2027 MY 7L, 200 hp Engine			2027 MY 7L, 270 hp Engine			2027 MY 11L, 350 hp Engine[a]	2027 MY 11L, 350 hp Engine and 2027 MY 15L 455hp Engine[a]	
Torque Converter Lockup in 1st (adoption rate)								
50%	50%	50%	50%	50%	50%	30%	30%	0%
6x2 Disconnect Axle (adoption rate)								
0%	0%	0%	0%	0%	0%	0%	25%	30%
AES (adoption rate)								
70%	70%	90%	70	70%	90%	70%	70%	90%
Stop-Start (adoption rate)								
30%	30%	0%	30%	30%	0%	20%	20%	0%
Neutral Idle (adoption rate)								
60%	60%	0%	60%	60%	0%	70%	70%	0%
Steer Tires (CRR kg/metric ton)								
6.8	6.2	6.2	6.7	6.2	6.2	6.2	6.2	6.2
Drive Tires (CRR kg/metric ton)								
6.9	6.9	6.9	7.5	6.9	6.9	7.5	6.9	6.9
Weight Reduction (lb)								
75	75	75	75	75	75	125	125	125

Note:
[a] The Multipurpose and Regional HHD standards are established using averages of configurations with different engines as described in Table 2-55.

In applying improvements due to technologies that were directly simulated in GEM but required post-processing to account for adoption rates less than 100 percent, each improvement was applied multiplicatively to the performance of the scenario vehicle that already had the improved tires, weight, and engine. The formula used follows the pattern illustrated in Equation 2-2. Similarly, the improvements due to technologies not modeled in GEM were included in this equation as noted. As described above in Chapter 2.9.3.1 for applicable technologies, the agencies used an energy-weighted and cycle-weighted average estimating method using cycle-specific CO_2 emissions reported in the GEM output file for baseline vehicles. For the idle cycles, the development version of GEM provides emissions in grams per hour. For the driving cycles, GEM provides emissions in grams per ton-mile. By multiplying those values by the average speed of each cycle and the default payload, GEM outputs in grams per ton-mile for the driving cycles are converted to grams per hour, and these are surrogates for the energy expended over those cycles. For example, in the medium heavy-duty Multipurpose subcategory with a payload of 5.6 tons, the baseline vehicle configuration has cycle-specific results of 284 g CO_2/ton-mile for the transient cycle, 202 g CO_2/ton-mile for the 55 cycle, 243 g CO_2/ton-mile for the 65 cycle, 10,226 g/hr for drive idle, and 5,284 g/hr for parked idle. By summing the products of the percent improvement expected over each cycle, the CO_2 emitted while completing the cycle, and the associated composite weighting of the cycle, and dividing by the sum of the products of the CO_2 emitted and cycle weightings, we obtain subcategory-specific improvement values for each technology. The complete set of calculations is available in the docket.[177]

Equation 2-2: Additional percent improvement beyond engine, tires, weight:

1-((1-DIF)*(1-AESa*AESe)*(1-NIa*NIe)*(1-SSa*SSe)*(1-NMTa*NMTe)*(1-TLa*TLe)*(1-ADa*ADe))

Where:

- DIF is the driveline improvement factor derived using engineering calculations, not directly modeled in GEM
- AESa and AESe are the adoption rate and effectiveness, respectively, in percent, of automatic engine shutdown, as modeled in GEM
- NIa and NIe are the adoption rate and effectiveness, respectively, in percent, of neutral idle, as modeled in GEM
- SSa and SSe are the adoption rate and effectiveness, respectively, in percent, of stop-start, as modeled in GEM
- NMTa and NMTe are the adoption rate and effectiveness, respectively, in percent, of a non-manual transmission, as modeled in GEM
- TLa and TLe are the adoption rate and effectiveness, respectively, in percent, of torque converter lockup in first gear, as modeled in GEM
- ADa and ADe are the adoption rate and effectiveness, respectively, in percent, of axle disconnect, as modeled in GEM

Table 2-82 Vocational Driveline Improvement Factors

	Class 2b-5			**Class 6-7**			**Class 8**		
	Urban	Multi-Purpose	Regional	Urban	Multi-Purpose	Regional	Urban	Multi-Purpose	Regional
CI 2021	0.019	0.018	0.018	0.019	0.019	0.019	0.019	0.018	0.017
CI 2024	0.041	0.036	0.029	0.041	0.036	0.029	0.040	0.036	0.026
CI 2027	0.061	0.053	0.037	0.061	0.053	0.037	0.060	0.052	0.034
SI 2021	0.027	0.026	0.026	0.028	0.027	0.027			
SI 2024	0.048	0.044	0.037	0.049	0.044	0.037			
SI 2027	0.067	0.059	0.045	0.068	0.060	0.045			

Table 2-83 and Table 2-84 present EPA's CO_2 standards and NHTSA's fuel consumption standards, respectively, for chassis manufacturers of Class 2b through Class 8 vocational vehicles for the beginning model year of the program, MY 2021.

Table 2-83 EPA CO_2 Standards for MY2021 Class 2b-8 Vocational Vehicles

EPA Standard For Vehicle With CI Engine Effective MY2021 (gram CO_2/ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	424	296	308
Multi-Purpose	373	265	261
Regional	311	234	205
EPA Standard for Vehicle with SI Engine Effective MY2021 (gram CO_2/ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7 (and C8 Gasoline)	
Urban	461	328	
Multi-Purpose	407	293	
Regional	335	261	

Table 2-84 NHTSA Fuel Consumption Standards for MY2021 Class 2b-8 Vocational Vehicles

NHTSA STANDARD FOR VEHICLE WITH CI ENGINE EFFECTIVE MY 2021 (FUEL CONSUMPTION GALLON PER 1,000 TON-MILE)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	41.6503	29.0766	30.2554
Multi-Purpose	36.6405	26.0314	25.6385
Regional	30.5501	22.9862	20.1375
NHTSA Standard for Vehicle with SI Engine Effective MY 2021 (Fuel Consumption gallon per 1,000 ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7 (and C8 Gasoline)	
Urban	51.8735	36.9078	
Multi-Purpose	45.7972	32.9695	
Regional	37.6955	29.3687	

EPA's vocational vehicle CO_2 standards and NHTSA's fuel consumption standards for the MY 2024 stage of the program are presented in Table 2-85 and Table 2-86, respectively. These reflect broader adoption rates of vehicle technologies already considered in the technology basis for the MY 2021 standards. The standards for vehicles powered by CI engines also reflect that in MY 2024, the separate engine standard would be more stringent, so the vehicle standard keeps pace with the engine standard.

Table 2-85 EPA CO_2 Standards for MY2024 Class 2b-8 Vocational Vehicles

EPA STANDARD FOR VEHICLE WITH CI ENGINE EFFECTIVE MY2024 (GRAM CO_2/TON-MILE)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	385	271	283
Multi-Purpose	344	246	242
Regional	296	221	194
EPA Standard for Vehicle with SI Engine Effective MY2024 (gram CO_2/ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7 (and C8 Gasoline)	
Urban	432	310	
Multi-Purpose	385	279	
Regional	324	251	

Table 2-86 NHTSA Fuel Consumption Standards for MY2024 Class 2b-8 Vocational Vehicles

NHTSA STANDARD FOR VEHICLE WITH CI ENGINE EFFECTIVE MY 2024 (FUEL CONSUMPTION GALLON PER 1,000 TON-MILE)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	37.8193	26.6208	27.7996
Multi-Purpose	33.7917	24.1650	23.7721
Regional	29.0766	21.7092	19.0570
NHTSA Standard for Vehicle with SI Engine Effective MY 2024 (Fuel Consumption gallon per 1,000 ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7 (and C8 Gasoline)	
Urban	48.6103	34.8824	
Multi-Purpose	43.3217	31.3942	
Regional	36.4577	28.2435	

EPA's vocational vehicle CO_2 standards and NHTSA's fuel consumption standards for the full implementation year of MY 2027 are presented in Table 2-87 and Table 2-88, respectively. These reflect even greater adoption rates of the same vehicle technologies considered in the basis for the previous stages of the Phase 2 standards. The MY 2027 standards for vocational vehicles powered by CI engines reflect additional engine technologies consistent with those on which the separate MY 2027 CI engine standard is based.

Table 2-87 EPA CO_2 Standards for MY2027 Class 2b-8 Vocational Vehicles

EPA STANDARD FOR VEHICLE WITH CI ENGINE EFFECTIVE MY2027 (GRAM CO_2/TON-MILE)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	367	258	269
Multi-Purpose	330	235	230
Regional	291	218	189
EPA Standard for Vehicle with SI Engine Effective MY2027 (gram CO_2/ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7 (and C8 Gasoline)	
Urban	413	297	
Multi-Purpose	372	268	
Regional	319	247	

Table 2-88 NHTSA Fuel Consumption Standards for MY2027 Class 2b-8 Vocational Vehicles

NHTSA STANDARD FOR VEHICLE WITH CI ENGINE EFFECTIVE MY 2027 (FUEL CONSUMPTION GALLON PER 1,000 TON-MILE)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7	Heavy Heavy-Duty Class 8
Urban	36.0511	25.3438	26.4244
Multi-Purpose	32.4165	23.0845	22.5933
Regional	28.5855	21.4145	18.5658
NHTSA Standard for Vehicle with SI Engine Effective MY 2027 (Fuel Consumption gallon per 1,000 ton-mile)			
Duty Cycle	Light Heavy-Duty Class 2b-5	Medium Heavy-Duty Class 6-7 (and C8 Gasoline)	
Urban	46.4724	33.4196	
Multi-Purpose	41.8589	30.1564	
Regional	35.8951	27.7934	

2.9.6.1 GEM-Based Custom Chassis Standards

Table 2-89 and Table 2-90 present EPA's CO_2 standards and NHTSA's fuel consumption standards, respectively, for custom vocational chassis. These standards may be selected by custom chassis manufacturers, who retain the option of electing to certify to the primary standards. (As already noted, these custom chassis vehicles will be required to use engines meeting the Phase 2 engine standards, and thus, should generally incorporate the same engine improvements as other vocational vehicles). The agencies have analyzed the technological feasibility of achieving these optional fuel consumption and CO_2 standards, based on projections of actions manufacturers may take to reduce fuel consumption and emissions to achieve the standards, and believe that the standards are technologically feasible throughout the regulatory useful life of the program.

These custom vehicle-level standards are predicated on a simpler set of vehicle technologies than the primary Phase 2 standard for vocational vehicles. In developing these optional standards, the agencies have evaluated the current levels of fuel consumption and emissions, the kinds of technologies that could be utilized by manufacturers to reduce fuel consumption and emissions, the associated lead time, the associated costs for the industry, fuel savings for the owner/operator, and the magnitude of the CO_2 reductions and fuel savings that may be achieved. After examining the possibilities of vehicle improvements, the agencies are basing the vehicle-level standards for coach buses, motor homes, school buses, transit buses, and refuse trucks on the performance of workday idle reduction technologies, tire pressure systems, simplified transmission improvements, and further tire rolling resistance improvements. The agencies are basing the standards for concrete mixers and emergency vehicles on use of tires with current average levels of rolling resistance. The EPA-only air conditioning standard is based on leakage improvements. Of these technologies, we believe that improved tire rolling resistance, neutral idle, and air conditioning leakage improvements are available today and may be adopted as early as MY 2021. The vehicle technology that we believe will benefit from more development time for engine and vehicle integration is stop-start idle reduction.

The MY 2024 standards reflect broader adoption rates of vehicle technologies already considered in the technology basis for the MY 2021 standards. EPA's custom chassis CO_2 standards and NHTSA's fuel consumption standards for the full implementation year of MY 2027 reflect even greater adoption rates of the same vehicle technologies considered as the basis for the MY 2024 standards.

As with the other regulatory categories of heavy-duty vehicles, NHTSA and EPA are adopting standards that apply to custom chassis vocational vehicles at the time of production, and EPA is adopting standards for a specified period of time in use (e.g., throughout the regulatory useful life of the vehicle).

The optional standards shown below were derived using baseline vehicle models with many attributes similar to those developed for the primary program, as described above in Chapter 2.9.2. For better transparency with respect to the incremental difference between the MY 2021 and MY 2027 vehicle standards, we have modeled a certified MY 2027 engine for both vehicle model years of optional custom chassis standards. Thus, chassis manufacturers who do not make their own engines may compare the two model years of standards presented in Table 2-89 and Table 2-90 and know that any differences are due solely to vehicle-level technologies.

Table 2-89 EPA Emission Standards for Custom Chassis (gram CO_2/ton-mile)

	MY 2021	MY 2027
Coach Bus	210	205
Motor Home	228	226
School Bus	291	271
Transit	300	286
Refuse	313	298
Mixer	319	316
Emergency	324	319

Table 2-90 NHTSA Fuel Consumption Standards for Custom Chassis (gallon per 1,000 ton-mile)

	MY 2021	MY 2027
Coach Bus	20.6287	20.1375
Motor Home	22.3969	22.2004
School Bus	28.5855	26.6208
Transit	29.4695	28.0943
Refuse	30.7466	29.2731
Mixer	31.3360	31.0413
Emergency	31.8271	31.3360

2.9.6.2 Summary of Vocational Vehicle Package Costs

The agencies have estimated the costs of the technologies that could be used to comply with the final Phase 2 vocational vehicle standards. The estimated costs are shown in Table 2-91 for MY2021, in for MY2024, and for MY 2027. Fleet average costs are shown for light, medium and heavy HD vocational vehicles in each duty-cycle-based subcategory – Urban, Multi-Purpose, and Regional. As shown in Table 2-91, in MY 2021 these range from approximately $900 for MHD and LHD Regional vehicles, up to $2,600 for HHD Regional vehicles. Those two lower-cost packages reflect zero hybrids, and the higher-cost package reflects significant adoption of automated transmissions. Many changes have been made to the cost estimates since proposal. In the RIA Chapter 2.12.2, the agencies present vocational vehicle technology package costs differentiated by MOVES vehicle type. These costs do not indicate the per-vehicle cost that may be incurred for any individual technology. For more specific information about the agencies' estimates of per-vehicle costs, please see the RIA Chapter 2.11. The engine costs listed represent the cost of an average package of diesel engine technologies as set out in RIA Chapter 2.7.7. Individual technology adoption rates for engine packages are described in RIA Chapter 2.9.1.2.2. For gasoline vocational vehicles, the agencies are projecting adoption of engine improvements that are reflected exclusively in the vehicle standard, see Chapter 2.9.1.2.1 above) for an estimated $138 added to the average SI vocational vehicle package cost beginning in MY 2021.

The details behind all these costs are presented in RIA Chapter 2.11, including the markups and learning effects applied and how the costs shown here are weighted to generate an overall cost for the vocational segment. These estimates have changed significantly from those presented in the proposal, due to changes in projected technology adoption rates as well as changes in direct costs that reflect comments received.

Table 2-91 Technology Package Incremental Costs for Vocational Vehicles for MY2021[a,b] (2013$)

	LIGHT HD			MEDIUM HD			HEAVY HD		
	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional
Engine[c]	$298	$298	$298	$275	$275	$275	$275	$275	$275
Tires	$0	$27	$27	$9	$9	$9	$13	$13	$13
Tire Pressure Monitoring	$123	$154	$184	$123	$154	$184	$233	$292	$350
Transmission	$217	$217	$217	$217	$217	$217	$186	$413	$1,519
Axle related	$13	$13	$13	$13	$13	$13	$20	$26	$32
Weight Reduction	$69	$69	$69	$69	$69	$69	$250	$250	$250
Idle reduction	$155	$155	$12	$160	$160	$12	$68	$68	$12
Hybridization	$178	$178	$0	$178	$178	$0	$178	$178	$0
Air Conditioning[d]	$22	$22	$22	$22	$22	$22	$22	$22	$22
Other [e]	$30	$30	$30	$49	$49	$49	$89	$89	$89
Total	$1,106	$1,164	$873	$1,116	$1,146	$851	$1,334	$1,625	$2,562

Notes:

[a] Costs shown are for the 2021 model year and are incremental to the costs of a vehicle meeting the Phase 1 standards. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to RIA Chapter 2.11.

[b] Note that values in this table include projected technology penetration rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated vehicle subcategories.

[c] Engine costs shown are for a light HD, medium HD or heavy HD diesel engines. For gasoline-powered vocational vehicles we are projecting $139 of additional engine-based costs beyond Phase 1.

[d] EPA's air conditioning standards are presented in Preamble Section V.C.

[e] Other incremental technology costs include electrified accessories and advanced shift strategy.

Table 2-92 presents estimated incremental costs for MY2024 for light, medium and heavy HD vocational vehicles in each duty-cycle-based subcategory – Urban, Multi-Purpose, and Regional. As shown, these range from approximately $1,300 for MHD and LHD Regional vehicles, up to $4,000 for HHD Regional vehicles. The increased costs above the MY 2021 values reflect increased adoption rates of individual technologies, while the individual technology costs are generally expected to remain the same or decrease, as explained in the RIA Chapter 2.11. For example, Chapter 2.11.7 presents MY 2024 hybridization costs that range from $6,046 to $15,872 per vehicle for vocational vehicles.

Table 2-92 Technology Package Incremental Costs for Vocational Vehicles for MY2024[a,b] (2013$)

	LIGHT HD			MEDIUM HD			HEAVY HD		
	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional
Engine[c]	$446	$446	$446	$413	$413	$413	$413	$413	$413
Tires	$0	$31	$33	$10	$10	$33	$13	$13	$53
Tire Pressure Monitoring	$155	$183	$211	$155	$183	$211	$294	$347	$401
Transmission	$276	$276	$276	$276	$276	$276	$222	$1,032	$2,193
Axle related	$24	$24	$24	$24	$24	$24	$37	$54	$60
Weight Reduction	$186	$186	$186	$186	$186	$186	$684	$684	$684
Idle reduction	$248	$248	$21	$256	$256	$21	$242	$242	$21
Hybridization	$550	$550	$0	$653	$653	$0	$844	$844	$0
Air Conditioning[d]	$20	$20	$20	$20	$20	$20	$20	$20	$20
Other[e]	$54	$54	$54	$89	$89	$89	$162	$162	$162
Total	$1,959	$2,018	$1,272	$2,082	$2,110	$1,274	$2,932	$3,813	$4,009

Notes:
[a] Costs shown are for the 2024 model year and are incremental to the costs of a vehicle meeting the Phase 1 standards. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to RIA Chapter 2.11.
[b] Note that values in this table include projected technology penetration rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated vehicle subcategories.
[c] Engine costs shown are for a light HD, medium HD or heavy HD diesel engines. For gasoline-powered vocational vehicles we are projecting $136 of additional engine-based costs beyond Phase 1.
[d] EPA's air conditioning standards are presented in Preamble Section V.C.
[e] Other incremental technology costs include electrified accessories and advanced shift strategy.

Table 2-93 presents estimated incremental costs for MY2027 for light, medium and heavy HD vocational vehicles in each duty-cycle-based subcategory – Urban, Multi-Purpose, and Regional. As shown, these range from approximately $1,500 for MHD and LHD Regional vehicles, up to $5,700 for HHD Regional vehicles. Although the Multipurpose and Urban subcategories are projected to adopt some high-cost technologies such as hybrids, the HHD Regional package comes out more costly because it reflects 90 percent adoption of automated transmissions. The engine costs shown represent the average costs associated with the MY 2027 vocational diesel engine standard described in Section II.D of the Preamble. For gasoline vocational vehicles, the agencies are projecting adoption of engine technologies with an estimated $125 added to the average SI vocational vehicle package cost in MY 2027. Further details on how these SI vocational vehicle costs were estimated are provided above in Chapter 2.9.1.

Table 2-93 Technology Package Incremental Costs for Vocational Vehicles for MY2027[a,b] (2013$)

	LIGHT HD			MEDIUM HD			HEAVY HD		
	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional	Urban	Multi-purpose	Regional
Engine[c]	$481	$481	$481	$446	$446	$446	$446	$446	$446
Tires	$12	$24	$24	$6	$24	$24	$12	$36	$36
Tire Pressure Monitoring	$187	$214	$240	$187	$214	$240	$355	$405	$456
Transmission	$271	$271	$293	$271	$271	$293	$220	$990	$3,269
Axle related	$35	$35	$35	$35	$35	$35	$52	$82	$87
Weight Reduction	$294	$294	$294	$294	$294	$294	$1,102	$1,102	$1,102
Idle reduction	$303	$303	$23	$314	$314	$23	$365	$365	$23
Hybridization	$857	$857	$0	$1,032	$1,032	$0	$1,353	$1,353	$0
Air Conditioning[d]	$20	$20	$20	$20	$20	$20	$20	$20	$20
Other[e]	$73	$73	$77	$122	$122	$127	$227	$227	$231
Total	$2,533	$2,571	$1,486	$2,727	$2,771	$1,500	$4,151	$5,025	$5,670

Notes:
[a] Costs shown are for the 2027 model year and are incremental to the costs of a vehicle meeting the Phase 1 standards. These costs include indirect costs via markups along with learning impacts. For a description of the markups and learning impacts considered in this analysis and how it impacts technology costs for other years, refer to RIA Chapter 2.11.
[b] Note that values in this table include projected technology penetration rates. Therefore, the technology costs shown reflect the average cost expected for each of the indicated vehicle subcategories.
[c] Engine costs shown are for a light HD, medium HD or heavy HD diesel engines. For gasoline-powered vocational vehicles we are projecting $125 of additional engine-based costs beyond Phase 1.
[d] EPA's air conditioning standards are presented in Preamble Section V.C.
[e] Other incremental technology costs include electrified accessories and advanced shift strategy.

2.10 Technology Application and Estimated Costs – Trailers

The agencies are adopting standards for trailers specifically designed to be pulled by Class 7 and 8 tractors. These standards are expressed as CO_2 and fuel consumption standards, and would apply to each trailer with respect to the emissions and fuel consumption that would be expected for a specific standard type of tractor pulling such a trailer. EPA and NHTSA believe it is appropriate to establish standards for trailers separately from tractors because they are separately manufactured by distinct companies which control every aspect of their design and thus are the appropriate entity to certify compliance; the agencies are not aware of any manufacturers that currently assemble both the finished tractor and the trailer. The legal basis for setting separate standards for trailers is discussed in the Preamble in Section I.E. This section of the RIA describes the analyses performed by the agencies as we developed the trailer program.

2.10.1 Trailer Subcategories Evaluated

The agencies evaluated several trailer subcategories for these rules. Though many of the same technologies are available for dry and refrigerated vans, the agencies evaluated these trailer types separately. The transport refrigeration unit (TRU) commonly located at the front of refrigerated trailers adds weight, has the potential to impact the aerodynamic characteristics of the trailer, and may limit the types of aerodynamic devices that can be applied. Additionally, "long box" vans in lengths 50 feet or longer and "short box" vans less than 50 feet in length were evaluated separately due to differences in both weight and use patterns. We have chosen 53-foot box vans to represent all long box vans in both compliance modeling and testing. Short box vans are represented by solo 28-foot vans. The agencies did test other trailer lengths and the results are presented in this chapter.

The agencies identified a list of work-performing devices that are sometimes added to standard box vans, which may inhibit the use of some aerodynamic devices. Trailer manufacturers may designate box vans that are restricted from using aerodynamic devices in one location on the trailer as "partial-aero" box vans. We believe these trailers have the ability to adopt single aerodynamic technologies, but do not expect them to be able to meet the same stringencies as the "full-aero" box vans throughout the program.

Additionally, manufacturers may designate box vans that have work-performing devices in two locations such that they inhibit the use of *all* practical aerodynamic devices as "non-aero" box vans that would not be expected to adopt aerodynamic technologies at any point in the program. These trailers have standards based on the use of tire technologies only. Similarly, we recognize the potential for CO_2- and fuel consumption reduction from three non-box trailers (e.g., tankers, flatbeds, and container chassis). Standards for these non-box trailers are also based on the use of tire technologies and do not reflect the use of aerodynamic technologies.

In summary, the agencies are adopting standards for ten trailer subcategories:

- Long box (longer than 50 feet) dry vans
- Long box (longer than 50 feet) refrigerated vans
- Short box (50 feet and shorter) dry vans
- Short box (50 feet and shorter) refrigerated vans
- Partial-aero long box dry vans
- Partial-aero long box refrigerated vans
- Partial-aero short box dry vans
- Partial-aero short box refrigerated vans
- Non-aero box vans (all lengths of dry and refrigerated vans)
- Non-box trailers (tanker, platform, container chassis only)

The analysis in the following sections describes our evaluation of the cost and effectiveness of the technologies used in the design of the Phase 2 trailer program. We conclude with a description of the development of our GEM-based equation that box van manufacturers will use for compliance.

2.10.2 Defining the Trailer Technology Packages

The impact of a trailer on the overall fuel efficiency and CO_2 emissions of a tractor-trailer vehicle varies depending on three main characteristics of the trailer: aerodynamic drag, tire rolling resistance, and weight. In this section, we outline the technologies that address these characteristics and the ones the agencies evaluated for the standards.

2.10.2.1 Aerodynamic Drag Reduction

The rigid, rectangular shape of box vans creates significant aerodynamic drag and makes them ideal candidates for aerodynamic technologies that can reduce drag and improve fuel consumption and CO_2 emissions. Current aerodynamic technologies for box vans have shown significant drag reductions, as discussed below. These technologies are designed to create a smooth transition of airflow from the tractor, around the trailer, and beyond the trailer. Box vans provide opportunities to address drag at the front, rear, and underside of the trailer, and the agencies considered several types of aerodynamic devices designed to address drag at all of these points. Table 2-94 lists common aerodynamic technologies for use on box vans and a description of their intended impact. Several versions of each of these technologies are commercially available and have seen increased adoption over the past decade. Performance of these devices varies based on their design, their location and orientation on the trailer, and the vehicle speed.

Table 2-94 Common Bolt-on Aerodynamic Technologies for Box Trailers

LOCATION ON TRAILER	EXAMPLE TECHNOLOGIES	INTENDED IMPACT ON AERODYNAMICS
Front	Front fairings and gap-reducing fairings	Reduce cross-flow through gap and smoothly transition airflow from tractor to the trailer
Rear	Rear fairings, boat tails and flow diffusers	Reduce pressure drag induced by the trailer wake
Underside	Side fairings and skirts, and underbody devices	Manage flow of air underneath the trailer to reduce turbulence, eddies and wake

2.10.2.1.1 Comparison of Technology Performance: SmartWay-Verification and GEM Results

SmartWay-verified technologies are evaluated on 53-foot dry vans. The verified technologies are grouped into bins that represent one percent, four percent, or five percent fuel savings relative to a typical long-haul tractor-trailer at 65-mph cruise conditions. Use of verified aerodynamic devices totaling at least five percent fuel savings, along with verified tires, qualifies a 53-foot dry van trailer for the “SmartWay Trailer” designation. In 2014, EPA expanded the program to include refrigerated vans and provided a “SmartWay Elite” designation if fleets adopt verified tires and aerodynamic equipment providing nine percent or greater fuel savings. To-date, ten aerodynamic technology packages from six manufacturers have received the SmartWay Elite designation. We may refer to SmartWay verification levels in this analysis, since the trailer industry is most familiar with these values as a measure of trailer performance.

It is important to note that the cruise speed results presented in SmartWay do not necessarily match the results of EPA’s Greenhouse gas Emissions Model (GEM), which is the tool the agencies will use for trailer standard development and compliance evaluation. Figure 2-56 shows a comparison of the CO_2 reductions calculated for the three individual drive cycles simulated in GEM: 65-mph cruise, 55-mph cruise, and a transient cycle. It also shows reductions using a combination of the three GEM cycles with the cycle weightings the agencies are assigning to represent long-haul and short-haul operation. The long-haul weighting is calculated as 86 percent 65-mph cruise, 9 percent 55-mph cruise, and 5 percent transient. The short-haul weighting is 64 percent 65-mph, 17 percent 55-mph, and 19 percent transient. These percent values are based on the drive cycle weightings used in EPA's Phase 1 tractor program.[178]

This figure could be used to estimate the difference in performance that can be expected when comparing a constant, 65-mph cruise test similar to SmartWay's performance tests (solid black line) to the results from GEM (wide dashes) or to other driving conditions. These results suggest that the SmartWay Elite target improvement of nine percent would be closer to eight percent using GEM's long-haul simulation, while tractor-trailers that drive closer to 55-mph would likely see improvements of 7 percent. It can also be seen that tractor-trailers driving under highly transient conditions are likely to observe much smaller improvements. These results are for illustrative purposes only and do not provide an exact correlation between test results, results from GEM, and real-world results.

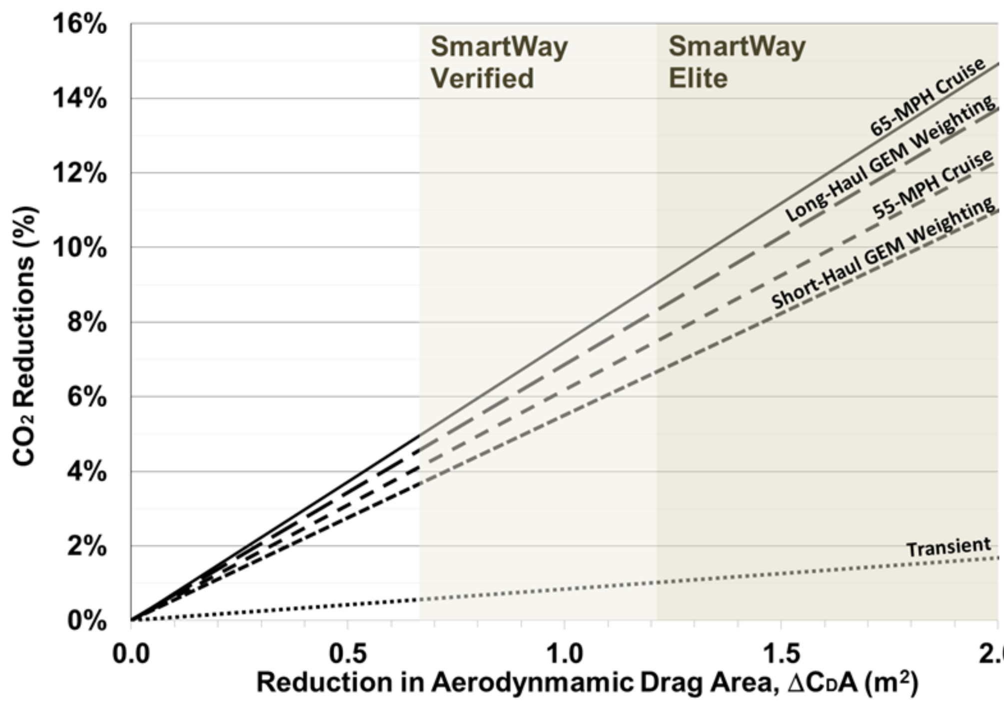


Figure 2-56 GEM Drive Cycles' Impact on Aerodynamic Performance for a 53-Foot Box Dry Van with a Tire Rolling Resistance Level of 5.0 kg/ton and No Weight Reduction

While the SmartWay program is currently limited to 53-foot dry and refrigerated vans, the Phase 2 program includes shorter trailers. Figure 2-57 compares the GEM drive cycles for a simulated 28-foot dry van, including two shaded bands to indicate the performance of technologies evaluated in our aerodynamic test program. Without a SmartWay performance level for short trailers, the technology bands in the Figure 2-56 and Figure 2-57 cannot be directly compared, but it can be seen that, qualitatively, skirts on 28-foot vans have much lower performance compared to SmartWay Verified technologies (e.g., many skirts on 53-foot vans). Additionally, short box vans (50 feet and shorter in length) are simulated with the GEM's short haul drive cycle weightings, which results in performance that is up to two percent lower than expected from constant 65-mph cruise speeds in the aerodynamic drag range considered in this program.

Similar to the trend shown in Figure 2-56, even short box vans that operate in 100 percent transient conditions experience a non-zero benefit from the use of aerodynamic devices. While the benefit is low in these conditions, we expect a majority of short box vans, even those that consider themselves exclusively "short-haul", will spend some time at highway speeds of 55-mph or faster, at which time the trailer will achieve CO_2 and fuel consumption reductions of at least one percent.

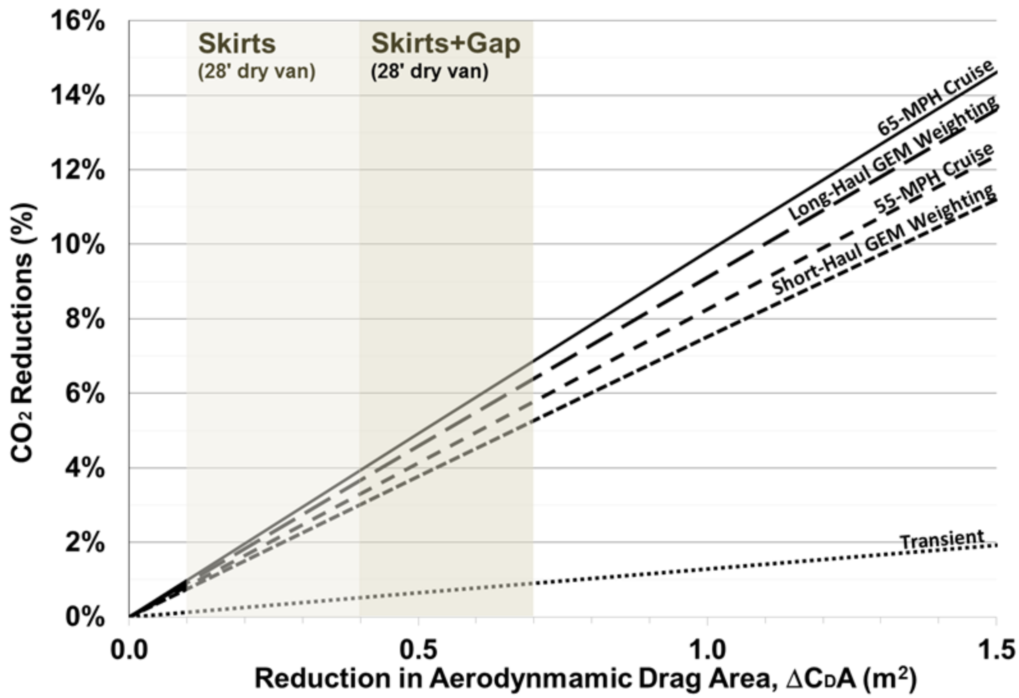


Figure 2-57 GEM Drive Cycles' Impact on Aerodynamic Performance for a 28-Foot Box Dry Van with a Tire Rolling Resistance Level of 5.0 kg/ton and No Weight Reduction

2.10.2.1.2 Aerodynamic Testing Results

EPA collected aerodynamic test data for many of the technologies mentioned previously on several tractor-trailer configurations using the four test methods outlined in our test procedures: coastdown, constant speed, wind tunnel, and CFD. The testing included multiple tractor models, trailer models (including 53-foot, 48-foot, 33-foot, and 28-foot lengths), and aerodynamic technologies. The results that follow are from coastdown, wind tunnel and CFD testing. Detailed descriptions of test setup and generation of these results, including constant speed, are provided in Chapter 3.2.

In this rulemaking, the aerodynamic performance of a tractor-trailer vehicle is quantified by the aerodynamic drag area, C_dA (coefficient of drag multiplied by frontal area), which is a function of both tractor and trailer aerodynamic characteristics. The following sections highlight the impact of tractor and trailer characteristics, wind, test procedure, and trailer devices on aerodynamic performance. These results were used to create the aerodynamic bins for trailer manufacturers to use in compliance.

2.10.2.1.2.1 Evaluation Trailer Model Effects

The aerodynamic performance of basic trailer models does not vary significantly from one manufacturer to the next. The wind tunnel results shown in Figure 2-58 indicate there is very little difference in performance between trailer manufacturers for their basic trailer models. The results shown are an average of six tractor models with each 53-foot trailer in the given configuration. A maximum variation of 0.2 m^2 is observed between trailer models with combinations of skirts and a tail. The other configurations have variation less than 0.1 m^2. These results suggest that the aerodynamic designs of current box vans do not drastically differ by manufacturer, and the addition of bolt-on technologies is expected to result in similar aerodynamic improvements from these base configurations.

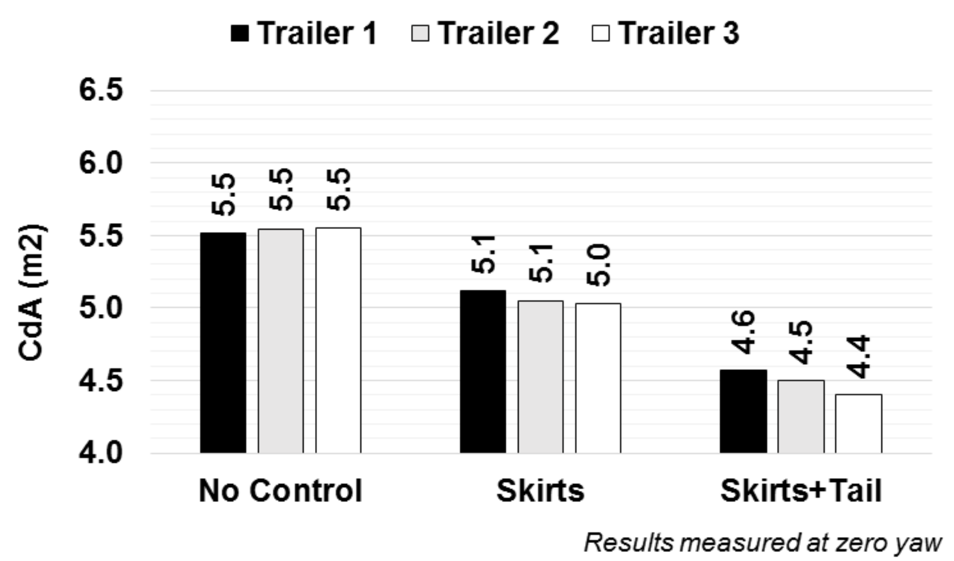


Figure 2-58 Variation in Performance of Trailer Devices due to Trailer Manufacturer; Average Absolute C_dA of Six Tractors Pulling each 53-foot Basic Dry Van Model

2.10.2.1.2.2 Evaluation Tractor Model Effects

Figure 2-59 shows that there is more variation in aerodynamic performance when considering tractor models. All of the tractors shown in the figure are Class 8 high roof sleeper cabs with similar aerodynamic features, but from four separate manufacturers. The absolute C_dA ranges from 0.2 m^2 to 0.3 m^2 depending on trailer configuration.

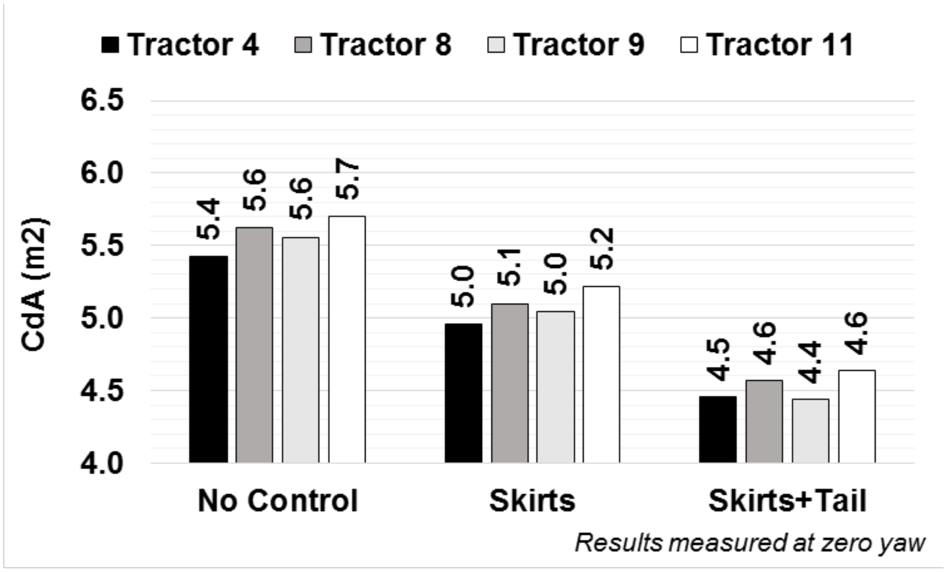


Figure 2-59 Variation in Aerodynamic Performance of Trailer Devices due to Tractor Manufacturer; Average Absolute C_dA of Three 53-Foot Dry Vans Pulled by each Tractor Model

By subtracting the absolute C_dA value of the "Skirts" and "Skirts+Tail" configurations from their corresponding "No Control" configuration, we obtain a change in CdA (i.e., "delta C_dA") that gives the relative impact of adding devices compared to a no control trailer. Considering a delta C_dA instead of absolute values reduces some of the impact of the tractor characteristics and consequently reduces the variation by nearly half. Figure 2-60 shows that the variation observed between tractor models is 0.15 m^2 or less when using delta C_dA. This reduction in variation due to vehicle characteristics is one of the reasons the agencies are choosing a delta C_dA approach for the Phase 2 trailer program's aerodynamic testing. The aerodynamic performance results in the rest of this section will be presented as delta C_dA.

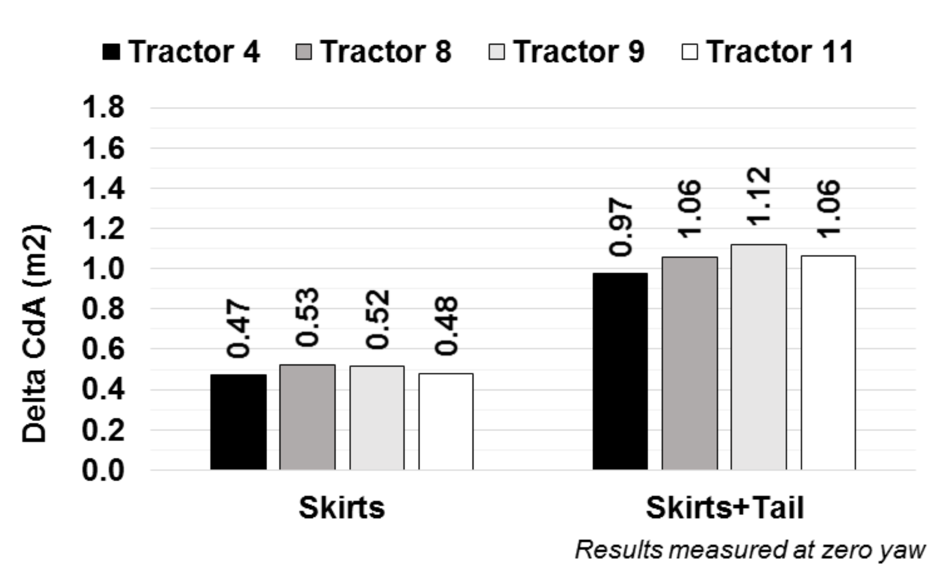


Figure 2-60 Variation in Aerodynamic Performance of Trailers Devices due to Tractor Manufacturer Relative to No Control Trailer; Average Delta C_dA of Three 53-Foot Dry Vans Pulled by each Tractor Model

2.10.2.1.2.3 Evaluation of Yaw Effects

As discussed in Chapter 2.8, the tractor program, which is using wind-averaged drag results, specifies the coastdown test procedures as a reference test method and manufacturers apply a correction factor to "alternative methods" (i.e., wind tunnel, CFD, or constant speed) in order to maintain consistency between methods. The trailer program did not propose to require a reference test, in order to reduce the test burden for manufacturers and allow them to choose an appropriate test method for their needs and resources. The agencies also proposed standards that were developed using zero yaw drag results. The agencies recognize that the benefits of aerodynamic devices for trailers can be better seen when measured considering multiple yaw angles, but we did not propose to accept wind-averaged drag results. The coastdown procedure has near-zero wind restrictions and we were concerned that devices that show larger benefits at greater yaw angles would not be captured in coastdown testing.

Commenters indicated that it was unlikely they would use coastdown testing for compliance. Instead, they would rely on wind tunnel and CFD. Additional commenters suggested that we consider wind-averaged results for the trailer program and, accordingly, we evaluated the coastdown and wind tunnel results again, including new results from tests that were completed following publication of the NPRM.

To evaluate the effect of wind, we compared the zero yaw and wind-averaged results from EPA's wind tunnel tests. All wind-average results in this section are calculated from a fourth-order polynomial fit to the measured yaw curve. As described in Chapter 3, the agencies found that the average of the results from the equation at positive and negative 4.5 degrees yaw angles was consistent with the wind-averaged results at 7 degrees and 65 miles per hour vehicle speed (see Chapter 3.2 of this RIA, and 40 CFR 1037.810).

The results shown in Figure 2-61 compare the delta C_dA at zero yaw with the wind-averaged values for tests of six different tractors pulling three different models of 53-foot dry vans. Figure 2-62 shows a similar comparison for two sets of tractor-trailers with solo 28-foot dry vans. The wind-averaged analysis generally results in a narrower range of performance for a given technology. The gap reducer technology shows minimal benefit under a zero yaw analysis for the 53-foot vans, but a measurable benefit when yaw angles are considered. Tails also show a noticeable improvement under yaw conditions. The short van results show larger increases in delta C_dA when wind-averaged results are considered.

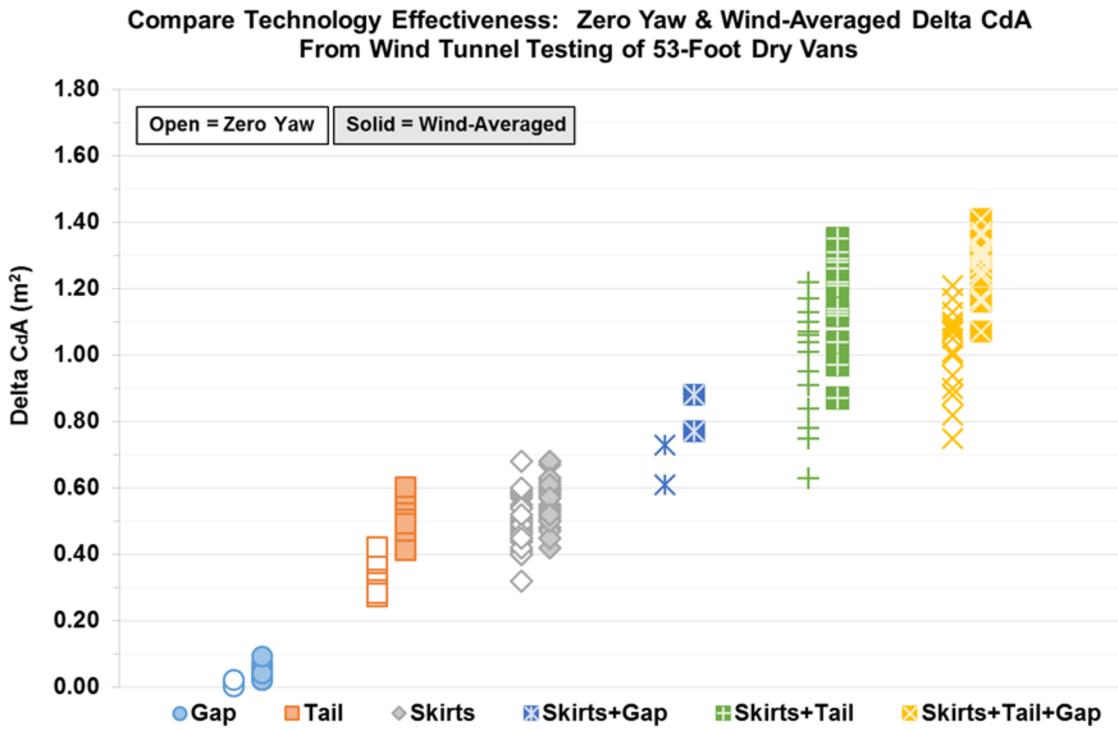


Figure 2-61 Comparison of Zero Yaw and Wind-Averaged Delta C_dA for Wind Tunnel Tests of 53-Foot Dry Vans; Results from Seven Class 8 Sleeper Cab Tractors and Three Dry Van Models

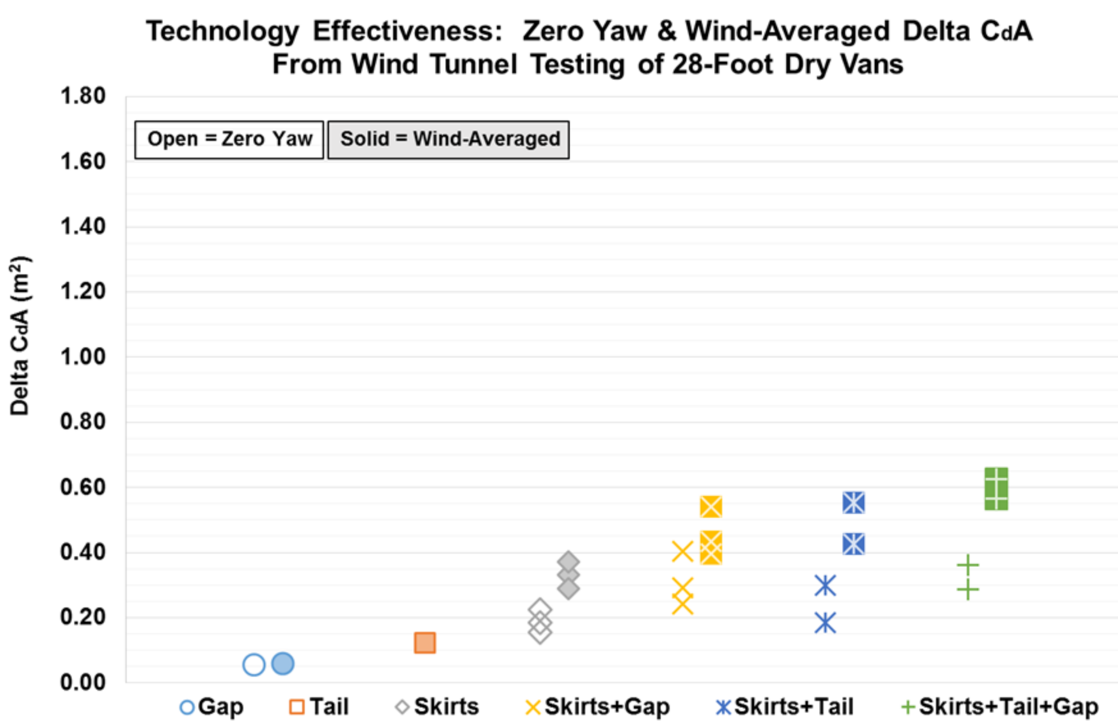


Figure 2-62 Comparison of Zero Yaw and Wind-Averaged Delta C_dA for Wind Tunnel Tests of 28-Foot Dry Vans; Results from Two Class 7 Day Cab Tractors and Two Dry Van Models

In light of trailer manufacturers' preference for wind tunnel and CFD, and the benefit observed when testing at higher yaw angles, we are adopting standards based on wind-averaged delta C_dA values. The following section describes the variation seen in our testing of the three test methods, including a comparison of the wind-averaged wind tunnel and CFD results to the coastdown values at near-zero yaw angles.

2.10.2.1.2.4 Evaluation of Test Procedure Effects

As mentioned previously, EPA evaluated trailer aerodynamic performance using three test procedures: coastdown, wind tunnel and CFD. EPA performed its wind tunnel testing at ARC Indy using a 1/8th-scale model of several tractor-trailers. We also obtained data from National Research Council of Canada (NRC) from a 30 percent scale model in their 9-meter wind tunnel.[179] Figure 2-63 compares the coastdown and two wind tunnel facilities. The tractor and trailer used in the coastdown and two wind tunnels are similar, but are not exact matches in these tests and we cannot directly compare the numerical results. The coastdown tractor corresponds to Tractor #3 in the coastdown results of Chapter 3.2 and the ARC wind tunnel model corresponds to Tractor #5 in the ARC wind tunnel results.[180] The NRC model is a generic tractor developed by NRC. The comparison of trailers with skirts suggest that the coastdown and wind tunnel methods produce similar results with these devices, and the effect of accounting for higher yaw does not improve the performance with these devices. The limited yaw effect with skirts was also observed in Figure 2. The yaw impact does appear to be larger when a tail is included in the trailer configuration. The two wind tunnel results are within 0.2 m^2, but the coastdown result is much lower than both wind tunnel values.

Figure 2-63 Comparison of Coastdown and Wind Tunnel Test Methods using Similar Tractor-Trailers with a 53-Foot Dry Van

We also compared CFD results from two separate CFD packages. One is based on Reynolds Averaged Navier-Stokes and the other is Lattice-Boltzmann-based. The two packages were tested using the same tractor-trailer model, though there were some differences in grid generation techniques, and open-road environments with a Reynolds number of 1.1e6. Figure

2-64 compares coastdown and wind tunnel results to those predicted by the CFD models. The coastdown tractor corresponds to Tractor #1 in the coastdown results of Chapter 3.2 and the wind tunnel tractor corresponds to Tractor #11 in the ARC wind tunnel results.[181] The results show some difference between the CFD packages in the skirt configuration, but the differences remain within 0.2 m^2 between all methods shown. Similar to zero yaw results in Figure 2-61, the coastdown results are much lower for the configuration with the tail, and we believe this is more of a yaw effect than a variability between methods.

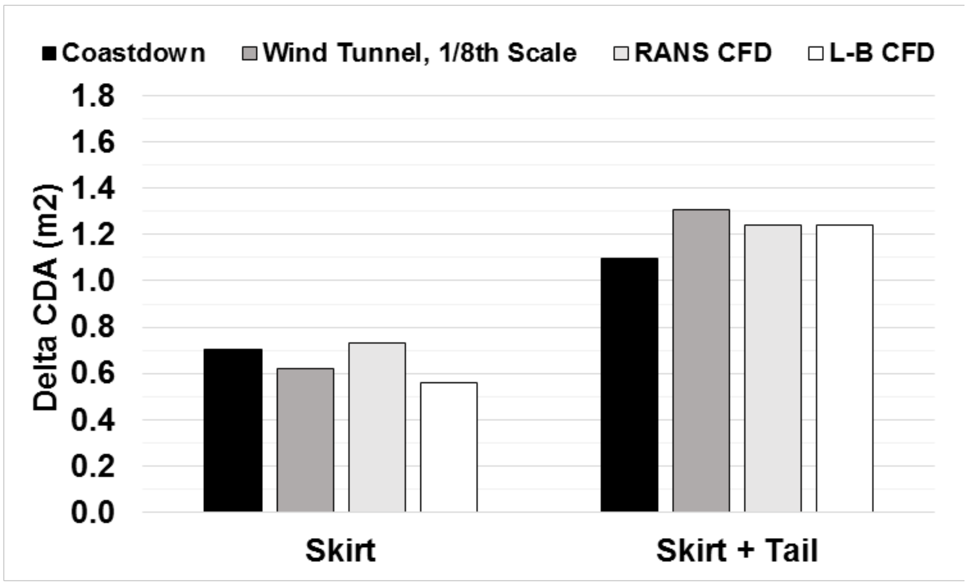


Figure 2-64 Comparison of Coastdown, Wind Tunnel and CFD Test Methods using Similar Tractor-Trailers with a 53-Foot Dry Van

In general, Figure 2-63 and Figure 2-64 show that the test methods are reasonably close for a given tractor-trailer configuration. We believe the lower values from the coastdown tests in configurations that include tails are likely due to the relatively low yaw angles of that test method, which was also seen in Figure 2-61 for 53-foot dry vans when comparing the zero yaw and wind-averaged results of tail configurations.

Figure 2-65 displays all of the aerodynamic test results for used in our analysis of 53-foot dry vans for the given configurations. Each data point is an individual test and the markers differ based on test method. You can see that the three test methods (which include two wind tunnel facilities and two CFD packages) produce similar results for most trailer configurations. With the exception of the one coastdown data point for the tail configuration, even the coastdown results at near-zero yaw are grouped relatively close to the results from the other test procedures.

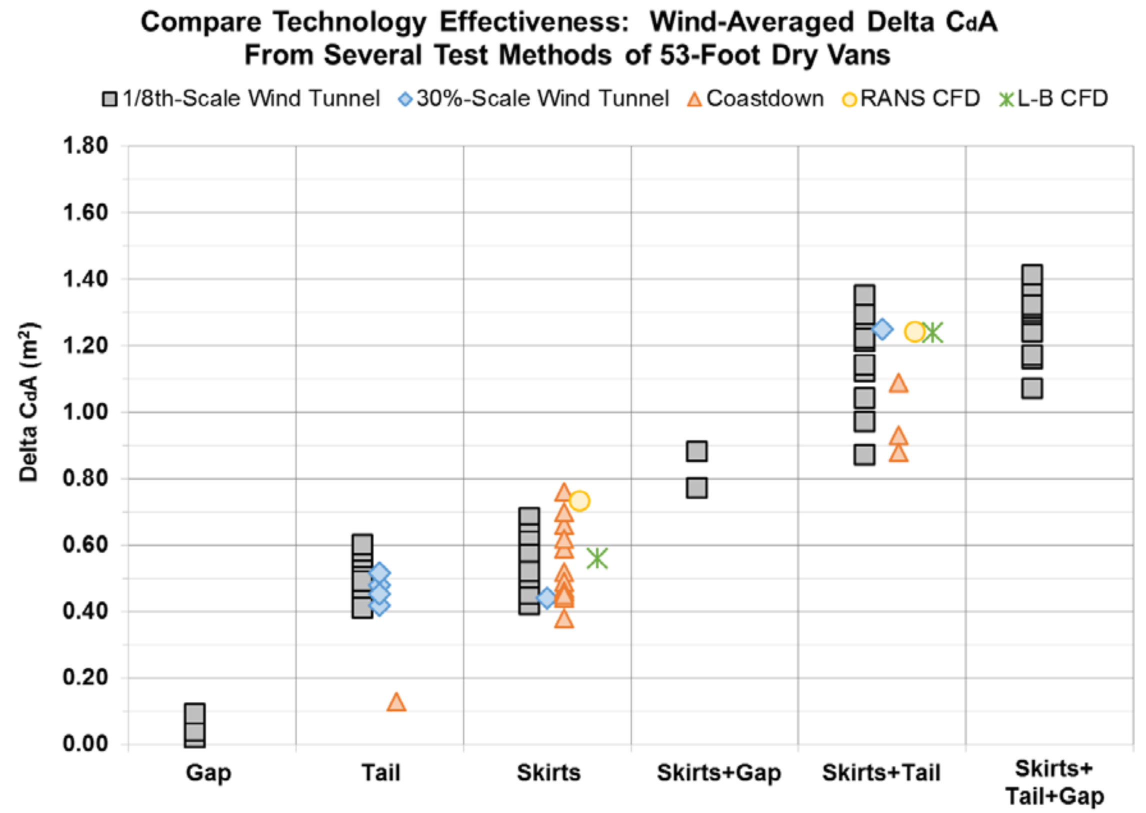


Figure 2-65 Technology Effectiveness for Several Devices on 53-Foot Dry Vans using Three Test Methods, Including Two Wind Tunnel Facilities and Two CFD Packages

2.10.2.1.2.5 Evaluation of Aerodynamic Device Performance

Bolt-on aerodynamic technologies can be used individually or in combination. This section summarizes our comparison of the performance of devices that were tested individually and in combination with other devices. EPA evaluated several combinations in its aerodynamic testing and those results are shown below.

Figure 2-66 shows the performance of three bolt-on devices when installed on three different 1/8th-scale trailer models in the wind tunnel. Each trailer is pulled by the same tractor (i.e., Tractor #4 from the ARC wind tunnel data). These three devices are often used in combination and it was of interest to investigate if the performance of these devices was additive when combined, or if the devices work synergistically to achieve greater reductions in combination.

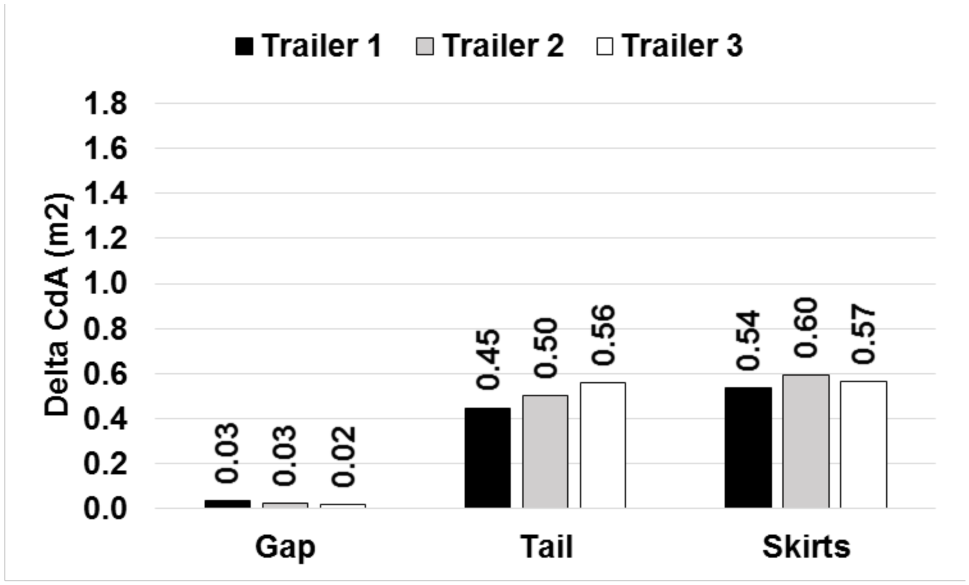


Figure 2-66 Wind Tunnel Performance of Individual Bolt-On Trailer Devices; Tractor #4 (ARC Wind Tunnel Data) Pulling Each Trailer

In comparison to the values shown in Figure 2-66, Figure 2-67 shows that the devices are more effective when combined, compared to the sum of their individual performances. For example, the sum of the individual performances of the tail and skirts on Trailer #1 is 0.98 m^2 and the sum of all three device performances is 1.02 m^2. Yet, when tested in combination, they achieve 1.13 m^2 and 1.17 m^2, respectively. Trailer #3 has similar levels of improvement for the combined devices (about 13 percent compared to the sum of the individual performances). However, the improvement from Trailer #2 is only about four percent. While these results suggest there may be synergies between these particular device combinations, we would not be able to predict a consistent improvement across all tractor and trailer models.

Figure 2-67 Wind Tunnel Performance of Combinations of Bolt-On Trailer Devices; Tractor #4 (ARC Wind Tunnel Data) Pulling Each Trailer

We tested a couple sets of devices that did not show an improvement when combined together in the wind tunnel. We tested a highly aero-equipped tractor (Tractor #5) pulling Trailer #1 with wheel covers installed. The delta C_dA for the wheelcovers was just 0.02 m^2, arguably within error in the test. The same tractor-trailer was tested with a combination of skirts, a tail, and a gap reducer for an improvement of 1.07 m^2. When the wheelcovers were added to the skirts/tail/gap combination, the resulting improvement was 1.08 m^2. This combination of devices did not show a significant benefit together. We also tested an aerodynamic system that composed of an underbody device and a rear top fairing. This system achieved a wind-averaged delta C_dA of 0.07 m^2 from the wind tunnel. The system was then tested in combination with a gap reducer and wheelcovers and the combination performed worse with a delta C_dA of 0.04 m^2. We did not test the same tractor-trailer with the gap reducer or wheelcovers individually and they may have had a negligible impact on the performance alone, but it does appear that these particular devices resulted in some dis-synergies when in combination.

These results suggest that there is not a consistent trend when devices are used in combination. Some of the most common devices show a range of improvements when combined, while others show no benefit or even a disbenefit. We expect that device manufacturers will continue to improve their designs and create new devices that may or may not be appropriate for use with other technologies. We cannot predict future performance and must rely on continued testing and validation of these devices, individually and in combination, to ensure the performance is accurately captured.

2.10.2.1.2.6 Evaluation of Trailer Length Effects

The results shown so far were for the 53-foot and 28-foot vans on which we are basing the standards and compliance program. EPA's wind tunnel testing also included an investigation of the aerodynamic performance of 33-foot and 48-foot dry vans and tandem 28-foot and 33-foot dry vans. This section begins with a comparison of the aerodynamic performance of trailers of different lengths, and concludes with a comparison of solo and tandem configurations. The agencies are including these results to give a general idea of the relative performance that could be expected when trailers of different lengths or configurations are used. Manufacturers will continue to use data from solo 28-foot and 53-foot trailer testing for compliance.

Figure 2-68 compares the performance of four dry van lengths. The day cab (DC) tractor is the same for the 28-foot, 48-foot, and 53-foot trailers shown. The 33-foot van was modeled with a MY 2014 sleeper cab in a separate test set. We are including the 33-foot results in the plot for qualitative assessment. You can see that the individual devices do not show a consistent trend in performance based on trailer length, but there is a noticeable trend of increased performance with increased length for combinations of devices.

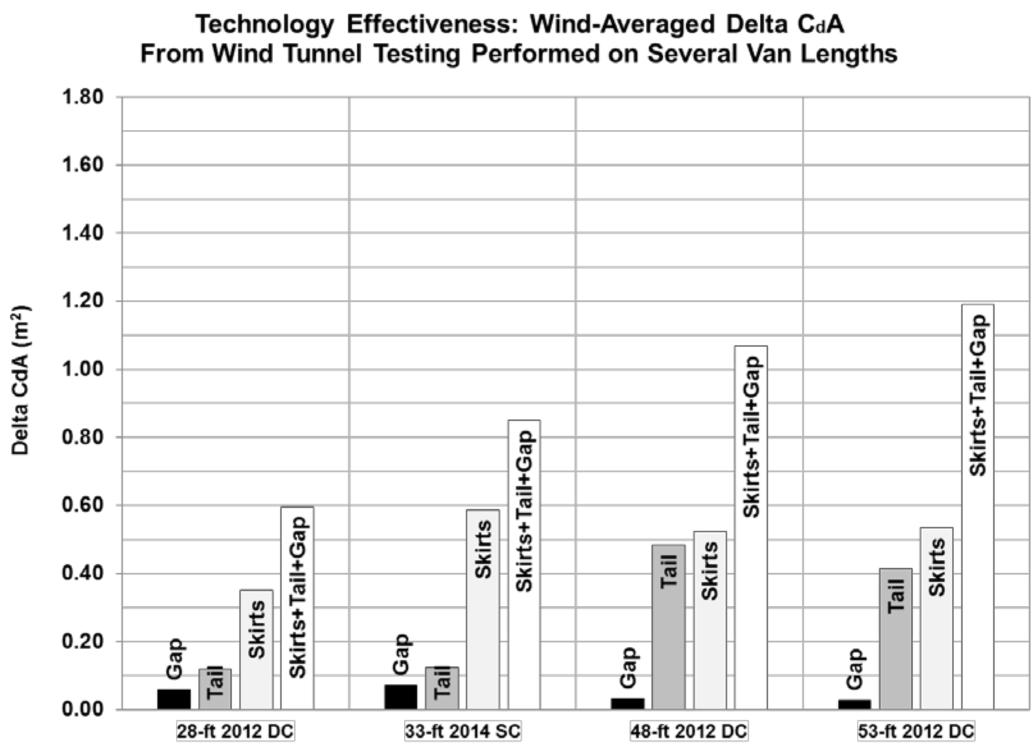


Figure 2-68 Comparison of Aerodynamic Performance of Devices on Several Dry Van Lengths; 2012 DC is a 6x4 Day Cab Tractor, and 2014 SC is a 6x4 Sleeper Cab

It should be noted that the 53-foot van is the only "long box van" in this set of trailers. The 28-foot, 33-foot, and 48-foot trailers are considered "short box vans" in this trailer program and are represented by a 28-foot trailer for compliance. These results suggest that the shorter surrogate test trailer will underestimate performance for the longer trailers in its regulatory subcategory, providing a conservative measure of potential benefits when the longer trailers are in use.

EPA also tested the 28-foot and 33-foot van in a tandem configuration. Each van pair was tested with skirts on the first trailer only, skirts on the second trailer only, skirts on both trailers, skirts and a gap reducer on both trailers, and skirts and a gap reducers on both trailers with a tail on the second trailer. As shown in Figure 2-69, the skirts perform similarly for a given length van when they are on an individual van only, but provide almost twice the benefit when installed on both vans. The addition of the tail further improves the performance of the pair of trailers.

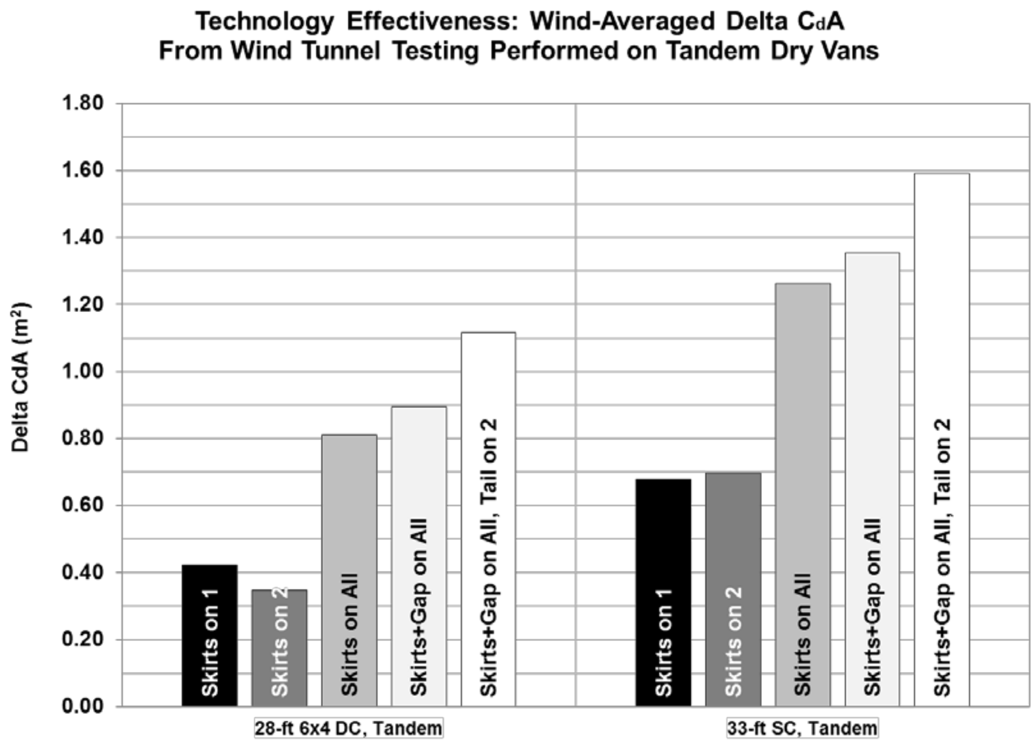


Figure 2-69 Comparison of Aerodynamic Device Performance on Tandem Dry Vans; the 28-foot Van is Pulled by a 6x4 Day Cab Tractor, and the 33-foot Van is Pulled by as a Sleeper Cab Tractor

Figure 2-70 compares the solo 28-foot and 33-foot dry van performances to the corresponding tandem configuration performances for three sets of trailer devices. For the tandem configurations, the skirts and gap reducers are installed on both vans in the pair, and the tail is only installed on the rear-most van. The results are presented as delta C_dA and it's important to note that the baseline C_dA for the solo and tandem configuration is much different. The C_dA of the solo no-control (baseline) 28-foot van is 6.0 m^2. The same trailer in tandem produces a baseline C_dA of 6.8 m^2, due to the increased number of locations for turbulence to be generated. The solo 33-foot trailer baseline, with additional length to generate turbulence, changes from 5.7 m^2 to 7.0 m^2 when in tandem. It is expected that the addition of trailer devices to limit the turbulence, would have a greater impact on the tandem configurations compared to the solo vans. In fact, for each of these sets of trailers, the tandem configuration resulted in a near-doubling of aerodynamic improvement with the addition of devices. This is encouraging, since many 28-foot vans are currently operated in tandem without any aerodynamic devices, and simply adding skirts to each van can drastically improve the aerodynamic performance of the vehicle. Additionally, the standards for short box vans are not predicated on the use of tails, but these results suggest that there is an added performance benefit if customers were to purchase and deploy a tail on vans that may be used in tandem.

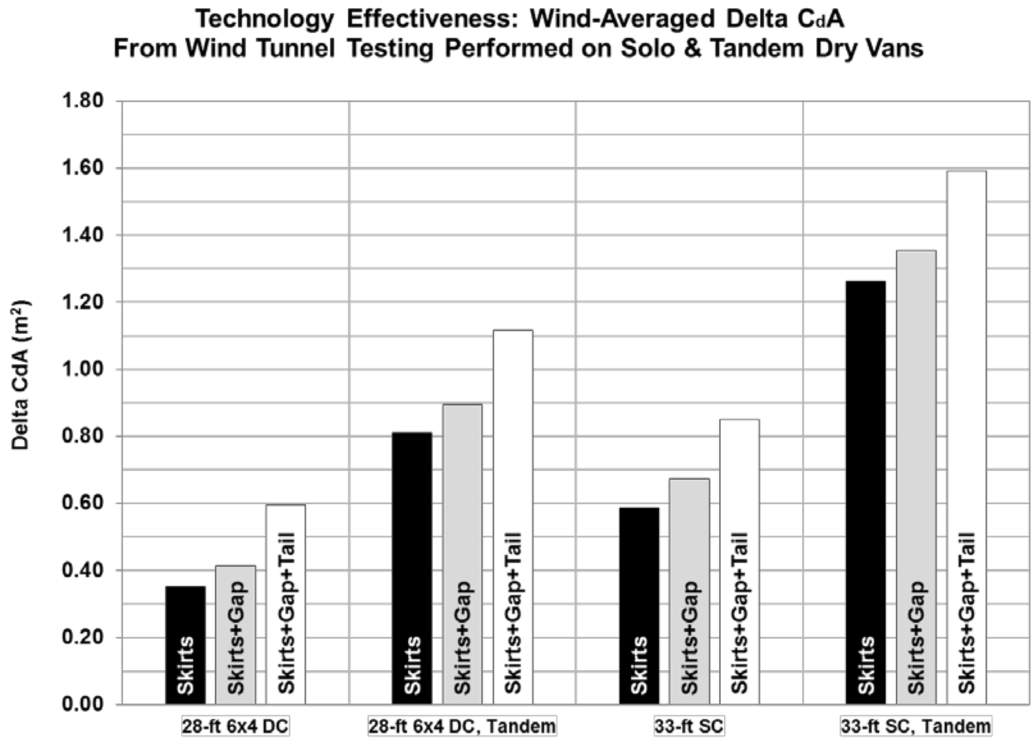


Figure 2-70 Comparison of Aerodynamic Device Performance on Solo and Tandem Dry Vans; the 28-foot Van is Pulled by a 6x4 Day Cab Tractor, and the 33-foot Van is Pulled by as a Sleeper Cab Tractor

2.10.2.1.3 Performance Bins for Aerodynamic Technologies

The agencies developed aerodynamic bins based on delta C_dA to encompass technologies that are expected to provide similar improvements in drag, and which are intended to account for variability due to tractor model, test method, device manufacturer, and trailer manufacturer. The proposed bins were based on zero yaw test results. For the final rulemaking, we are adopting standards based on wind-averaged aerodynamic test data, for reasons explained immediately below. In addition, we completed several test programs after the NPRM. The bins described here reflect the new test results, and our use of wind-averaged values.

Figure 2-71 overlays the aerodynamic bins that we proposed in the NPRM on our recent wind-averaged test results. While some of the technologies fit into those bins, many of the same technologies overlap two or more bins. In addition, when the results are wind-averaged, tails and skirts have similar performance, suggesting that they should be in the same bin.

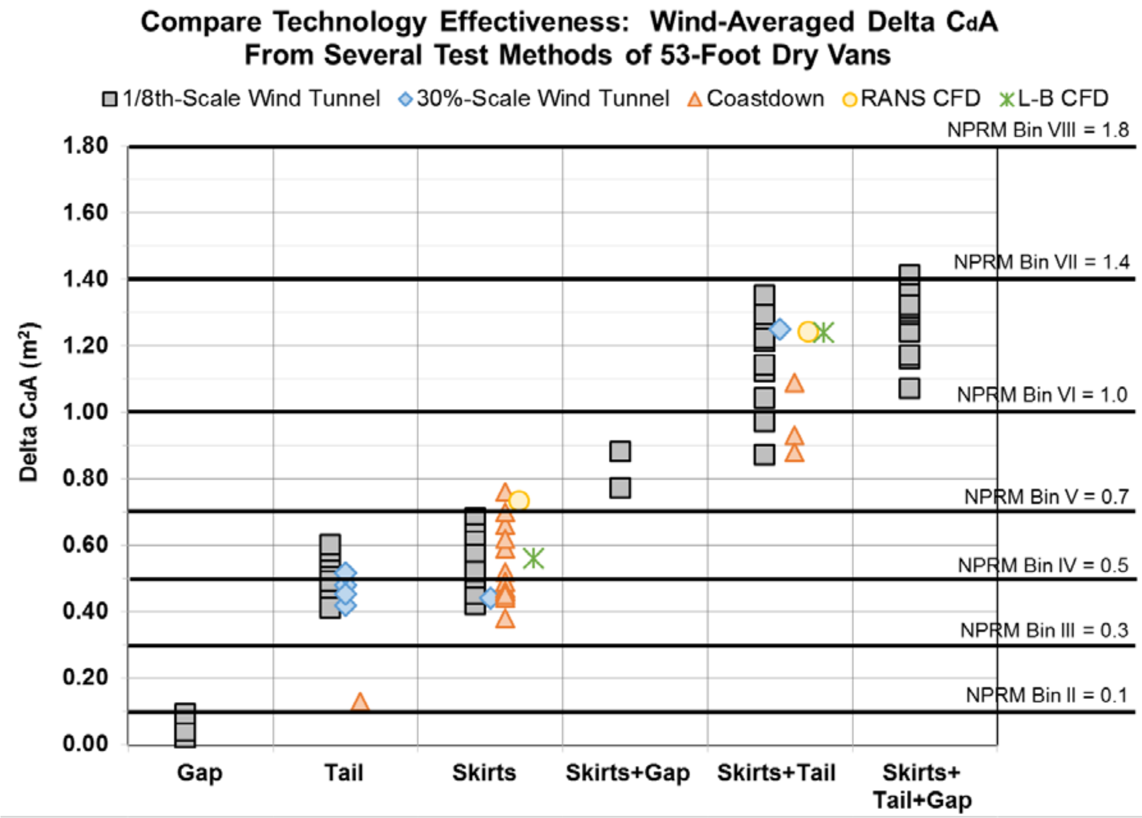


Figure 2-71 Wind-Averaged Trailer Aerodynamic Test Results Relative to the NPRM Bins

We adjusted the aerodynamic bins to reflect the additional data and the use of wind-averaged results, as seen in Figure 2-72. The most notable difference is that we expanded the lower bins. The Bin II threshold delta CdA remains 0.1 m^2. Anything below that threshold is assigned a value of zero. The NPRM Bins III, IV and V were reduced to two bins, such that Bins II, III and IV are each a width of 0.3 m^2. Technologies that achieve a threshold value of 0.4 m^2 or greater, such as most of the skirts and tails tested, are assigned to Bin III. Bin IV, which has a threshold of 0.7 m^2, includes the configurations tested with skirts and gap reducers, and some of the lower performing skirt and tail combinations. A majority of the skirts and tail combinations and skirts, tails and gap reducer combinations are in Bin V, which is assigned a value of 1.0 m^2. These combinations represent the highest performing devices that we tested. Bins V, VI, and VII are identical to the highest bins from the NPRM. The agencies observed one device combination that presently meets Bin VI, suggesting that this bin can be met with combinations of existing aerodynamic technologies. The agencies believe that there is ample lead time to optimize additional existing Bin V combinations such that they can also meet Bin VI by MY 2027.

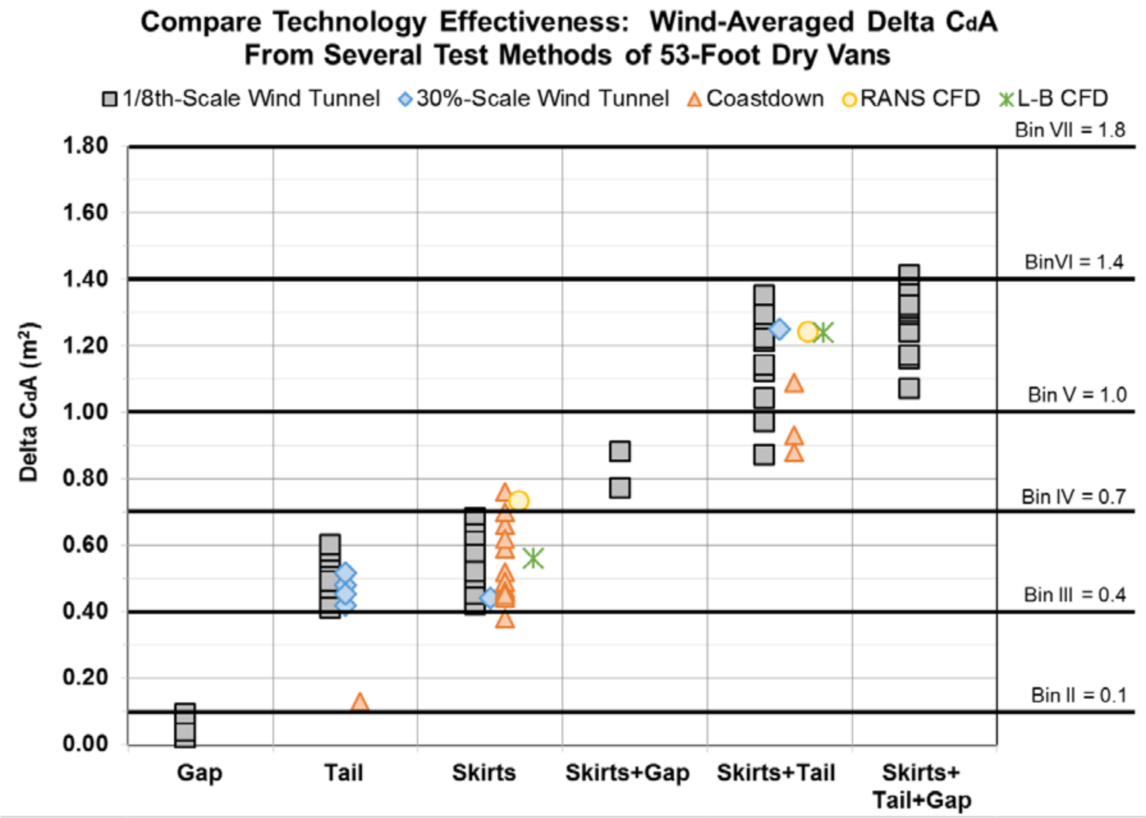


Figure 2-72 Wind-Averaged 53-Foot Dry Van Aerodynamic Test Results Relative to the Aerodynamic Bins that will be Used for Compliance

Much of our testing focused on 53-foot trailers, but we did test several combinations of solo 28-foot trailers that will be used to represent all short box vans in compliance testing. Figure 2-73 shows the wind-averaged results for two 28-foot dry vans in several configurations from wind tunnel and coastdown testing. Similar to the 53-foot dry van results, the performance of tails and skirts fit into the same bin. It is interesting to note that these results suggest a 28-foot dry van with skirts and a gap reducer have similar performance as a skirts and tail combination.

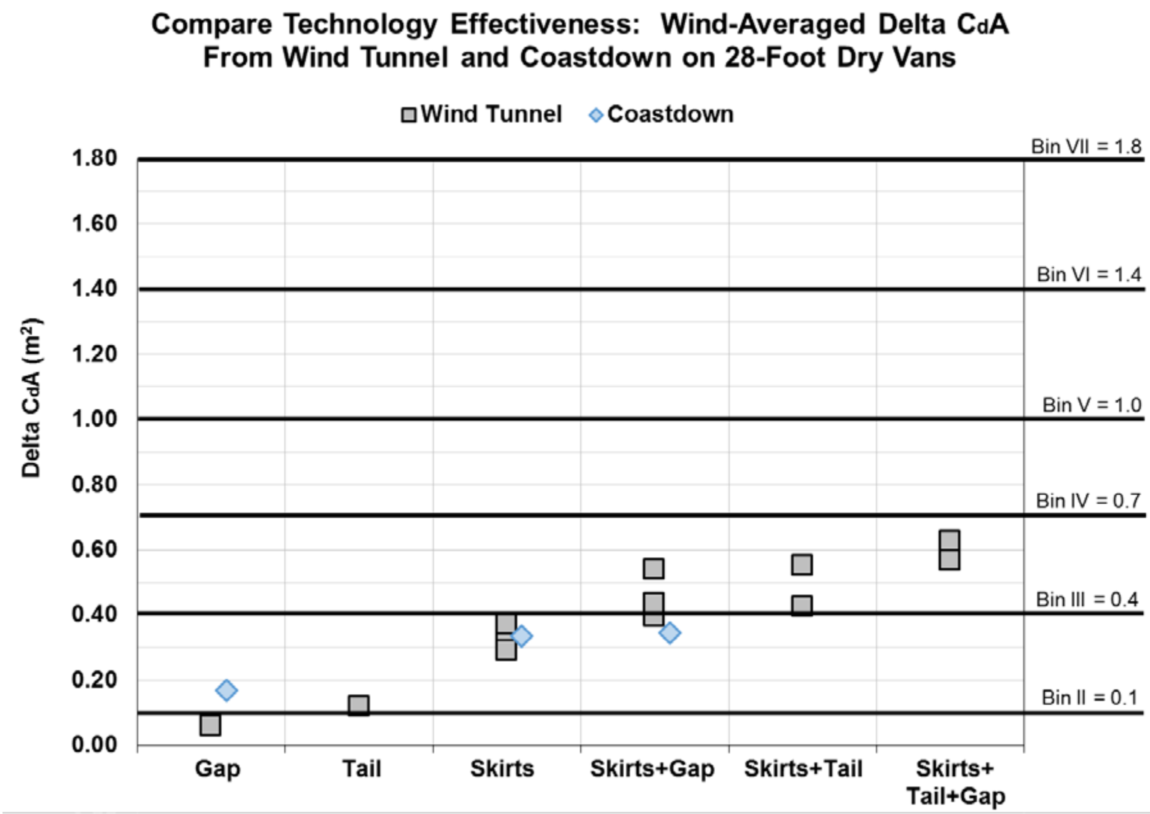


Figure 2-73 Wind-Averaged 28-Foot Dry Van Aerodynamic Test Results Relative to the Aerodynamic Bins that will be Used for Compliance

While the agencies have chosen to test and regulate 28-foot box vans individually, they are often pulled in a tandem configuration, which restricts the types of aerodynamic devices that can be applied on the rear of the trailers. We expect rear devices such as boat tails would not be practical for 28-foot box vans, since those devices are only deployable when the trailer is in the rear position. We did not base our standards on the use of rear devices. However, the short box van subcategories include other trailer lengths (e.g., 40-foot and 48-foot) that would be able to use rear aerodynamic devices and we do not restrict the use of those devices as a means of achieving compliance. We presented results from 28-foot configurations that included tails to demonstrate the level of performance that can be expected when operating with those devices. Table 2-95 below summarizes the bin structure that the agencies will use as the basis for compliance. Also included in the table are example aerodynamic packages that the agencies used for our cost analysis summarized below in Chapter 2.10.4.3 and fully described in in Chapters 2.11 and 2.12. Note that the same technologies are assumed to work for dry and refrigerated vans in each length category. We assume manufacturers that wish to achieve bins where our example packages include gap reducers can have a different, similarly effective technology installed in a separate location on refrigerated vans without additional cost. In each set of example technologies, we present packages for bin performance that were not observed in our testing. We considered these packages to be “Optimized Combinations” and assume their cost to be that of an appropriately sized skirt, tail and gap reducer. The highest bins in each category is assumed to require changes to the design of the trailer, and we did not estimate a cost for those bins.

Table 2-95 Aerodynamic Technology Bins used to Evaluate Trailer Benefits and Costs

BIN	DELTA CDA		EXAMPLE TECHNOLOGY PACKAGES	
	Measured	GEM Input Value	Long Vans	Short Vans
Bin I	< 0.10	0.0	No Aero Devices	No Aero Devices
Bin II	0.10 - 0.39	0.1	High Performing Gap Reducer	Skirts or Tail
Bin III	0.40 - 0.69	0.4	Skirts or Tail	Skirts + Gap Reducer
Bin IV	0.70 - 0.99	0.7	Skirts + Gap Reducer	Optimized Combinations
Bin V	1.00 - 1.39	1.0	Skirts + Tail	Changes to Trailer Design
Bin VI	1.39 - 1.79	1.4	Optimized Combinations	
Bin VII	> 1.80	1.8	Changes to Trailer Design	

The agencies used EPA's Greenhouse gas Emissions Model (GEM) vehicle simulation tool to conduct this analysis. Within GEM, the aerodynamic performance of each trailer subcategory is evaluated by subtracting the delta C_dA shown in Table 2-95 from the C_dA value representing a specific standard tractor pulling a trailer with no CO_2- or fuel consumption-reducing technologies (i.e., a "no-control" trailer). EPA's aerodynamic testing of Class 8 high roof sleeper cab tractors pulling standard 53-foot dry vans in its no-control baseline configuration (zero aerodynamic trailer technologies) produced an average C_dA value of 5.9 m^2 in coastdown testing and an average wind-averaged C_dA from wind tunnel tests was 6.0 m^2. The average C_dA value for the solo 28-foot dry van in its no-control configuration was 5.3 m^2 for coastdown and the average C_dA from wind tunnel results were 5.6 m^2 when wind-averaged.

The agencies chose to model the no-control long dry van subcategory using a default C_dA value of 6.0 m^2 (the mean wind-averaged C_dA from EPA's wind tunnel testing) in GEM. We also chose the wind tunnel result of 5.6 m^2 to represent the short dry van subcategory. The agencies did not test any refrigerated vans, but we assumed a refrigerated van's TRU would behave similar to a gap reducer. Our test results did not show gap reducer technologies to have a significant effect on C_dA and the agencies assigned the same default C_dA to refrigerated and dry box vans in GEM. The trailer subcategories that have design standards (i.e., non-box and non-aero box trailers) do not have numerical standards to meet, and thus do not have defaults in GEM. Table 2-96 illustrates the no-control drag areas (C_dA) associated with each trailer subcategory.

Table 2-96 Default C_dA Values Associated with the No Control Trailer Configuration within GEM

TRAILER SUBCATEGORY	DRY VAN
Long Dry Van	6.0
Short Dry Van	5.6
Long Ref. Van	6.0
Short Ref. Van	5.6

2.10.2.2 Tire Rolling Resistance

2.10.2.2.1 Lower Rolling Resistance Tires

On a typical Class 8 long-haul tractor-trailer, over 40 percent of the total energy loss from tires is attributed to rolling resistance from the *trailer* tires.[182] Trailer tire rolling resistance values were collected by the agencies to use in the GEM-simulated tractor-trailer vehicle for Phase 1. The agencies found that the average coefficient of rolling resistance (CRR) for new trailer tires at that time was 6.0 kg/ton. This value was applied in GEM for the standard trailer used for tractor compliance in the Phase 1 tractor program. For Phase 2, the agencies are adopting the same baseline CRR for trailer tires and consider all box van tires with CRR values below 6.0 kg/ton to be "lower rolling resistance" (LRR) tires. For reference, a trailer tire that qualifies as a SmartWay-verified tire must meet a CRR value of 5.1 kg/ton, a 15 percent CRR reduction from the trailer tire identified in Phase 1. Our research of rolling resistance indicates an additional CRR reduction of 15 percent or more from the SmartWay verification threshold is possible with tires that are available in the commercial market today.

Similar to the case of tractor tires, LRR tires are available as either dual or as single wide-based tires for trailers. Single wide-based tires achieve CRR values that are similar to their dual counterparts, but have an added benefit of weight reduction, which can be an attractive option for trailers that frequently maximize cargo weight.

2.10.2.2.2 Performance Levels for LRR Tires

Similar to the Phase 2 tractor and vocational vehicle programs, the trailer program is based on performance reflecting adoption of lower rolling resistance tires (or, for the non-aero subcategories, actually adopting such tires). Feedback from several box trailer manufacturers indicates that the standard tires offered on their new trailers are SmartWay-verified tires (i.e., CRR of 5.1 kg/ton or better). An informal survey of members from the Truck Trailer Manufacturers Association (TTMA) indicates about 85 percent of box vans sold today have SmartWay tires.[183] While some trailers continue to be sold with tires of higher rolling resistances, the agencies believe most box trailer tires currently achieve the baseline trailer tire CRR of 6.0 kg/ton or better.

The agencies evaluated two levels of box van tire performance for these rules beyond the baseline trailer tire with a CRR of 6.0 kg/ton. The first performance level was set at the criteria for SmartWay-verification for trailer tires, 5.1 kg/ton, which is a 15 percent reduction in CRR from the baseline. As mentioned previously, several tire models available today achieve rolling resistance values well below the present SmartWay threshold. The agencies expect that tire manufacturers will continue to respond to demand for more efficient tires and will offer increasing numbers of tire models with rolling resistance values significantly better than today's typical LRR tires. We believe it is reasonable to expect the trailer industry could adopt tires with rolling resistances at a second performance level early in the program. The agencies prosed standards based on meeting an additional eight percent reduction in rolling resistance by MY 2024, but, given that such a high fraction of new box vans are already adopting LRR tires, we are adopting standards based on a CRR performance of 4.7 kg/ton by MY 2021. The agencies evaluated these three tire rolling resistance levels, summarized in Table 2-97, in the feasibility analysis of the following sections.

We received comment from Michelin supporting the use of 6.0 kg/ton as the box van tire rolling resistance baseline, but they expressed concern that the SmartWay threshold of 5.1 kg/ton does not apply for non-box trailers, and could compromise their operation. In addition, the Rubber Manufacturers Association indicated that a baseline of 6.0 kg/ton does not apply to non-box trailers. The agencies agree that the baseline tires for non-box trailers should have a higher roller resistance, but we did not receive any comments that included C_{RR} data. For the analysis for the final rules, the agencies used 2014 tire rolling resistance information submitted by tractor and vocational manufacturers for Phase 1 compliance to establish a revised baseline C_{RR} value of 6.5 kg/ton for non-box trailer manufacturer. Table 2-97 summarizes the rolling resistance levels we evaluated in the Phase 2 trailer program.

Table 2-97 Summary of Trailer Tire Rolling Resistance Levels Evaluated

ROLLING RESISTANCE LEVEL	CRR (KG/TON)
Level 1 (Non-Box Baseline)	6.5
Level 2 (Box Van Baseline)	6.0
Level 3	5.1
Level 4	4.7

2.10.2.3 Tire Pressure Systems

The inflation pressure of tires also impacts the rolling resistance. Tractor-trailers operating with all tires under-inflated by 10 psi have been shown to increase fuel consumed by up to one percent.[184] Tires can gradually lose pressure from small punctures, leaky valves or simply diffusion through the tire casing. Changes in ambient temperature can also affect tire pressure. Trailers that remain unused for long periods of time between hauls may experience any of these conditions. A 2003 FMCSA report found that nearly one in five trailers had at least one tire under-inflated by 20 psi or more. If drivers or fleets are not diligent about checking and attending to under-inflated tires, the trailer may have much higher rolling resistance and much higher CO_2 emissions and fuel consumption.

2.10.2.3.1 Types of Tire Pressure Systems

Tire pressure monitoring systems (TPMS) and automatic tire inflation systems (ATIS) are designed to address under-inflated tires. Both systems alert drivers if a tire's pressure drops below its set point. TPMS simply monitors the tires and require user-interaction to reinflate to the appropriate pressure. Today's ATIS take advantage of trailers' air brake systems to supply air back into the tires (continuously or on demand) until a selected pressure is achieved. In the event of a slow leak, ATIS have the added benefit of maintaining enough pressure to allow the driver to get to a safe stopping area.[185] As described in Chapter 2.4.3.3, the agencies will recognize both systems in the Phase 2 trailer program.

2.10.2.3.2 Performance of Tire Pressure Systems

Estimates of the benefits of tire pressure systems vary depending on the base level of maintenance already performed by the driver or fleet, as well as the number of miles the trailer travels. Trailers that are well maintained or that travel fewer miles would experience less benefits from these systems compared to trailers that often drive with poorly inflated tires or log many miles. The agencies believe these systems can provide a CO_2 and fuel consumption benefit to most trailers. With ATIS use, trailers that have lower annual vehicle miles traveled (VMT) due to long periods between uses would be less susceptible to low tire pressures when they resume activity. Trailers with high annual VMT or frequent changes in ambient conditions would experience the fuel savings associated with consistent tire pressures. TPM systems would provide a warning of inappropriate tire pressure and the agencies believe the operators have sufficient incentive to correct the pressure as soon as possible. Tire inflation systems could provide a CO_2 and fuel consumption savings of 0.5-2.0 percent, depending on the degree of under-inflation in the trailer system.

Maintaining tire pressure is important to fuel consumption. Tire manufacturers estimate a tire pressure 10 psi below target results in a 0.9 percent increase in fuel consumption. Two studies have evaluated truck and trailer tire inflation including FMCSA (2003) and TMC (2002).[186,187] In the 2003 FMCSA study, tire inflation (psi) was measured in 3,200 tractors and 1,300 trailers. The TMC study measured tire inflation rates in two fleets and found that only 38 percent of sampled trailer tires were within +/- 5 psi of target pressure as prescribed by tire manufacturers. The study also found that more than 20 percent of tires were 20 psi or more underinflated and four percent of tires were 50 psi or more underinflated compared to the target. The FMCSA study found similar results. These figures suggest under inflation of tractor and trailer tires in the U.S. fleet could result in an increase in fuel consumption of approximately one to two percent. Most recently, FMCSA (2014) evaluated trailer ATIS on trailers in two test fleets.[188] The study found ATIS on trailers, in conjunction with TPMS use on tractors, improved fuel consumption 1.4 percent in test trucks as compared to control trucks in those fleets.

NHTSA and EPA recognize the role of proper tire inflation in maintaining optimum tire rolling resistance during normal trailer operation. For these rules, rather than require performance testing of tire pressure systems, the agencies will recognize the with a single default reduction for manufacturers that incorporate ATIS or TPMS into their trailer designs. Based on information available today, we believe that there is a narrow range of performance among technologies available and among systems in typical use. We proposed to assign a 1.5 percent reduction in CO_2 and fuel consumption for all trailers that implement ATIS, and no credit for TPMS due to their inherent dependence on operator interaction.[189] Based on comments, we are assigning a 1.2 percent reduction for ATIS and a 1.0 for TPMS. The discounted TPMS value is meant to reflect our acceptance that a notification will incentivize an operator to address the problem, but we cannot ensure that it will be done. We believe the use of these systems can improve tire pressure maintenance and reduce tire rolling resistance.

2.10.2.4 Weight Reduction

Reduction in trailer tare (or empty) weight can lead to fuel consumption reductions in two ways. For applications where payload is not limited by weight restrictions, the overall weight of the tractor and trailer would be reduced and would lead to improved fuel efficiency. For applications where payload is limited by weight restrictions, the lower trailer weight would allow additional payload to be transported during the truck's trip, so g/ton-mile emissions would decrease. Weight reduction opportunities in trailers exist in both the structural components and in the wheels and tires. Manufacturers commonly replace components such as roof posts, bows, side posts, cross members, floor joists, and floor sections with lighter weight options.

Major lower-weight options are not offered consistently by all trailer manufacturers across the industry. For example, some manufacturers have already marketed lower-weight major components for many years, while others to date have not done so. There is no clear "baseline" for current trailer weight against which lower-weight designs could be compared for regulatory purposes. Trailer manufacturers do not generally sell a single model. Instead, each sale is likely to include customer-specified configurations with application-specific components. For this reason, the agencies do not believe it would be appropriate or fair across the industry to identify a single trailer as a standard baseline from which to apply overall weight reductions toward compliance. However, the agencies do believe it would be appropriate to allow a manufacturer to account for weight reductions that involve substituting very specific, traditionally heavier components with lower-weight options that are not currently widely adopted in the industry. This method allows manufacturers to easily identify and install components that will improve benefit them in compliance.

The agencies recognize that when weight reduction is applied to a trailer, some operators will replace that saved weight with additional payload. To account for this in the average trailer represented in the GEM vehicle simulation tool, it is assumed that one-third of the weight reduction is applied to the payload. For tractor-trailers simulated in GEM, it takes a weight reduction of nearly 1,000 pounds before a one percent fuel savings is achieved and about a 2,500 pound reduction to reach three percent savings. The component substitutions identified by the agencies result in weight reductions of less than 500 pounds, yet can cost over $1,000. The agencies believe that few trailer manufacturers would apply weight reduction solely as a means of achieving reduced fuel consumption and CO_2 emissions, and the standards that can be met without reducing weight. However, we will offer weight reduction as an option for box trailer manufacturers who wish to apply it to some of their trailers as part of their compliance strategy.

2.10.2.4.1 Weight Reduction Options Recognized in these Rules

For these rules, the agencies have identified several conventional components with available lighter-weight substitutes (e.g., substituting conventional dual tires with steel wheels with single wide-based tires and aluminum wheels). We are adopting values for the associated weight-related savings that would be applied with these substitutions for compliance. We believe that the initial cost of these component substitutions is currently substantial enough that only a relatively small segment of the industry has adopted these technologies today.

In addition to weight reduction associated with replacing standard steel wheels with aluminum versions, and adopting single wide-based tires in place of dual tires, the agencies have identified 11 common trailer components that have lighter weight options available.[190,191,192,193] Some of the references include confidential data that outlined weight savings and costs associated with these material substitutions. Table 2-98 lists the components, and estimates of weight savings and costs obtained by the agencies. The table includes one update to the weight reduction value assigned to floor cross-members. The Aluminum Association indicated that this value should be 250 pounds and we adjusted the table accordingly.

Manufacturers that adopt these technologies would sum the associated weight reductions and apply those values in GEM. Steel wheels can be replaced with aluminum wheels and two dual tires can be replaced with single wide-based tires on aluminum wheels. Relatively large weight savings are possible by replacing steel upper coupler assemblies or suspension sub-frames with aluminum versions, but these substitutions are more expensive and more labor-intensive to install.

Table 2-98 Weight Reduction Options for Trailers

COMPONENT	MATERIAL SUBSTITUTION	WEIGHT REDUCTION (LB)
Hub and Drum (per axle)	Cast Iron to Aluminum	80
Floor	Hardwood to Aluminum	375
Floor	Hardwood to Composite	245
Floor Crossmembers	Steel to Aluminum	250
Landing Gear	Steel to Aluminum	50
Rear Door	Steel to Aluminum	187
Rear Door Surround	Steel to Aluminum	150
Roof Bows	Steel to Aluminum	100
Side Posts	Steel to Aluminum	300
Slider Box	Steel to Aluminum	150
Structure for Suspension Assembly	Steel to Aluminum	280
Upper Coupler Assembly	Steel to Aluminum	430

In addition to these conventional components, manufacturers have the option to evaluate their own trailer weight reduction through the off-cycle testing provisions outlined in the regulations. Manufacturers can seek approval of a baseline trailer from their own recent production, and compare its weight to a new, lighter-weight model through an “A to B” weight measurement. The difference between these two trailers can be applied in GEM for a weight reduction value.

2.10.2.5 Effectiveness of Technologies

The final standards for trailers are predicated on four performance parameters: aerodynamic drag reduction, tire rolling resistance reduction, and the adoption of tire pressure systems and weight reduction. Table 2-99 summarizes the performance levels for each of these parameters based on the technology characteristics outlined in Chapter 2.10.2.

Table 2-99 Performance Parameters for the Trailer Program

AERODYNAMICS (DELTA CDA, M^2)	
Bin I	0.0
Bin II	0.1
Bin III	0.4
Bin IV	0.7
Bin V	1.0
Bin VI	1.4
Bin VII	1.8
Tire Rolling Resistance (CRR, kg/ton)	
Level 1 (Non-Box Baseline)	6.5
Level 2 (Box Van Baseline)	6.0
Level 3	5.1
Level 4	4.7
Tire Inflation System (% reduction)	
ATIS	1.2
TPMS	1.0
Weight Reduction (pounds)	
Weight	1/3 added to payload, remaining reduces overall vehicle weight

As part of the process of demonstrating compliance, trailer manufacturers will perform an aerodynamic test and measure a delta C_dA. The delta C_dA value will determine which Bin value the manufacturer will supply to GEM (i.e. the GEM equation) for compliance. While manufacturers are required to use the exact value assigned to the aerodynamic bins, they are free to use any tire rolling resistance value obtained from tire testing.

These performance parameters have different effects on each trailer subcategory due to differences in the simulated trailer characteristics. Table 2-100 shows the agencies' estimates of the effectiveness of each parameter for four box trailer types. Each technology was evaluated in GEM using the baseline parameter values for the other technology categories. For example, each aerodynamic bin was evaluated using the Tire Level 1 (6.0 kg/ton) and the Base weight reduction option (zero pounds). The table shows that aerodynamic improvements offer the largest potential for CO_2 emissions and fuel consumption reductions, making them relatively effective technologies.

Table 2-100 Effectiveness (Percent Reduction in CO_2 Emissions and Fuel Consumption) of Technologies for the Box Van Subcategories

AERODYNAMICS	DELTA CDA (M^2)	DRY VAN		REFRIGERATED VAN	
		Long	Short	Long	Short
Bin I	0.0	0%	0%	0%	0%
Bin II	0.1	1%	1%	1%	1%
Bin III	0.4	3%	3%	3%	3%
Bin IV	0.7	5%	5%	5%	5%
Bin V	1.0	7%	7%	7%	7%
Bin VI	1.4	9%	10%	9%	10%
Bin VII	1.8	12%	13%	12%	13%
Tire Rolling Resistance	CRR (kg/ton)	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
Level 2 (Baseline)	6.0	0%	0%	0%	0%
Level 3	5.1	2%	1%	2%	1%
Level 4	4.7	3%	2%	3%	2%
Weight Reduction	Weight (lb)	Dry Van		Refrigerated Van	
		Long	Short	Long	Short
Baseline	0	0%	0%	0%	0%
Option 1	100	0%	0%	0%	0%
Option 2	500	1%	1%	1%	1%
Option 3	1000	1%	2%	1%	2%
Option 4	2000	2%	4%	2%	4%

2.10.3 Defining the Baseline Trailers

2.10.3.1 No-Control Default Tractor-Trailer Vehicles within GEM

The regulatory purpose of EPA's heavy-duty vehicle compliance tool, GEM, is to combine the effects of trailer technologies through simulation so that they can be expressed as kg/ton-mile and gal/100 ton-mile and thus avoid the need for direct testing of each trailer model being certified. The trailer program has separate standards for each trailer subcategory, and a unique tractor-trailer vehicle was chosen to represent each subcategory for compliance. In the Phase 2 update to GEM, each trailer subcategory is modeled as a particular trailer being pulled by a standard tractor depending on the physical characteristics and use pattern of the trailer. Table 2-101 highlights the relevant vehicle characteristics for the no-control default tractor-trailer of each subcategory. Level 1 trailer tires are used, and the drag area, which is a function of the aerodynamic characteristics of both the tractor and trailer, is set to the Bin I values shown previously in Table 2-96. Weight reduction and tire pressure systems are not applied in these baselines. In general, long box vans are pulled by sleeper cab tractors, and short box vans are pulled by 4x2 day cabs.

Table 2-101 Characteristics of the No-Control Default Tractor-Trailer Vehicles in GEM

	DRY VAN		REFRIGERATED VAN	
Trailer Length	Long	Short	Long	Short
Standard Tractor				
Class	Class 8	Class 7	Class 8	Class 7
Cab Type	Sleeper	Day	Sleeper	Day
Roof Height	High	High	High	High
Axle Configuration	6x4	4x2	6x4	4x2
Engine	2018 MY 15L, 455 HP	2018 MY 11L, 350 HP	2018 MY 15L, 455 HP	2018 MY 11L, 350 HP
Steer Tire RR (kg/ton)	6.54	6.54	6.54	6.54
Drive Tire RR (kg/ton)	6.92	6.92	6.92	6.92
Drag Area, C_dA (m^2)	6.0	5.6	6.0	5.6
Number of Trailer Axles	2	1	2	1
Trailer Tire RR (kg/ton)	6.00	6.00	6.00	6.00
Total Weight (kg)	31978	18306	33778	20106
Payload (tons)	19	10	19	10
Tire Pressure System Use	0	0	0	0
Weight Reduction (lb)	0	0	0	0
Drive Cycle Weightings				
65-MPH Cruise	86%	64%	86%	64%
55-MPH Cruise	9%	17%	9%	17%
Transient Driving	5%	19%	5%	19%

2.10.3.2 Baseline Tractor-Trailer Vehicles to Evaluate Benefits and Costs

In order to evaluate the benefits and costs of the standards, it is necessary to establish a reference point for comparison. The trailer technologies described in this section exist in the market today, and their adoption is driven by available fuel savings as well as by the voluntary SmartWay Partnership and California's Heavy Duty Greenhouse Gas Emission Reduction Measure tractor-trailer requirements. To estimate the costs and benefits for these rules, the agencies identified baseline tractor-trailers for each trailer subcategory based on the technology adoption rates we project would exist if this trailer program was not implemented.

The agencies received comments suggesting our baseline adoption rates were too low for several technologies and we made changes to our baseline trailers that in most cases should address the comments. First, we created separate baselines for box vans that qualify as full-aero, partial-aero and non-aero. We believe market forces will not significantly drive adoption of CO_2- and fuel-consumption reducing technologies for trailers with work performing equipment (e.g., lift gates) and we are accordingly projecting zero adoption of the technologies in the baselines for partial-and non-aero box vans. Similarly, we project zero adoption of these technologies for the non-box trailers. We updated the baseline tire rolling resistance level for non-box trailers to reflect the lower 6.5 kg/ton value in response to RMA's comment that these trailers have different operational characteristics and should not have the same baseline tires as box vans.

An informal survey of TTMA members in 2014 indicated that 35 percent of long vans and less than 2 percent of vans under 53-foot in length include aerodynamic devices, yet over 80 percent have adopted lower rolling resistance tires. The agencies believe the trailers for which manufacturers have adopted these technologies are likely to be trailers that would qualify as "full-aero" vans, and we created separate baselines to reflect these values. We project that aerodynamics will increase to 40 percent adoption for full-aero long vans (dry and refrigerated) and 5 percent for full-aero short vans by 2018 without this rulemaking. We project adoption of lower rolling resistance tires (Level 3) to 90 percent and ATIS to 45 percent. We held these adoption rates constant throughout the timeframe of the rules. Table 2-102 summarizes the updated baseline trailers for each trailer subcategory.

Table 2-102 Adoption Rates and Average Performance Parameters for the Flat Baseline Trailers

TECHNOLOGY	LONG VANS	SHORT VANS	ALL PARTIAL-AERO, NON-AERO VANS	ALL NON-BOX TRAILERS
Aerodynamics				
Bin I	55%	95%	100%	100%
Bin II		5%		
Bin III	40%			
Bin IV	5%			
Bin V				
Bin VI				
Bin VII				
Average Delta C_dA (m^2) [a]	*0.2*	*0.0*	*0.0*	*0.0*
Tire Rolling Resistance				
Level 1				100%
Level 2	10%	10%	100%	
Level 3	90%	90%		
Level 4				
Average C_{RR} (kg/ton) [a]	*5.2*	*5.2*	*6.0*	*6.5*
Tire Pressure Systems				
ATIS	45%	30%		
TPMS				
Average % Reduction [a]	*0.5%*	*0.3%*	*0.0%*	*0.0%*
Weight Reduction				
Weight (lb) [b]				

Notes:

[a] Combines adoption rates with performance levels shown in Table 2-99

[b] Weight reduction was not projected for the baseline trailers

Also shown in Table 2-102 are average aerodynamic performance (delta C_dA), average tire rolling resistance (CRR), and average reductions due to use of tire pressure and weight reduction for each stage of the program. These values indicate the performance of theoretical average tractor-trailers that the agencies project would be in use if no federal regulations were in place for trailer CO_2 and fuel consumption. These average tractor-trailer vehicles serve as baselines for each trailer subcategory.

Because the agencies cannot be certain about future trends, we also considered a second baseline. This dynamic baseline reflects the possibility that absent a Phase 2 regulation, there will be continuing adoption of aerodynamic technologies in the long box trailer market after 2018 that reduce fuel consumption and CO_2 emissions. This case assumes the research funded and conducted by the federal government, industry, academia and other organizations will, after 2018, result in the adoption of additional aerodynamic technologies beyond the levels required to comply with existing regulatory and voluntary programs. One example of such research is the Department of Energy Super Truck program which had a goal of demonstrating cost-effective measures to improve the efficiency of Class 8 long-haul freight trucks by 50 percent by 2015.[O] This baseline assumes that by 2040, 75 percent of new full-aero long vans will be equipped with SmartWay-verified aerodynamic devices. The agencies project that the lower rolling resistance tires and ATIS adoption will remain constant. Table 2-103 shows the agencies' projected adoption rates of technologies in the dynamic baseline.

Table 2-103 Projected Adoption Rates and Average Performance Parameters for the Dynamic Baseline for Long Dry and Refrigerated Vans (all other trailers are the same as Table 2-102)

TECHNOLOGY	LONG DRY AND REFRIGERATED				
Model Year	2018	2021	2024	2027	2040
Aerodynamics					
Bin I	55%	50%	45%	40%	20%
Bin II					
Bin III	40%	45%	50%	55%	75%
Bin IV	5%	5%	5%	5%	5%
Bin V					
Bin VI					
Bin VII					
Average Delta C_dA (m^2) [a]	*0.2*	*0.3*	*0.3*	*0.3*	*0.4*
Tire Rolling Resistance					
Level 1					
Level 2	10%	10%	10%	10%	10%
Level 3	90%	90%	90%	90%	90%
Level 4					
Average C_{RR} (kg/ton) [a]	*5.2*	*5.2*	*5.2*	*5.2*	*5.2*
Tire Inflation					
ATIS	45%	45%	45%	45%	45%
TPMS					
Average % Reduction [a]	*0.5%*	*0.5%*	*0.5%*	*0.5%*	*0.5%*
Weight Reduction (lbs)					
Weight [b]					

Notes:
A blank cell indicates a zero value
[a] Combines adoption rates with performance levels shown in Table 2-99
[b] Weight reduction was not projected for the baseline trailers

The agencies applied the vehicle attributes from Table 2-101 and the average performance values from Table 2-102 in the Phase 2 GEM vehicle simulation to calculate the CO_2 emissions and fuel consumption performance of the reference tractor-trailers. The results of these simulations are shown in Table 2-104. We used these CO_2 and fuel consumption values to calculate the relative benefits of the standards. Note that the large difference between the per

[O] Daimler Truck North America. SuperTruck Program Vehicle Project Review. June 19, 2014. Docket EPA-HQ-OAR-2014-0827.

ton-mile values for long and short trailers is due primarily to the large difference in assumed payload (19 tons compared to 10 tons) and the differing drive cycles as seen in Table 2-101. The small difference between the dry and refrigerated vans of the same length is due to the weight difference between the subcategories. Refrigerated vans have an additional 1800 pounds added to account for the TRU. The alternative baseline in Table 2-103 impacts the long-term projections of benefits beyond 2027, which are analyzed in Chapters 5 through 7 of this RIA. The non-box trailers and non-aero box vans are not included in this baseline analysis, because we are adopting design standards for these trailers. As such, these trailers would not have standards to meet. Instead, they would have minimum tire technology requirements.

Table 2-104 CO_2 Emissions and Fuel Consumption Results for the Baseline Tractor-Trailers

	FULL-AERO DRY VAN		FULL-AERO REFRIGERATED VAN		PARTIAL-AERO DRY VAN		PARTIAL-AERO REFRIGERATED VAN	
Length	Long	Short	Long	Short	Long	Short	Long	Short
CO_2 Emissions (g/ton-mile)	83.2	126.5	84.9	130.3	86.1	128.5	87.9	132.4
Fuel Consumption (gal/1000 ton-miles)	8.17289	12.42633	8.33988	12.79961	8.45776	12.62279	8.63458	13.00589

2.10.4 Effectiveness and Costs of the Standards

The agencies evaluated several alternatives for the trailer program. The analysis below is for the alternative we believe reflects the agencies' statutory authorities. This alternative is fully implemented in model year (MY) 2027.

2.10.4.1 Projected Technology Adoption Rates for the Final Standards

The agencies designed the trailer program to have no averaging in MY 2018 through MY 2026. In those years, all box vans sold must meet the standards using any combination of available technologies. In MY 2027, when the trailer manufacturers are more comfortable with compliance and the industry is more familiar with the technologies, the agencies are adopting averaging provisions to allow additional flexibility for the full-aero box van subcategories that have the most stringent standards. See Section IV.F(5)(a) of the Preamble to this rulemaking for additional information about averaging. Table 2-105 through Table 2-107 present sets of assumed adoption rates for aerodynamic, tire, and tire pressure technologies that a manufacturer could apply to meet the box van standards. Since the agencies are not adopting averaging for MY 2018-MY 2026, the adoption rates consist of the combination of a single aerodynamic bin, tire rolling resistance level, and tire pressure system. As mentioned previously, manufacturers can choose other combinations to meet the standards.

The adoption rates in Table 2-98 begins with all long box trailers achieving current SmartWay-level aerodynamics (Bin III) in MY 2018 with a stepwise progression to achieving Bin V in 2024. The adoption rates for short box trailers assume no adoption of aerodynamic devices in MY 2018, adoption of single aero devices in MY 2021, and combinations of devices by MY 2024. The shorter lengths of these trailers can restrict the design of aerodynamic technologies that fully match the SmartWay-like performance levels of long boxes and we don't assume adoption at the same Bin-levels. We nevertheless expect that trailer and device manufacturers will continue to innovate skirt, under-body, rear, and gap-reducing devices and combinations to achieve improved aerodynamic performance on these shorter trailers.

The MY 2027 standards for the full-aero box vans are based on an averaging program. The gradual increase in assumed adoption of aerodynamic technologies throughout the phase-in to the MY 2027 standards recognizes that even though many of the technologies are available today and technologically feasible throughout the phase-period, their adoption on the scale of the program will likely take time. EPA's aerodynamic testing does not show technologies capable of achieving Bin VI for long vans or Bin IV for short vans. As a result, we did not assume a similar step-wise progression to 100 percent adoption of those bins. We do believe that the interim standards provide an incentive to drive innovation over the 10 years leading up to MY 2027 and that aerodynamic improvements at these highest performance levels will be possible when the program is fully implemented.

We are aware that there is already a high adoption of SmartWay-verified tires (Level 3) and we expect most manufacturers will install these tires to meet the standards in MY 2018, and will adopt even lower rolling resistance tires as they become available. By MY 2021, we project that adoption of Level 4 tires will be used to meet the standards. The agencies are also assuming that all box vans will adopt ATIS throughout the program, though manufacturers do have the option to install TPMS if they would prefer to make up the difference using other technologies. As mentioned previously, the agencies did not include weight reduction in their technology adoption projections, but certain types of weight reduction could be used as a compliance pathway.

The agencies proposed that the partial-aero box vans would track with the full-aero van standards until MY 2024. Wabash commented that these trailers would not be able to meet standards after MY 2021. The agencies reconsidered the partial-aero standards and recognize that it would be difficult to meet the proposed MY 2024 standards without the use of multiple devices and that partial-aero trailers, by definition, are restricted from using multiple devices. For these reasons, the agencies redesigned the partial-aero standards, such that trailers with qualifying work-performing equipment can meet standards that would be achievable with the use of a single aerodynamic device throughout the program. The partial-aero standards do, however, increase in stringency slightly in MY 2021 to reflect the use of improved lower rolling resistance tires.

Similar to our analyses of the baseline cases, the agencies derived a single set of performance parameters for each subcategory by weighting the performance levels included in Table 2-99 by the corresponding adoption rates. These performance parameters represent a compliant vehicle for each trailer subcategory and we present these values in the tables.

Table 2-105 Projected Adoption Rates and Average Performance Parameters for Long Box Vans

TECHNOLOGY	LONG BOX DRY & REFRIGERATED VANS			
Model Year	2018	2021	2024	2027
Aerodynamic Technologies				
Bin I				
Bin II				
Bin III	100%			
Bin IV		100%		
Bin V			100%	30%
Bin VI				70%
Bin VII				
Average Delta C_dA (m^2) [a]	*0.4*	*0.7*	*1.0*	*1.3*
Trailer Tire Rolling Resistance				
Level 1				
Level 2				5%
Level 3	100%			
Level 4		100%	100%	95%
Average C_{RR} (kg/ton) [a]	*5.1*	*4.7*	*4.7*	*4.8*
Tire Pressure Systems				
ATIS	100%	100%	100%	100%
TPMS				
Average Reduction (%) [a]	*1.2%*	*1.2%*	*1.2%*	*1.2%*
Weight Reduction				
Weight (lb) [b]				

Notes:
A blank cell indicates a zero value
[a] Combines projected adoption rates with performance levels shown in Table 2-99
[b] This set of adoption rates did not apply any assumed weight reduction to meet these standards for these trailers

Table 2-106 Projected Adoption Rates and Average Performance Parameters for Short Box Vans

TECHNOLOGY	SHORT BOX DRY & REFRIGERATED VANS			
Model Year	2018	2021	2024	2027
Aerodynamic Technologies				
Bin I				
Bin II		100%		
Bin III			100%	40%
Bin IV				60%
Bin V				
Bin VI				
Bin VII				
Average Delta C_dA (m^2) [b]	*0.0*	*0.1*	*0.4*	*0.6*
Trailer Tire Rolling Resistance				
Level 1				
Level 2				5%
Level 3	100%			
Level 4		100%	100%	95%
Average C_{RR} (kg/ton) [b]	*5.1*	*4.7*	*4.7*	*4.8*
Tire Pressure Systems				
ATIS	100%	100%	100%	100%
TPMS				
Average Reduction (%) [c]	*1.2%*	*1.2%*	*1.2%*	*1.2%*
Weight Reduction				
Weight (lb) [b]				

Notes:
A blank cell indicates a zero value
[a] The majority of short box trailers are 28 feet in length. We recognize that they are often operated in tandem, which limits the technologies that can be applied (for example, boat tails).
[b] Combines projected adoption rates with performance levels shown in Table 2-99
[c] This set of adoption rates did not apply any assumed weight reduction to meet these standards for these trailers

Table 2-107 Projected Adoption Rates and Average Performance Parameters for Partial-Aero Box Vans

TECHNOLOGY	PARTIAL-AERO LONG BOX VANS		PARTIAL-AERO SHORT BOX VANS	
Model Year	2018	2021+	2018	2021+
Aerodynamic Technologies				
Bin I				
Bin II				100%
Bin III	100%	100%		
Bin IV				
Bin V				
Bin VI				
Bin VII				
Bin VIII				
Average Delta C_dA (m^2) [b]	*0.4*	*0.4*	*0.0*	*0.1*
Trailer Tire Rolling Resistance				
Level 1				
Level 2				
Level 3	100%		100%	
Level 4		100%		100%
Average C_{RR} (kg/ton) [b]	*5.1*	*4.7*	*5.1*	*4.7*
Tire Pressure Systems				
ATIS	100%	100%	100%	100%
TPMS				
Average Reduction (%) [c]	1.2%	1.2%	1.2%	1.2%
Weight Reduction				
Weight (lb) [b]				

Notes:
A blank cell indicates a zero value
[a] Combines projected adoption rates with performance levels shown in Table 2-99
[b] This set of adoption rates did not apply weight reduction to meet these standards for these trailers

The adoption rates shown in these tables are one set of many possible combinations that box trailer manufacturers could apply to achieve the same average stringency. If a manufacturer chose these adoption rates, a variety of technology options exist within the aerodynamic bins, and several models of LRR tires exist for the levels shown. Alternatively, technologies from other aero bins and tire levels could be used to comply. It should be noted that van manufacturers are not limited to specific aerodynamic and tire technologies, since these are performance-based standards, and manufacturers will not be constrained to adopt any particular way to demonstrate compliance. Certain types of weight reduction, for example, may be used as a compliance pathway.

Non-aero box vans with two or more work-related special components, and non-box trailers (tankers, flatbeds, and container chassis) are not shown in the tables above, because they have design-based tire standards. These trailers will install tires that meet a specified rolling resistance and tire pressure systems. A tire-based program significantly reduces the compliance burden for these manufacturers by reducing the amount of tracking and eliminating the need to run GEM (or utilize the equation derived from GEM). The agencies are adopting these tire-only requirements in two stages. In MY 2018, manufacturers would be required to use tires meeting a rolling resistance of Level 3 or better and install tire pressure systems on all non-aero box vans. Non-box trailers would also need tire pressure systems, but their tire rolling resistance threshold is Level 2. In model years 2021 and later, these trailers would continue to install tire pressure systems, but an additional level of rolling resistance is required. At minimum, manufacturers of non-aero box vans and non-box trailers must install TPMS to comply with the standard; however, they have the option to install ATIS though they will not receive any additional credit for doing so. The agencies are assuming, as shown in Table 2-108, that manufacturers of these trailers would adopt TPMS at all stages of the program.

Table 2-108 Design Standard Tire Technology Requirements for the Non-Aero Box Van and Non-Box Trailers

TECHNOLOGY	NON-AERO BOX VANS		NON-BOX TRAILERS	
Model Year	2018	2021+	2018	2021+
Minimum CRR (kg/ton)	*5.1*	*4.7*	*6.0*	*5.1*
Tire Pressure System	TPMS or ATIS	TPMS or ATIS	TPMS or ATIS	TPMS or ATIS

2.10.4.2 Derivation of the Standards

The average performance parameters from the previous tables were applied as input values to the GEM vehicle simulation to derive the HD Phase 2 fuel consumption and CO_2 emissions standards for each subcategory of box trailers.

The standards are shown in Table 2-109 and Table 2-110. Over the four stages of the trailer program, the full-aero box vans longer than 50 feet will reduce their CO_2 emissions and fuel consumption by two percent, five percent, seven percent and nine percent compared to their flat baselines for each year in Table 2-104. Full-aero box vans 50-feet and shorter will achieve reductions of one percent, two percent, four percent and six percent compared to their flat baseline cases. The partial-aero long and short box van standards will reduce CO_2 and fuel consumption by six percent and four percent, respectively, by MY 2021. The design-based tires standards for non-box trailers and non-aero box vans would provide reductions of two percent in MY 2018 and three percent in MY 2021 and later.

Table 2-109 Standards for Full-Aero Box Vans

MODEL YEAR	SUBCATEGORY	DRY VAN		REFRIGERATED VAN	
	Length	Long	Short	Long	Short
2018 - 2020	EPA Standard (CO_2 Grams per Ton-Mile)	81.3	125.4	83.0	129.1
	Voluntary NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.98625	12.31827	8.15324	12.68173
2021 - 2023	EPA Standard (CO_2 Grams per Ton-Mile)	78.9	123.7	80.6	127.5
	NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.75049	12.15128	7.91749	12.52456
2024 - 2026	EPA Standard (CO_2 Grams per Ton-Mile)	77.2	120.9	78.9	124.7
	NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.58350	11.87623	7.75049	12.24951
2027 +	EPA Standard (CO_2 Grams per Ton-Mile)	75.7	119.4	77.4	123.2
	NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.43615	11.72888	7.60314	12.10216

Table 2-110 Standards for Partial-Aero Box Vans

MODEL YEAR	**SUBCATEGORY**	**DRY VAN**		**REFRIGERATED VAN**	
	LENGTH	**LONG**	**SHORT**	**LONG**	**SHORT**
2018 - 2020	EPA Standard (CO_2 Grams per Ton-Mile)	81.3	125.4	83.0	129.1
	Voluntary NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.98625	12.31827	8.15324	12.68173
2021 +	EPA Standard (CO_2 Grams per Ton-Mile)	80.6	123.7	82.3	127.5
	NHTSA Standard (Gallons per 1,000 Ton-Mile)	7.91749	12.15128	8.08448	12.52456

2.10.4.3 Projected Cost of Trailer Standards

The agencies evaluated technology costs for 53-foot dry and refrigerated vans and 28-foot dry vans, which we believe are representative of the majority of trailers in the long and short box trailer categories, respectively. Similar tire technology costs were assumed for the non-box trailer subcategory. We identified costs for each technology package evaluated and projected out the costs for each year of the program. A summary of the technology costs is included in Table 2-111 through Table 2-114 for the four phases of the trailer program, with additional details available in RIA Chapter 2.12. Costs shown in the following tables are for the specific model year indicated and are incremental to the average baseline costs, which includes some level of adoption of these technologies as shown in Table 2-102. For example, the tire costs for the full-aero subcategories are $1-$2, because there is already a very high adoption of LRR tires in the baseline. Therefore, the technology costs in the following tables reflect the average cost expected for each of the indicated trailer subcategories. Throughout the trailer program discussion, the non-aero box van subcategory is treated as a single category, because all lengths of these trailers have identical design standards. However, two costs for this subcategory are shown to reflect the difference in the number of tires expected on the different length trailers (i.e., long vans are assumed to have two axles and eight tires, while short vans have a single axle and four tires).

Note that these costs do not represent actual costs for the individual components, because some fraction of the component costs has been subtracted to reflect some use of these components in the baseline. These costs include indirect costs via markups along with learning impacts and also reflect estimated costs of the compliance process. For more on the estimated technology costs exclusive of adoption rates, refer to Chapter 2.12.

Table 2-111 Trailer Technology Incremental Costs in the 2018 Model Year (2013$)

	LONG VANS, FULL AERO	LONG VANS, PARTIAL AERO	SHORT VANS, FULL AERO	SHORT VANS, PARTIAL AERO	LONG VANS, NO AERO	SHORT VANS, NO AERO	NON-BOX
Aerodynamics	$367	$742	$0	$0	$0	$0	$0
Tires	$2	$40	$1	$20	$40	$20	$28
Tire inflation system	$347	$659	$338	$494	$421	$210	$421
Total	$716	$1,441	$339	$514	$461	$231	$448

Table 2-112 Trailer Technology Incremental Costs in the 2021 Model Year (2013$)

	LONG VANS, FULL AERO	LONG VANS, PARTIAL AERO	SHORT VANS, FULL AERO	SHORT VANS, PARTIAL AERO	LONG VANS, NO AERO	SHORT VANS, NO AERO	NON-BOX
Aerodynamics	$743	$679	$450	$475	$0	$0	$0
Tires	$17	$49	$9	$25	$49	$25	$23
Tire inflation system	$321	$609	$313	$457	$389	$195	$389
Total	$1,081	$1,337	$772	$957	$438	$219	$412

Table 2-113 Trailer Technology Incremental Costs in the 2024 Model Year (2013$)

	LONG VANS, FULL AERO	LONG VANS, PARTIAL AERO	SHORT VANS, FULL AERO	SHORT VANS, PARTIAL AERO	LONG VANS, NO AERO	SHORT VANS, NO AERO	NON-BOX
Aerodynamics	$899	$645	$879	$451	$0	$0	$0
Tires	$11	$48	$6	$24	$48	$24	$27
Tire inflation system	$294	$558	$286	$418	$357	$178	$357
Total	$1,204	$1,251	$1,171	$894	$405	$202	$383

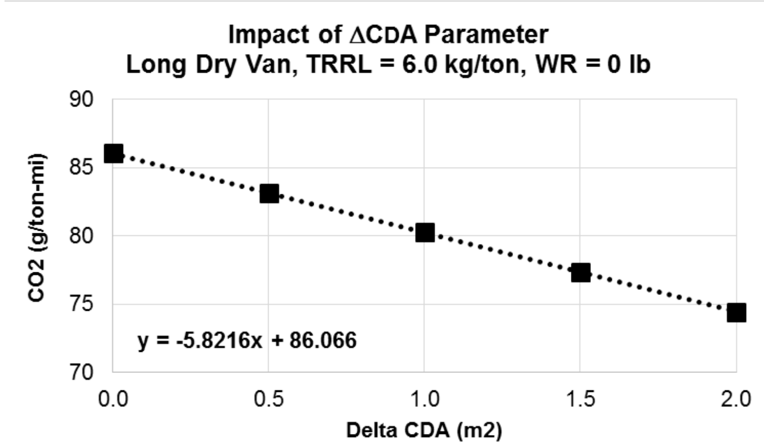
Table 2-114 Trailer Technology Incremental Costs in the 2027 Model Year (2013$)

	LONG VANS, FULL AERO	LONG VANS, PARTIAL AERO	SHORT VANS, FULL AERO	SHORT VANS, PARTIAL AERO	LONG VANS, NO AERO	SHORT VANS, NO AERO	NON-BOX
Aerodynamics	$1,069	$623	$921	$436	$0	$0	$0
Tires	$22	$44	$11	$22	$44	$22	$16
Tire inflation system	$279	$529	$272	$397	$338	$169	$338
Total	$1,370	$1,196	$1,204	$855	$382	$191	$354

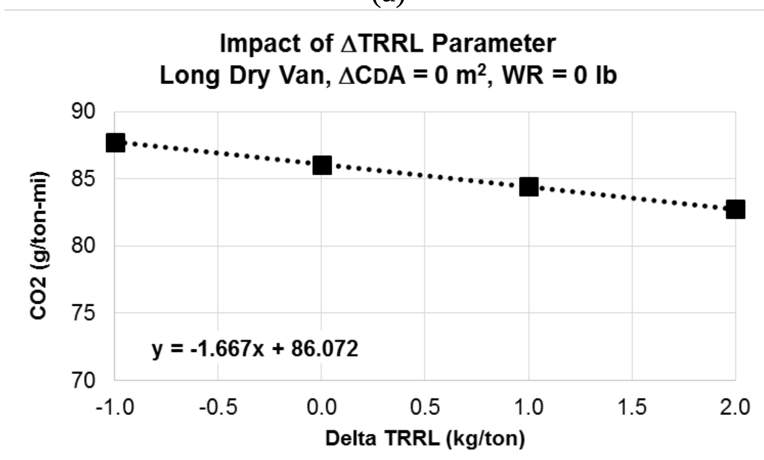
2.10.5 Evaluation of Compliance Option using GEM-Based Equation

EPA created the Greenhouse gas Emissions Model (GEM) as a compliance tool for heavy-duty vehicles. Users provide specific performance parameters to the model and GEM calculates CO_2 emissions and fuel consumption results. As described previously, the Phase 2 GEM is designed to accept four performance variables as trailer inputs: change in drag area (delta C_dA), tire rolling resistance level (TRRL), tire pressure systems, and weight reduction (WR). The reduction applied when using a tire pressure system is accounted for after the vehicle simulation is complete. The other performance parameters directly impact the results of the vehicle simulation, by changing the drag, rolling resistance and weight of the simulated vehicle.

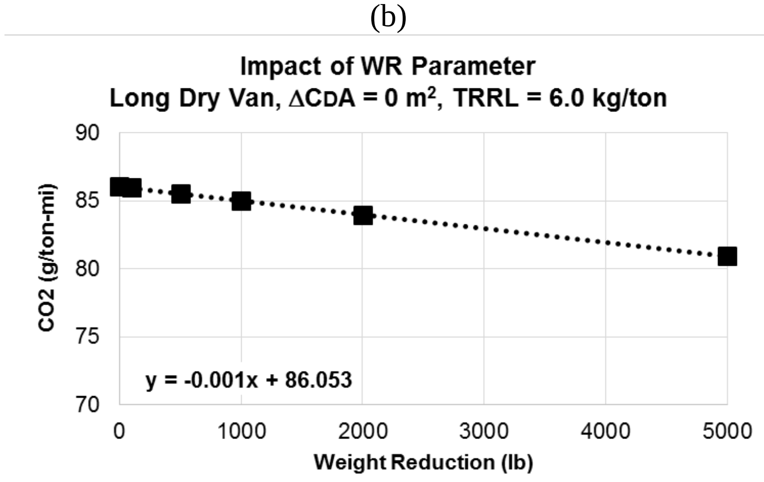
We performed a sensitivity analysis for delta C_dA, TRRL and WR to evaluate their effect on the model's results. In the analysis to follow, all of the calculations are shown in terms of CO_2 emissions; use a conversion of 10,180 grams CO_2 per gallon of diesel fuel to calculate the corresponding fuel consumption values. Figure 2-74 through Figure 2-77 show GEM's CO_2 results from the proposal for a parameter sweep of a simulated Class 8 tractor pulling each of the four box van trailers. It can be seen that each of the three parameters has a linear impact on CO_2 emissions. A curve fit was applied to each data set and the equation is displayed on each plot. The intercept in each parameter sweep data set is the baseline CO_2 result considering a no-control trailer, and this value is consistent for all parameters for a given trailer. The coefficients indicate the relationship between the assessed parameter and the model's CO_2 result. A similar analysis was repeated with the GEM version that was updated since the NPRM. The coefficients of the regression curves differ, but the trends remain the same.



(a)



(b)



(c)

Figure 2-74 Impact of (a) Delta C_dA, (b) Delta C_{RR}, and (c) Weight Reduction on CO_2 Results of a GEM-Simulated Long Dry Van

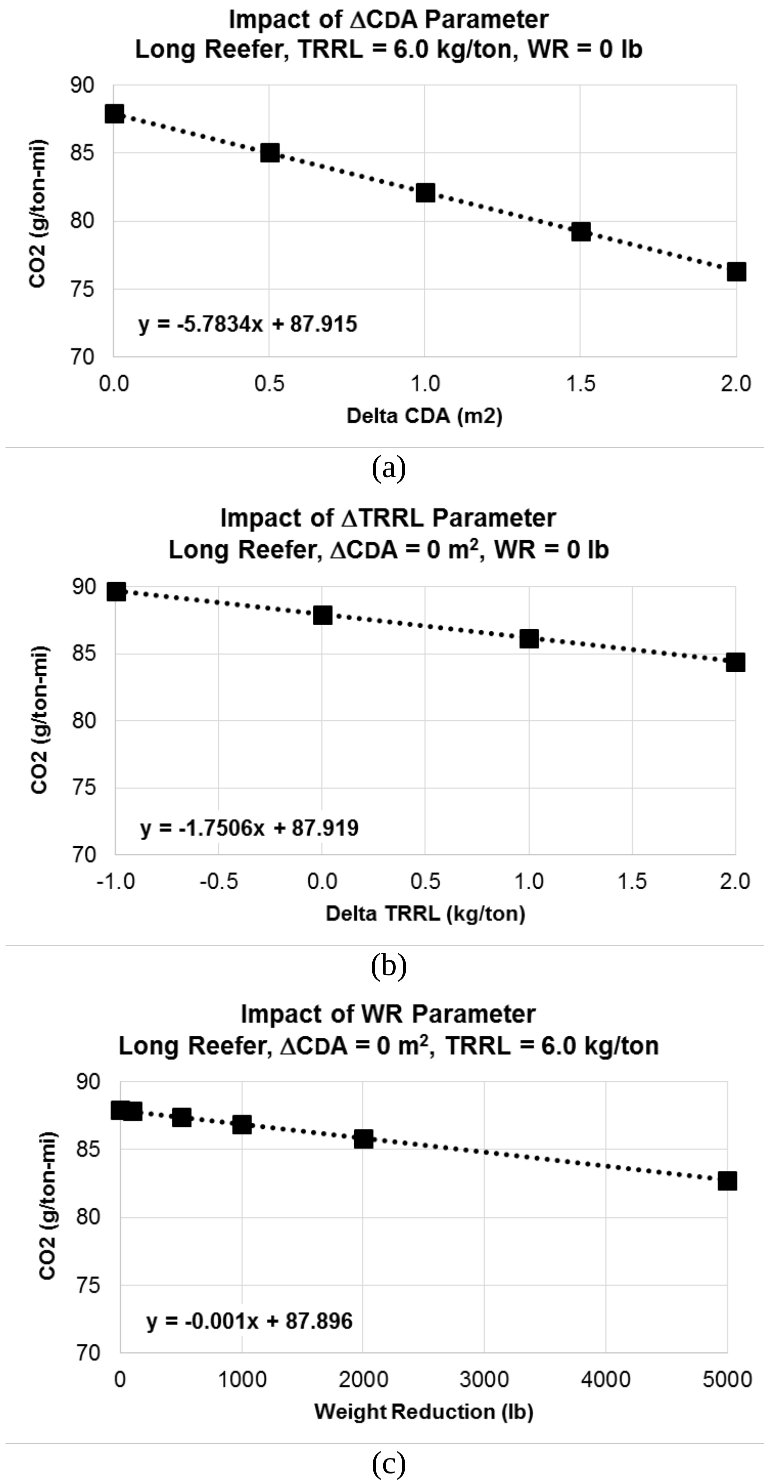
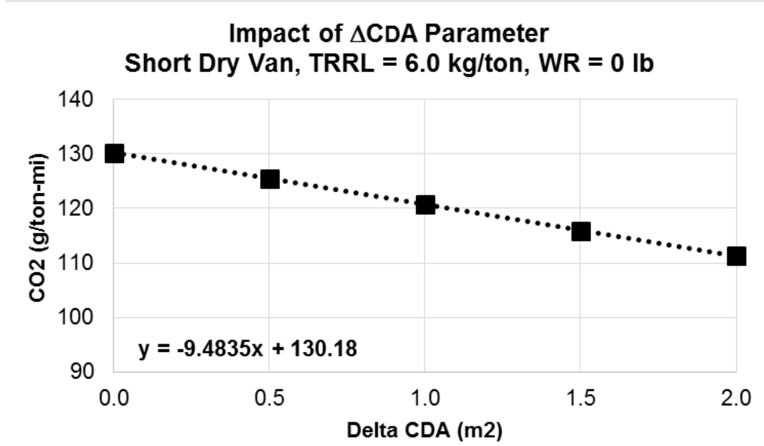
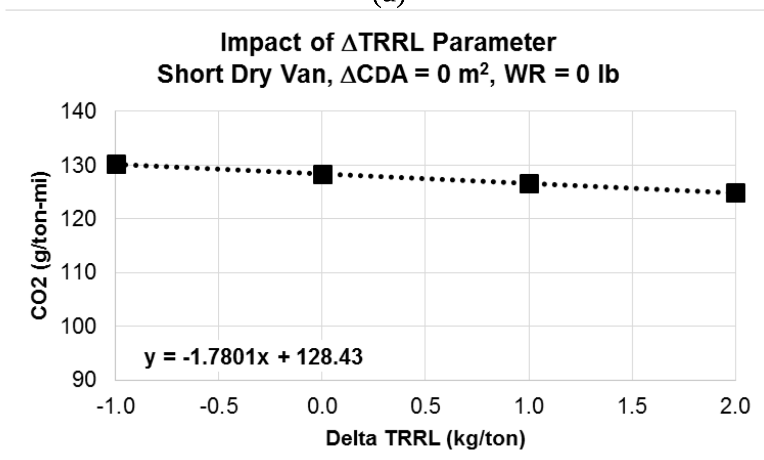


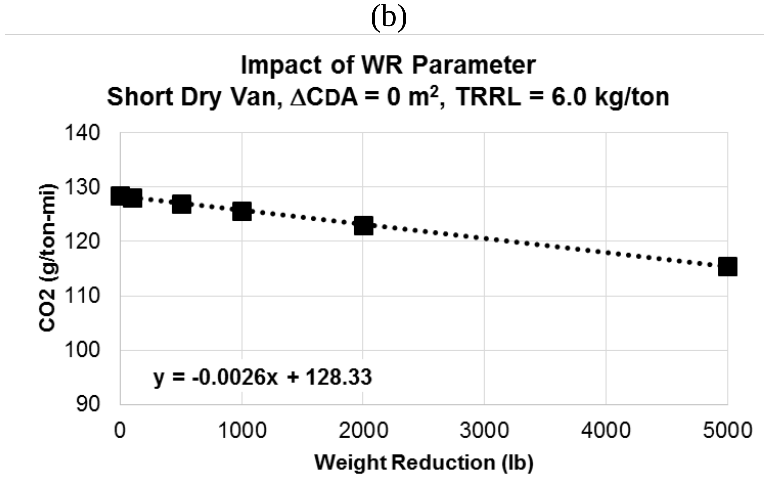
Figure 2-75 Impact of (a) Delta C_dA, (b) Delta C_{RR}, and (c) Weight Reduction on CO_2 Results of a GEM-Simulated Long Refrigerated Van



(a)

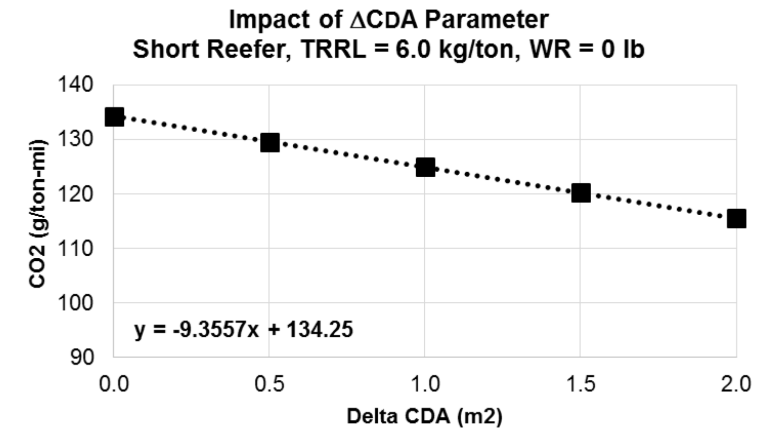


(b)

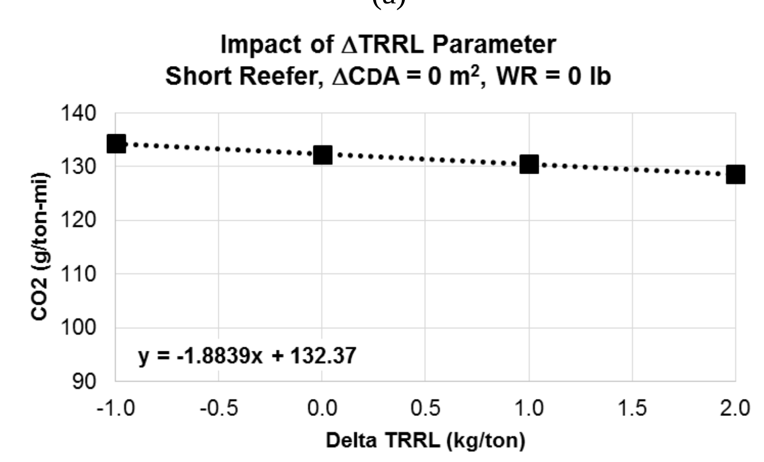


(c)

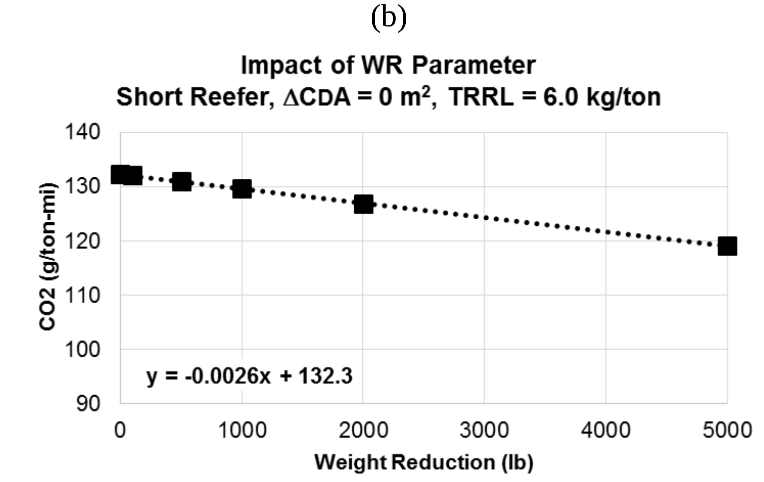
Figure 2-76 Impact of (a) Delta C_dA, (b) Delta C_{RR}, and (c) Weight Reduction on CO_2 Results of a GEM-Simulated Short Dry Van



(a)



(b)



(c)

Figure 2-77 Impact of (a) Delta C_dA, (b) Delta C_{RR}, and (c) Weight Reduction on CO_2 Results of a GEM-Simulated Short Refrigerated Van

Additional GEM simulations were performed for each of the four box trailer subcategories to assess the combined effect of these parameters. As seen in Figure 2-78 and Figure 2-79 for the long dry van simulation, the coefficients of the curve fit equations were not significantly changed, indicating that the combined impacts of these parameters on GEM's CO_2 results were additive. Similar trends were seen with the simulations for the other trailer subcategories, though the results are not shown here.

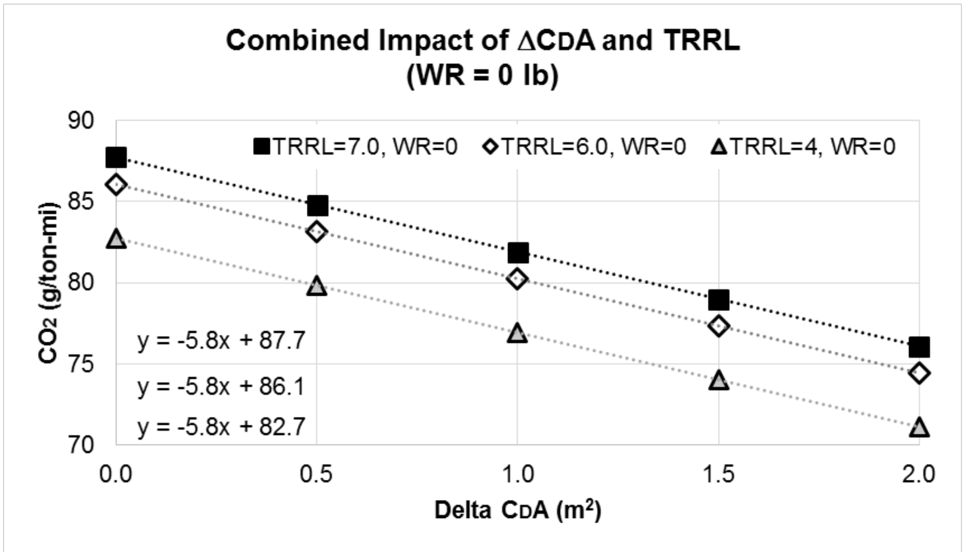


Figure 2-78 Combined Impact of Drag Area and Tire Rolling Resistance Level on CO_2 Results of a GEM-Simulated Long Dry Van with No Weight Reduction

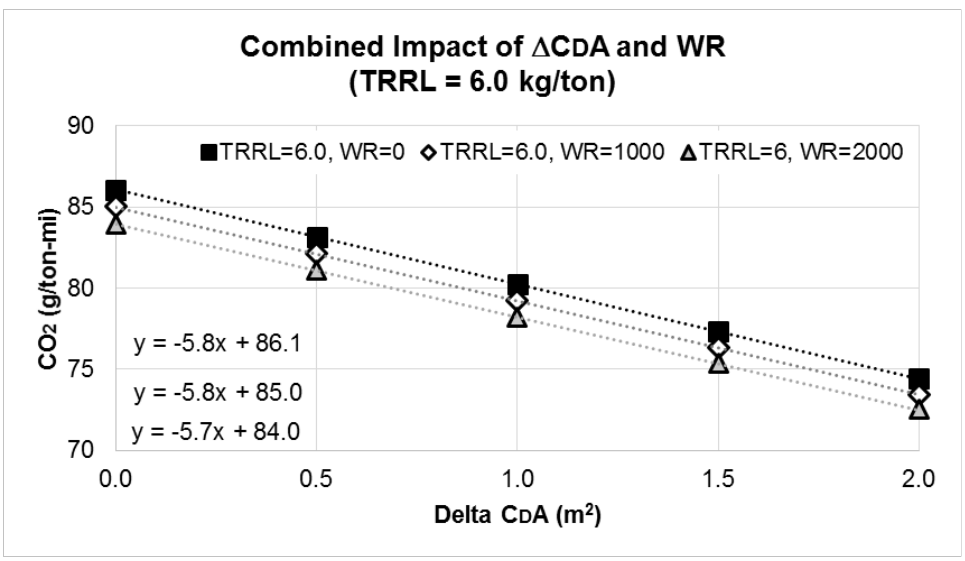


Figure 2-79 Combined Impact of Drag Area and Weight Reduction on CO_2 Results of a GEM-Simulated Long Dry Van at a Tire Rolling Resistance Level of 5.1 kg/ton

The results presented Figure 2-78 and Figure 2-79 suggest that these parameters could be combined into a single equation to calculate CO_2 emissions. Equation 2-3 is the result of combining the updated curve fit equations for long box dry vans.

Equation 2-3 Combination of Curve Fit Equations for Long Dry Van GEM Input Parameters

$$y = 86.1 - 1.7(\Delta TRRL) - 5.8(\Delta C_D A) - 0.0010(WR)$$

Our regulations specify that TRRL be an absolute measure of a tire's coefficient of rolling resistance (not a *change* in rolling resistance). As a result, Equation 2-3 was modified such that the variables of the equation matched the trailer inputs required by GEM. Equation 2-4 is the resulting equation.

Equation 2-4 Modified Equation for Long Dry Vans to Account for TRRL Input Parameter

$$y = 76.1 + 1.7(TRRL) - 5.8(\Delta C_D A) - 0.0010(WR)$$

Each of the trailer subcategories follows the same general format and a generic equation is shown in Equation 2-5. Table 2-115 summarizes the corresponding constants for each of the trailer subcategories.

Equation 2-5 General GEM-Based CO_2 Equation for Trailer Subcategories

$$e_{CO2} = C_1 + C_2(TRRL) + C_3(\Delta C_D A) + C_4(WR)$$

Table 2-115 Constants for GEM-Based CO_2 Equation for Trailer Subcategories (See Equation 2-5)

TRAILER SUBCATEGORY	C_1	C_2	C_3	C_4
Long Dry Van	76.1	1.67	-5.82	-0.00103
Long Refrigerated Van	77.4	1.75	-5.78	-0.00103
Short Dry Van	117.8	1.78	-9.48	-0.00258
Short Refrigerated Van	121.1	1.88	-9.36	-0.00264

Over 100 GEM vehicle simulations were performed for a range of delta C_dA, TRRL and weight reduction values. The results of these simulations were compared to CO_2 results calculated using Equation 2-5 for each trailer subcategory. The following figures show the equation and GEM have nearly identical CO_2 results.

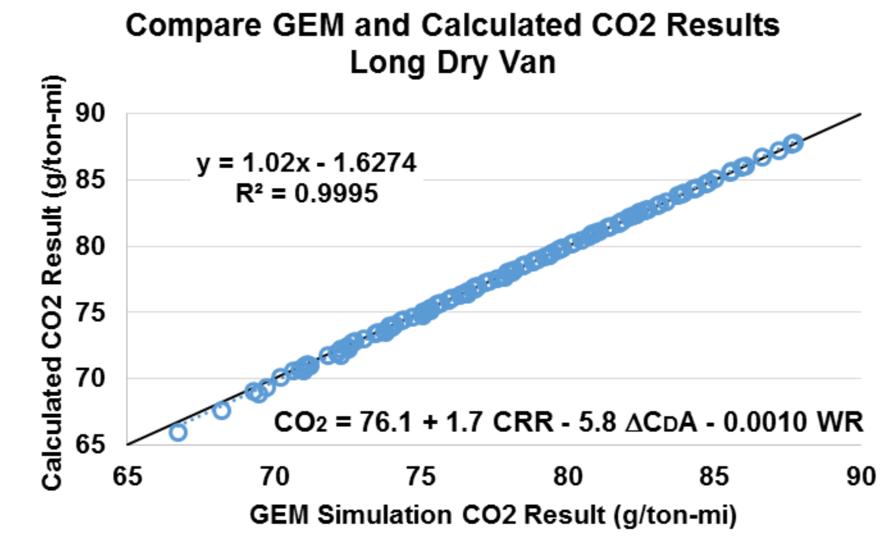


Figure 2-80 Comparison of GEM and Calculated CO_2 Results for a Long Dry Van

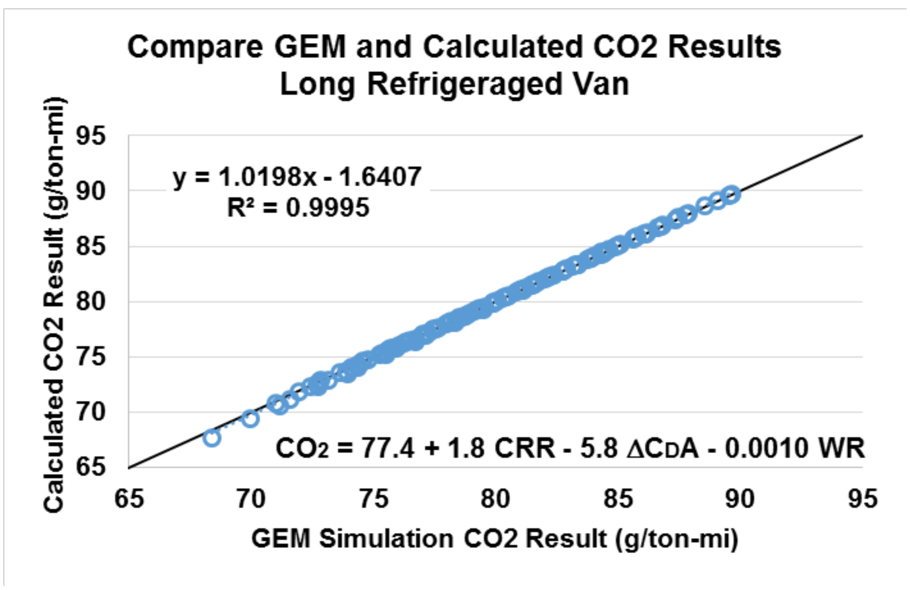


Figure 2-81 Comparison of GEM and Calculated CO_2 Results for a Long Refrigerated Van

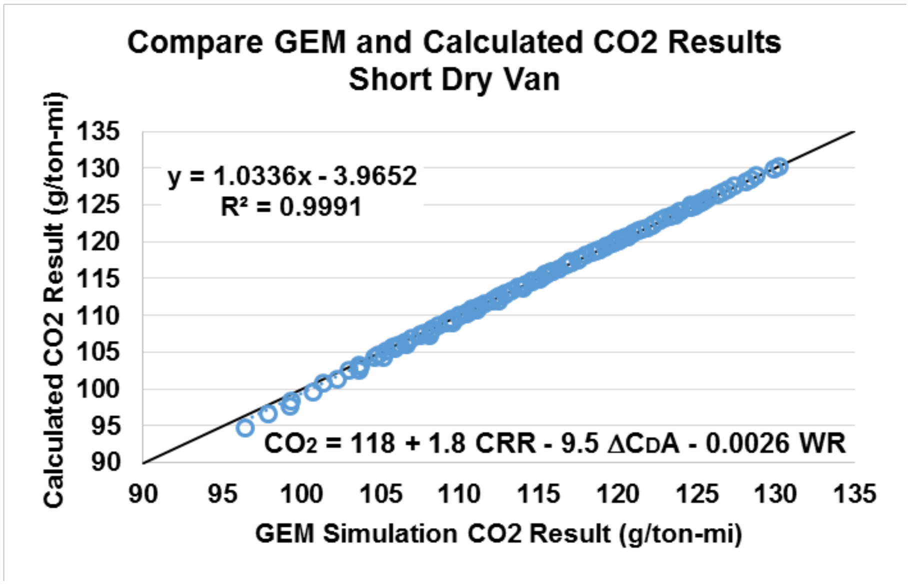


Figure 2-82 Comparison of GEM and Calculated CO_2 Results for a Short Dry Van

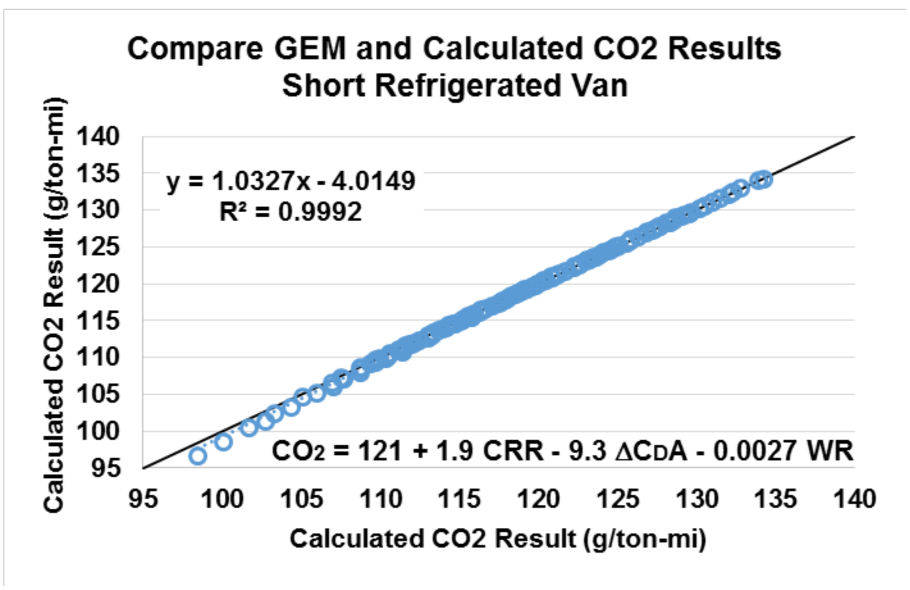


Figure 2-83 Comparison of GEM and Calculated CO_2 Results for a Short Refrigerated Van

The comparisons shown in Figure 2-80 through Figure 2-83 suggest that an equation may offer a simplified approach for trailer manufacturers to calculate CO_2 without the use of GEM. Equation 2-6 below is a slight modification to Equation 2-5. As mentioned previously, the trailer program is also offering the use of tire pressure systems as a means achieving the standards. This parameter is not considered in Equation 2-5. Equation 2-6 includes a constant, C_5, to address the use of tire pressure systems. Constant C_5 is equal to unity (1.0) for trailers that do not have tire pressure systems installed, equal to 0.988 (accounting for the 1.2 percent reduction) for trailers that include ATIS, and equal to 0.990 for trailers that include TPMS. As

mentioned previously, one can use a conversion factor of 10,180 grams CO_2 per gallon of diesel fuel to calculate the corresponding fuel consumption values.

Table 2-116 summarizes the constants available to manufacturers when using Equation 2-6 for compliance.

Equation 2-6 GEM-Based Compliance Equation for Phase 2 Trailer Program

$$e_{CO2} = [C_1 + C_2 \cdot (TRRL) + C_3 \cdot (\Delta C_D A) + C_4 \cdot (WR)] \cdot C_5$$

Table 2-116 Constants for GEM-Based CO_2 Equation for Trailer Subcategories (See Equation 2-6)

TRAILER SUBCATEGORY	C_1	C_2	C_3	C_4	C_5		
					No Tire Pressure System	ATIS Installed	TPMS Installed
Long Dry Van	76.1	1.67	-5.82	-0.00103	1.000	0.988	0.990
Long Refrigerated Van	77.4	1.75	-5.78	-0.00103			
Short Dry Van	117.8	1.78	-9.48	-0.00258			
Short Refrigerated Van	121.1	1.88	-9.36	-0.00264			

The updates to GEM that were made following the NPRM impacted the trailer model and resulted in a change to the constants for the GEM-based compliance equation that will be used by trailer manufacturers. We repeated the process of generating and validating the new constants, and, similar to the proposal, these updated values accurately recreate the GEM calculations for each trailer subcategory. Consequently, the agencies are adopting this equation-based compliance approach with the new constants shown in Table 2-116 for the final Phase 2 trailer program.

2.11 Technology Costs

2.11.1 Overview of Technology Cost Methodology Learning Effects on Technology Costs

Chapter 2.11.1.2 presents the methods used to address indirect costs in this analysis. Chapter 2.11.1.3 presents the learning effects applied throughout this analysis. In Chapter 2.11.2 through 2.11.10 we present individual technology costs including: the direct manufacturing costs (DMC), their indirect costs (IC) and their total costs (TC, TC=DMC+IC). Note that we also present technology penetration rates for most technologies and the resultant total cost as applied to a technology package (which we have denoted as TCp, where TCp=TC x Adoption Rate). The tables presented show the adoption rate for, generally, alternatives 1a and 3 where 1a represents the reference case (or the "no action" case) and 3 represents the preferred policy case (i.e. the standards adopted in this final rule). Note also that some TCp values appear as negative values in some tables (notably the lower rolling resistance (LRR) tire tables). This is because certain LRR tires are expected in the reference case but are then expected to be removed in the policy case and replaced by more aggressive LRR tires. In such cases, the reference case tires show negative TCp costs since they are being removed and replaced.

2.11.1.1 Direct Manufacturing Costs

The direct manufacturing costs (DMCs) used throughout this analysis are derived from several sources. Many of the tractor, vocational and trailer DMCs can be sourced to the Phase 1 rules which, in turn, were sourced largely from a contracted study by ICF International for EPA.[194] There was no serious disagreement regarding these estimated costs in the public comments to the Phase 1 rules. We have updated those costs by converting them to 2012 dollars, as described in Section IX.B.1.e of the Preamble, and by continuing the learning effects described in the Phase 1 rules and in Section IX. B.1.c of the Preamble. The new tractor, vocational and trailer costs can be sourced to a more recent study conducted by Southwest Research Institute (SwRI) under contract to NHTSA.[195] The cost methodology used by SwRI in that study was to estimate retail costs then work backward from there to derive a DMC for each technology. The agencies did not agree with the approach used by Tetra Tech to move from retail cost to DMC as it disagreed with EPA's look at retail price equivalents in the HD engine and truck industry on which EPA has based the indirect cost markup approach to estimate indirect costs, as discussed more in Chapter 2.11.1.2. As such, the agencies have used an approach consistent with past GHG/CAFE/fuel consumption rules by dividing estimated retail prices by our estimated retail price equivalent markups to derive an appropriate DMC for each technology. We describe our RPEs in Chapter 2.11.1.2.

For HD pickups and vans, we have relied primarily on the Phase 1 rules and the light-duty 2017-2025 model year rule since most technologies expected on these vehicles are, in effect, the same as those used on light-duty pickups. Many of those technology DMCs are based on cost teardown studies which the agencies consider to be the most robust method of cost estimation. However, many of the HD versions of those technologies would be expected to be more costly than their light-duty counterparts because of the heavier HD vehicles and/or the higher power and torque characteristics of their engines. Therefore, we have scaled upward where appropriate many of the light-duty DMCs for this analysis. We have also used some costs developed under contract to NHTSA by SwRI (the study mentioned above).[196]

Importantly, in our methodology, all technologies are treated as being sourced from a supplier rather than being developed and produced in-house. As such, some portion of the total indirect costs of making a technology or system—those costs incurred by the supplier for research, development, transportation, marketing etc.—are contained in the sales price to the engine and/or vehicle manufacturer (i.e., the original equipment manufacturer (OEM)). That sale price paid by the OEM to the supplier is the DMC we estimate.

2.11.1.2 Indirect Costs

To produce a unit of output, engine and truck manufacturers incur direct and indirect costs. Direct costs include cost of materials and labor costs. Indirect costs are all the costs associated with producing the unit of output that are not direct costs – for example, they may be related to production (such as research and development [R&D]), corporate operations (such as salaries, pensions, and health care costs for corporate staff), or selling (such as transportation, dealer support, and marketing). Indirect costs are generally recovered by allocating a share of the costs to each unit of a good sold (e.g., an engine, a truck, etc.). Although it is possible to account for direct costs allocated to each unit of good sold, it is more challenging to account for indirect costs allocated to a unit of goods sold. To make a cost analysis process more feasible, markup factors, which relate total indirect costs to total direct costs, have been developed. These factors are often referred to as retail price equivalent (RPE) multipliers.

Cost analysts and regulatory agencies (including both EPA and NHTSA) have frequently used these multipliers to predict the resultant impact on costs associated with manufacturers' responses to regulatory requirements. The best approach, if it were possible, to determining the impact of changes in direct manufacturing costs on a manufacturer's indirect costs would be to actually estimate the cost impact on each indirect cost element. However, doing this within the constraints of an agency's time or budget is not always feasible, or the technical, financial, and accounting information to carry out such an analysis may simply be unavailable.

RPE multipliers provide, at an aggregate level, the relative shares of revenues (Revenue = Direct Costs + Indirect Costs + Net Income) to direct manufacturing costs. Using RPE multipliers implicitly assumes that incremental changes in direct manufacturing costs produce common incremental changes in all indirect cost contributors as well as net income. However, a concern in using the RPE multiplier in cost analysis for new technologies added in response to regulatory requirements is that the indirect costs of vehicle modifications are not likely to be the same for different technologies. For example, less complex technologies could require fewer R&D efforts or less warranty coverage than more complex technologies. In addition, some simple technological adjustments may, for example, have no effect on the number of corporate personnel and the indirect costs attributable to those personnel. The use of RPEs, with their assumption that all technologies have the same proportion of indirect costs, is likely to overestimate the costs of less complex technologies and underestimate the costs of more complex technologies. Table 2-117 shows the RPE factors used in developing indirect costs in past, and this, agency analyses.

Table 2-117 Industry Retail Price Equivalent (RPE) Factors

INDUSTRY	RPE
Heavy engine manufacturers	1.28
Heavy truck manufacturers	1.36
Light-duty vehicle manufacturers	1.50

To address this concern, modified multipliers have been developed by EPA, working with a contractor, for use in rulemakings. These multipliers are referred to as indirect cost multipliers (or ICMs). In contrast to RPE multipliers, ICMs assign unique incremental changes to each indirect cost contributor as well as net income.

ICM = (direct cost + adjusted indirect cost)/(direct cost)

Developing the ICMs from the RPE multipliers requires developing adjustment factors based on the complexity of the technology and the time frame under consideration: the less complex a technology, the lower its ICM, and the longer the time frame for applying the technology, the lower the ICM. This methodology was used in the cost estimation for the recent light-duty MYs 2012-2016 and MYs 2017-2025 rulemaking and for the heavy-duty MYs 2014-2018 rulemaking. There was no serious disagreement with this approach in the public comments to any of these rulemakings. The ICMs for the light-duty context were developed in a peer-reviewed report from RTI International and were subsequently discussed in a peer-reviewed journal article.[197] Importantly, since publication of that peer-reviewed journal article, the agencies have revised the methodology to include a return on capital (i.e., profits) based on the assumption implicit in ICMs (and RPEs) that capital costs are proportional to direct costs, and businesses need to be able to earn returns on their investments.

For the heavy-duty pickup truck and van cost projections in this rule, the agencies have used ICM adjustment factors developed for light-duty vehicles, inclusive of a return on capital, primarily because the manufacturers involved in this segment of the heavy-duty market are the same manufacturers that build light-duty trucks.

For the combination tractors, vocational vehicles, and heavy-duty engine cost projections in this rule, the agencies are again using the ICMs used in the HD Phase 1 rules. Those ICMs were developed by RTI International under EPA contract to update EPA's methodology for accounting for indirect costs associated with changes in direct manufacturing costs for heavy-duty engine and truck manufacturers.[198] In addition to the indirect cost contributors varying by complexity and time frame, there is no reason to expect that the contributors would be the same for engine manufacturers as for truck manufacturers. The resulting report from RTI provides a description of the methodology, as well as calculations of the indirect cost multipliers that are being used as the basis for the markups used in this rule. These indirect cost multipliers were used, along with calculations of direct manufacturing costs, to provide estimates of the full additional costs associated with new technologies.

As explained in the Phase 1 final rules, and entirely consistent with the analysis supporting that program, the agencies have made some changes to both the ICM factors and to the method of applying those factors relative to the factors developed by RTI and presented in their reports. The first of these changes was done in response to continued thinking among the agencies about how past ICMs have been developed and about which data sources are the most appropriate on which to rely in determining the appropriate ICMs. The second change was done in response to both staff concerns and public feedback suggesting that the agencies were inappropriately applying learning effects to indirect costs via the multiplicative approach to applying the ICMs.

Regarding the first change – to the ICM factors themselves – a little background must first be provided. In the original work done under contract to EPA by RTI International,[199] EPA experts had undergone a consensus approach to determining the impact of specific technology changes on the indirect costs of a company. Subsequently, EPA experts underwent a blind survey to make this determination on a different set of technology changes. This subsequent effort, referred to by EPA as a modified-Delphi approach, resulted in different ICM determinations. This effort is detailed in a memorandum contained in the docket for this rulemaking.[200] Upon completing this effort, EPA determined that the original RTI values should be averaged with the modified-Delphi values to arrive at the final ICMs for low and medium complexity technologies and that the original RTI values would be used for high complexity level 1 while the modified-Delphi values would be used for high complexity level 2. These final ICMs were used in the 2012-2016 light-duty GHG/CAFE rulemaking. Subsequent to that, EPA contracted with RTI to update their light-duty report with an eye to the heavy-duty industry. In that effort, RTI determined the RPE of both the heavy-duty engine and heavy truck industries, then applied the light-duty indirect cost factors—those resulting from the averaging of the values from their original report with the modified-Delphi values—to the heavy-duty RPEs to arrive at heavy-duty specific ICMs. That effort is described in their final heavy-duty ICM report mentioned above.[201]

During development of the Phase 1 heavy-duty final rules, the agencies decided that the original light-duty RTI values, given the technologies considered for low and medium complexity, should no longer be used and that we should rely solely on the modified-Delphi values for these complexity levels. The original light-duty RTI study used low rolling resistance tires as a low complexity technology example and a dual clutch transmission as a medium complexity technology. Upon further thought, the technologies considered for the modified Delphi values (passive aerodynamic improvements for low complexity and turbocharging with downsizing for medium complexity) were considered by the agencies to better represent the example technologies. As a result, the modified-Delphi values were to become the working ICMs for low and medium complexity rather than averaging those values with the original RTI report values. The agencies have also re-examined the technology complexity categories that were assigned to each light-duty technology and modified these assignments to better reflect the technologies that are now used as proxies for each category. This decision impacted the low and medium complexity heavy-duty ICMs too because the modified-Delphi values alone were to be applied to the heavy-duty RPEs to arrive at heavy-duty ICMs rather than using the averaged values developed for the light-duty 2012-2016 rulemaking.

A secondary-level change was also made as part of this ICM recalculation to the light-duty ICMs and, therefore, to the ICMs used in the Phase 1 HD final rules and again in this analysis for HD pickups and vans. That change was to revise upward the RPE level reported in the original RTI report from an original value of 1.46 to 1.5 to reflect the long term average RPE.

The original RTI study was based on 2008 data. However, an analysis of historical RPE data indicates that, although there is year to year variation, the average RPE has remained roughly 1.5. ICMs are applied to future year's data and therefore the agencies believed and continue to believe that it is most appropriate to base ICMs on the historical average rather than a single year's result. Therefore, ICMs were adjusted to reflect this average level. As a result, the High 1 and High 2 ICMs used for HD pickups and vans were changed for the Phase 1 final rules and we continue to use those changed values here.

Table 2-118 shows the ICM values used in this rule. Near term values are used in early years, depending on the technology, and account for differences in the levels of R&D, tooling, and other indirect costs that would be incurred. Once the program has been fully implemented, some of the indirect costs would no longer be attributable to the standards and, as such, a lower ICM factor is applied to direct costs in later years.

Table 2-118 Indirect Cost Multipliers Used in this Analysis[a]

CLASS	COMPLEXITY	NEAR TERM	LONG TERM
HD Pickup Trucks and Vans	Low	1.24	1.19
	Medium	1.39	1.29
	High1	1.56	1.35
	High2	1.77	1.50
Loose diesel engines	Low	1.15	1.13
	Medium	1.24	1.18
	High1	1.28	1.19
	High2	1.44	1.29
Loose gasoline engines	Low	1.24	1.19
	Medium	1.39	1.29
	High1	1.56	1.35
	High2	1.77	1.50
Vocational Vehicles, Combination Tractors and Trailers	Low	1.18	1.14
	Medium	1.30	1.23
	High1	1.43	1.27
	High2	1.57	1.37

Note:
[a] Rogozhin, A., et. al., "Using indirect cost multipliers to estimate the total cost of adding new technology in the automobile industry," International Journal of Production Economics (2009); "Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies," Helfand, G., and Sherwood, T., Memorandum dated August 2009; "Heavy Duty Truck Retail Price Equivalent and Indirect Cost Multipliers," Report prepared by RTI International and Transportation Research Institute, University of Michigan, July 2010.

The second change made to the ICMs during development of the Phase 1 final rules had to do with the way in which the ICMs were applied. Until that time, we had applied the ICMs, as done in any analysis that relied on RPEs, as a pure multiplicative factor. This way, a direct manufacturing cost of, say, $100 would have been multiplied by an ICM of 1.24 to arrive at a marked up technology cost of $124. However, as learning effects (discussed below) are applied to the direct manufacturing cost, the indirect costs are also reduced accordingly. Therefore, in year 2 the $100 direct manufacturing cost might reduce to $97 and the marked up cost would become $120 ($97 x 1.24). As a result, indirect costs have been reduced from $24 to $23. Given that indirect costs cover many things such as facility-related costs, electricity, etc., it is perhaps not appropriate to apply the ICM to the learned direct costs, at least not for those indirect cost elements unlikely to change with learning. The agencies decided that it was more appropriate only to allow warranty costs to decrease with learning since warranty costs are tied to direct manufacturing costs (since warranty typically involves replacement of actual parts which should be less costly with learning).[P] However, the remaining elements of the indirect costs should remain constant year-over-year, at least until some of those indirect costs are no longer attributable to the rulemaking effort that imposed them (such as R&D).

As a result, the ICM calculation became more complex with the analysis supporting the Phase 1 final rules, and we continue to use that more complex calculation here. We first establish the year in which the direct manufacturing costs are considered "valid." For example, a cost estimate might be considered valid today, or perhaps not until high volume production is reached in some future model year. That year is considered the base year for the estimated cost. That cost is the cost used to determine the "non-warranty" portion of the indirect costs. For example, the near term non-warranty portion of the loose diesel engine low complexity ICM is 0.149 (the warranty versus non-warranty portions of the ICMs are shown in Table 2-119). For the improved water pump technology we have estimated a direct manufacturing cost of $82.66 (2012$) in MY 2014. So the non-warranty portion of the indirect costs would be $12.32 ($82.66 x 0.149). This value would be added to the learned direct manufacturing cost for each year through 2022 since the near term markup is considered appropriate for that technology through 2022. Beginning in 2023, when long-term indirect costs begin, the additive factor would become $10.08 ($82.66 x 0.122). Additionally, the $82.66 cost in 2014 would become $80.18 in MY 2015 due to learning ($82.66 x (1-3 percent)). So, while the warranty portion of the indirect costs would be $0.49 ($82.66 x 0.006) in 2014, they would decrease to $0.48 ($80.18 x 0.006) in 2015 as warranty costs decrease with learning. The resultant indirect costs for the water pump would be $12.81 ($12.32+$0.49) in MY 2014 and $12.80 ($12.32+$0.48) in MY2015, and so on for subsequent years.

Importantly, since the bulk of the indirect costs calculated using this methodology are the non-warranty costs, and since those costs do not change over with learning, one cannot look at the ICMs shown in Table 2-118 and assume that our HD pickup and van total costs are, in general, 1.24 or 1.39 times the direct costs (since most technologies considered for application in HD pickups and vans are low and medium technologies). This can be illustrated by building on the example presented above for a water pump on a heavy diesel engine. We already calculated the MY 2014 total cost as $95.46 (2012$, $82.66+$12.32+$0.49). This is an effective markup of 1.155 ($95.46/$82.66). This is expected since the cost is based in 2014 and the near term ICM is 1.155. In MY2022, the final year of near term markups for this technology, the total cost would be $80.21 since the learned direct cost has reduced to $67.50, the non-warranty indirect costs (calculated above) remain $12.32, and the warranty indirect costs have become $0.39 ($67.50x0.006). So, in MY2022, we now have an effective markup of 1.19 ($80.21/$67.50).

[P] We note that the labor portion of warranty repairs does not decrease due to learning. However, we do not have data to separate this portion and so we apply learning to the entire warranty cost. Because warranty costs are a small portion of overall indirect costs, this has only a minor impact on the analysis.

Table 2-119 Warranty and Non-Warranty Portions of ICMs

		SHORT-TERM		LONG-TERM	
CLASS	COMPLEXITY	WARRANTY	NON-WARRANTY	WARRANTY	NON-WARRANTY
HD Pickup and Vans	Low	0.012	0.230	0.005	0.187
	Medium	0.045	0.343	0.031	0.259
	High1	0.065	0.499	0.032	0.314
	High2	0.074	0.696	0.049	0.448
Loose diesel engines	Low	0.006	0.149	0.003	0.122
	Medium	0.022	0.213	0.016	0.165
	High1	0.032	0.249	0.016	0.176
	High2	0.037	0.398	0.025	0.265
Loose gasoline engines	Low	0.012	0.230	0.005	0.187
	Medium	0.045	0.343	0.031	0.259
	High1	0.065	0.499	0.032	0.314
	High2	0.074	0.696	0.049	0.448
Vocational Vehicles, Combination Tractors and Trailers	Low	0.013	0.165	0.006	0.134
	Medium	0.051	0.252	0.035	0.190
	High1	0.073	0.352	0.037	0.233
	High2	0.084	0.486	0.056	0.312

The complexity levels and subsequent ICMs applied throughout this analysis for each technology are shown in Table 2-120. One notable change since the proposal is to waste heat recovery which used a short term markup through 2025 in the proposal but uses that markup through 2027 in this final rule.

Table 2-120 Indirect Cost Markups and Near Term/Long Term Cutoffs Used in this Analysis

TECHNOLOGY	APPLIED TO	ICM COMPLEXITY	NEAR TERM THRU
Cylinder head improvements 1	LH/MH/HH Engines	Low	2022
Cylinder head improvements 2	LH/MH/HH Engines	Low	2027
Turbo efficiency improvements 1	LH/MH/HH, HD Pickup & Van Engines	Low	2022
Turbo efficiency improvements 2	LH/MH/HH Engines	Low	2027
EGR cooler efficiency improvements 1	LH/MH/HH Engines	Low	2022
EGR cooler efficiency improvements 2	LH/MH/HH Engines	Low	2027
Water pump improvements 1	LH/MH/HH Engines	Low	2022
Water pump improvements 2	LH/MH/HH Engines	Low	2027
Oil pump improvements 1	LH/MH/HH Engines	Low	2022
Oil pump improvements 2	LH/MH/HH Engines	Low	2027
Fuel pump improvements 1	LH/MH/HH Engines	Low	2022
Fuel pump improvements 2	LH/MH/HH Engines	Low	2027
Fuel rail improvements 1	LH/MH/HH Engines	Low	2022
Fuel rail improvements 2	LH/MH/HH Engines	Low	2027
Fuel injector improvements 1	LH/MH/HH Engines	Low	2022
Fuel injector improvements 2	LH/MH/HH Engines	Low	2027
Piston improvements 1	LH/MH/HH Engines	Low	2022
Piston improvements 2	LH/MH/HH Engines	Low	2027
Valve train friction reductions 1	LH/MH/HH Engines	Low	2022
Valve train friction reductions 2	LH/MH/HH Engines	Low	2027
Turbo compounding 1	LH/MH/HH Engines	Low	2022
Turbo compounding 2	LH/MH/HH Engines	Low	2027
Aftertreatment improvements 1	LH/MH/HH Engines	Low	2022

Aftertreatment improvements 2	LH/MH/HH Engines	Low	2024
Model based control	LH/MH/HH Engines	Low	2022
Waste heat recovery	HH Engines	Medium	2027
Engine friction reduction 1	HD Pickup & Van Engines	Low	2018
Engine friction reduction 2	HD Pickup & Van Engines	Low	2024
Engine changes to accommodate low friction lubes	HD Pickup & Van Engines	Low	2018
Variable valve timing – coupled	HD Pickup & Van Engines	Low	2018
Variable valve timing – dual	HD Pickup & Van Engines	Medium	2018
Stoichiometric gasoline direct injection	HD Pickup & Van Engines	Medium	2018
Cylinder deactivation	HD Pickup & Van Engines	Medium	2018
Cooled EGR	HD Pickup & Van Engines	Medium	2024
Turbocharging & downsizing	HD Pickup & Van Engines	Medium	2018
“Right sized” diesel engine	HD Pickup & Van vehicles, Tractors	Low	2022
6 speed transmission	HD Pickup & Van vehicles	Medium	2018
8 speed transmission	HD Pickup & Van vehicles, Vocational	Medium	2018
Automated & Automated manual transmission (AMT)	Vocational, Tractors	Medium	2022
High efficiency gearbox (HEG)	Vocational, Tractors, HD Pickup & Vans	Low	2022, 2024
Early torque converter lockup (TORQ)	Vocational, HD Pickup & Vans	Low	2022, 2018
Auto transmission, power-shift	Tractors	Medium	2022
Dual clutch transmission	Tractors	Medium	2022
Driveline integration	Vocational	Low	2022
6x2 axle	Tractors	Low	2022
Axle disconnect	Vocational	Low	2022
Axle downspeed	Tractors	Low	2022
High efficiency axle	Vocational, Tractors	Low	2022
Lower RR tires 1	HD Pickup & Van vehicles	Low	2018
Lower RR tires 2	HD Pickup & Van vehicles	Low	2024
Low drag brakes	HD Pickup & Van vehicles	Low	2018
Electric power steering	HD Pickup & Van vehicles	Low	2018
High efficiency transmission	HD Pickup & Van vehicles	Low	2024
Driveline friction reduction	HD Pickup & Van vehicles	Low	2022
Improved accessories (electrification)	HD Pickup & Van vehicles	Low	2018
Improved accessories (electrification)	Vocational, Tractors	Low	2022
Lower RR tires 1	Vocational , Tractors, Trailers	Low	2022
Lower RR tires 2	Vocational , Tractors, Trailers	Low	2022
Lower RR tires 3	Vocational , Tractors, Trailers s	Medium	2025
Lower RR tires 4	Vocational , Tractors, Trailers	Medium	2028
Lower RR tires 5	Vocational , Tractors, Trailers	Medium	2031
Automated Tire Inflation System (ATIS)	Tractors, Trailers	Low	2022
Tire Pressure Monitoring System	Vocational, Tractors & Trailers	Low	2022
Aero 1	HD Pickup & Van vehicles	Low	2018
Aero 2	HD Pickup & Van vehicles	Medium	2024
Aero Bins 1 thru 4	Tractors	Low	2022
Aero Bin 5 thru 7	Tractors	Medium	2025
Aero Bins 1 thru 8	Trailers	Low	2018
Weight reduction (via single wide tires and/or aluminum wheels)	Tractors	Low	2022
Weight reduction via material changes	HD Pickup & Van vehicles	Low	2018
Weight reduction via material changes – 200 lbs, 400 lbs	Vocational	Low	2022
Weight reduction via material changes – 1000 lbs	Vocational	Medium	2022
Weight reduction via material changes	Tractors	Low	2022
Auxiliary power unit (APU), battery APU, APU with DPF	Tractors	Low	2022

Fuel operated heater (FOH)	Tractors	Low	2022
Air conditioning leakage	Vocational, Tractors	Low	2022
Air conditioning efficiency	Tractors	Low	2022
Neutral idle	Vocational	Low	2022
Stop-start (no regeneration)	HD Pickup & Van vehicles	Medium	2018
Stop-start (with enhancements)	Vocational	Medium	2022
Auto Engine Shutdown System	Vocational, Tractors	Low	2022
Mild hybrid	HD Pickup & Van vehicles	High1	2024
Mild hybrid	Vocational	High1	2025
Strong hybrid	HD Pickup & Van vehicles	High1	2024
Hybrid without stop-start	Vocational	High1	2022
Advanced cruise control	Tractors	Low	2022

There is some level of uncertainty surrounding both the ICM and RPE markup factors. The ICM estimates used in this rule group all technologies into three broad categories and treat them as if individual technologies within each of the three categories (low, medium, and high complexity) would have the same ratio of indirect costs to direct costs. This simplification means it is likely that the direct cost for some technologies within a category will be higher and some lower than the estimate for the category in general. More importantly, the ICM estimates have not been validated through a direct accounting of actual indirect costs for individual technologies. RPEs themselves are inherently difficult to estimate because the accounting statements of manufacturers do not neatly categorize all cost elements as either direct or indirect costs. Hence, each researcher developing an RPE estimate must apply a certain amount of judgment to the allocation of the costs. Moreover, RPEs for heavy- and medium-duty trucks and for engine manufacturers are not as well studied as they are for the light-duty automobile industry. Since empirical estimates of ICMs are ultimately derived from the same data used to measure RPEs, this affects both measures. However, the value of RPE has not been measured for specific technologies, or for groups of specific technologies. Thus, even if we assume that the examined technology accurately represents the average impact on all technologies in its representative category, applying a single average RPE to any given technology by definition overstates costs for very simple technologies, or understates them for more advanced technologies in that group.

2.11.1.3 Learning Effects on Technology Costs

For some of the technologies considered in this analysis, manufacturer learning effects would be expected to play a role in the actual end costs. The “learning curve” or “experience curve” describes the reduction in unit production costs as a function of accumulated production volume. In theory, the cost behavior it describes applies to cumulative production volume measured at the level of an individual manufacturer, although it is often assumed—as both agencies have done in past regulatory analyses—to apply at the industry-wide level, particularly in industries that utilize many common technologies and component supply sources. Both agencies believe there are indeed many factors that cause costs to decrease over time. Research in the costs of manufacturing has consistently shown that, as manufacturers gain experience in production, they are able to apply innovations to simplify machining and assembly operations, use lower cost materials, and reduce the number or complexity of component parts. All of these factors allow manufacturers to lower the per-unit cost of production (*i.e.*, the manufacturing learning curve).[202]

The agencies have a detailed description of the learning effect in the light-duty 2012-2016 rulemaking. Most studies of the effect of experience or learning on production costs appear to assume that cost reductions begin only after some initial volume threshold has been reached, but not all of these studies specify this threshold volume. The rate at which costs decline beyond the initial threshold is usually expressed as the percent reduction in average unit cost that results from each successive doubling of cumulative production volume, sometimes referred to as the learning rate. Many estimates of experience curves do not specify a cumulative production volume beyond which cost reductions would no longer occur, instead depending on the asymptotic behavior of the effect for learning rates below 100 percent to establish a floor on costs.

In past rulemaking analyses, as noted above, both agencies have used a learning curve algorithm that applied a learning factor of 20 percent for each doubling of production volume. NHTSA has used this approach in analyses supporting recent CAFE rules. In its analyses, EPA has simplified the approach by using an "every two years" based learning progression rather than a pure production volume progression (*i.e.*, after two years of production it was assumed that production volumes would have doubled and, therefore, costs would be reduced by 20 percent).

In the light-duty 2012-2016 rulemaking, the agencies employed an additional learning algorithm to reflect the volume-based learning cost reductions that occur further along on the learning curve. This additional learning algorithm was termed "time-based" learning simply as a means of distinguishing this algorithm from the volume-based algorithm mentioned above, although both of the algorithms reflect the volume-based learning curve supported in the literature.[203] To avoid confusion, we now refer to this learning algorithm as the "flat-portion" of the learning curve. This way, we maintain the clarity that all learning is, in fact, volume-based learning, and the level of cost reductions depend only on where on the learning curve a technology's learning progression is. We distinguish the flat-portion of the curve from the steep-portion of the curve to indicate the level of learning taking place in the years following implementation of the technology. The agencies have applied the steep-portion learning algorithm for those technologies considered to be newer technologies likely to experience rapid cost reductions through manufacturer learning and the flat-portion learning algorithm for those technologies considered to be mature technologies likely to experience minor cost reductions through manufacturer learning. As noted above, the steep-portion learning algorithm results in 20 percent lower costs after two full years of implementation (*i.e.*, the 2016 MY costs are 20 percent lower than the 2014 and 2015 model year costs). Once the steep-portion learning steps have occurred (for technologies having the steep-portion learning algorithm applied), flat-portion learning at 3 percent per year becomes effective for 5 years. For technologies having the flat-portion learning algorithm applied), flat-portion learning at 3 percent per year begins in year 2 and remains effective for 5 years. Beyond 5 years of learning at 3 percent per year, 5 years of learning at 2 percent per year, then 5 at 1 percent per year become effective. There was no serious disagreement with this approach in the public comments to any of the GHG/fuel economy/consumption rulemakings.

Learning effects are applied to most but not all technologies because some of the expected technologies are already used rather widely in the industry and, presumably, learning impacts have already occurred. The steep-portion learning algorithm was applied for only a handful of technologies that are considered to be new or emerging technologies. Most technologies have been considered to be more established given their current use in the fleet and, hence, the lower flat-portion learning algorithm has been applied. The learning algorithms applied to each technology are summarized in Table 2-121. One change has been made since the proposal to waste heat recovery which used learning algorithm 12 in the proposal but uses a new learning algorithm 14 in this final rule.

Table 2-121 Learning Effect Algorithms Applied to Technologies Used in this Analysis

TECHNOLOGY	APPLIED TO	LEARNING ALGORITHM	LEARNING FACTOR “CURVE” [A]
Cylinder head improvements 1	LH/MH/HH Engines	Flat	2
Cylinder head improvements 2	LH/MH/HH Engines	Flat	13
Turbo efficiency improvements 1	LH/MH/HH, HD Pickup & Van Engines	Flat	2
Turbo efficiency improvements 2	LH/MH/HH Engines	Flat	13
EGR cooler efficiency improvements 1	LH/MH/HH Engines	Flat	2
EGR cooler efficiency improvements 2	LH/MH/HH Engines	Flat	13
Water pump improvements 1	LH/MH/HH Engines	Flat	2
Water pump improvements 2	LH/MH/HH Engines	Flat	13
Oil pump improvements 1	LH/MH/HH Engines	Flat	2
Oil pump improvements 2	LH/MH/HH Engines	Flat	13
Fuel pump improvements 1	LH/MH/HH Engines	Flat	2
Fuel pump improvements 2	LH/MH/HH Engines	Flat	13
Fuel rail improvements 1	LH/MH/HH Engines	Flat	2
Fuel rail improvements 2	LH/MH/HH Engines	Flat	13
Fuel injector improvements 1	LH/MH/HH Engines	Flat	2
Fuel injector improvements 2	LH/MH/HH Engines	Flat	13
Piston improvements 1	LH/MH/HH Engines	Flat	2
Piston improvements 2	LH/MH/HH Engines	Flat	13
Valve train friction reductions 1	LH/MH/HH Engines	Flat	2
Valve train friction reductions 2	LH/MH/HH Engines	Flat	13
Turbo compounding 1	LH/MH/HH Engines	Flat	2
Turbo compounding 2	LH/MH/HH Engines	Flat	13
Aftertreatment improvements 1 & 2	LH/MH/HH Engines	Flat	2
Model based control	LH/MH/HH Engines	Flat	13
Waste heat recovery	HH Engines	Steep	14
Engine friction reduction 1 & 2	HD Pickup & Van Engines	None	1
Engine changes to accommodate low friction lubes	HD Pickup & Van Engines	None	1
Variable valve timing	HD Pickup & Van Engines	Flat	8
Stoichiometric gasoline direct injection	HD Pickup & Van Engines	Flat	7
Cylinder deactivation	HD Pickup & Van Engines	Flat	8
Cooled EGR	HD Pickup & Van Engines	Flat	7
Turbocharging & downsizing	HD Pickup & Van Engines	Flat	7
“Right sized” diesel engine	HD Pickup & Van vehicles, Tractors	None	1

6 speed transmission	HD Pickup & Van vehicles	Flat	7
8 speed transmission	HD Pickup & Van vehicles, Vocational	Flat	7
Automated & Automated manual transmission (AMT)	Vocational, Tractors	Flat	12
High efficiency gearbox (HEG)	Vocational, Tractors, HD Pickup & Vans	Flat	13, 6
Early torque converter lockup (TORQ)	Vocational, HD Pickup & Vans	Flat	13, 8
Auto transmission, power-shift	Tractors	Flat	12
Dual clutch transmission	Tractors	Flat	12
Driveline integration	Vocational	Flat	13
6x2 axle	Tractors	Flat	12
Axle disconnect	Vocational	None	1
Axle downspeed	Tractors	Flat	12
High efficiency axle	Vocational, Tractors	Flat	12
Lower RR tires 1	HD Pickup & Van vehicles	None	1
Lower RR tires 2	HD Pickup & Van vehicles	Steep	11
Low drag brakes	HD Pickup & Van vehicles	None	1
Electric power steering	HD Pickup & Van vehicles	Flat	8
High efficiency transmission	HD Pickup & Van vehicles	Flat	6
Driveline friction reduction	HD Pickup & Van vehicles	Flat	3
Improved accessories (electrification)	HD Pickup & Van vehicles	Flat	8
Improved accessories	Tractors	Flat	12
Improved fan	Tractors	Flat	12
Lower RR tires 1	Vocational , Tractors, Trailers	Flat	2
Lower RR tires 2	Vocational , Tractors, Trailers	Flat	2
Lower RR tires 3	Vocational , Tractors, Trailers	Flat	12
Lower RR tires 4	Vocational , Tractors, Trailers	Flat	13
Lower RR tires 5	Vocational, Tractors, Trailers		13
Automated Tire Inflation System (ATIS)	Tractors, Trailers	Flat	12
Tire Pressure Monitoring System (TPMS)	Vocational, Tractors, Trailers	Flat	12
Aero 1 & 2	HD Pickup & Van vehicles	Flat	8
Aero Bins 1 & 2	Tractors	None	1
Aero Bin 3	Tractors	Flat	2
Aero Bins 4 thru 7	Tractors	Steep	4
Aero Bins 1 thru 8	Trailers	Flat	2
Weight reduction (via single wide tires and/or aluminum wheels)	Tractors	Flat	2

Weight reduction via material changes	HD Pickup & Van vehicles	Flat	6
Weight reduction via material changes	Vocational, Tractors	Flat	13
Auxiliary power unit (APU), battery APU, APU with DPF	Tractors	Flat	2
Fuel operated heater (FOH)	Tractors	Flat	2
Air conditioning leakage	Vocational, Tractors	Flat	2
Air conditioning efficiency	Tractors	Flat	12
Neutral idle	Vocational	None	1
Stop-start (no regeneration)	HD Pickup & Van vehicles	Steep	9
Stop-start (with enhancements)	Vocational	Flat	13
Mild hybrid	HD Pickup & Van vehicles	Flat	6
Mild hybrid	Tractors	Flat	12
Strong hybrid	HD Pickup & Van vehicles	Steep	11
Hybrid without stop-start	Vocational	Steep	11
Advanced cruise control	Tractors	Flat	12

Note:
[a] See table and figure below.

The actual year-by-year factors for the numbered curves shown in Table 2-121 are shown in Table 2-122 and are shown graphically in Figure 2-84.

Table 2-122 Year-by-year Learning Curve Factors for the Learning Curves Used in this Analysis

CURVE[A]	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1.000	0.970	0.941	0.913	0.885	0.868	0.850	0.833	0.817	0.800	0.784	0.769	0.761	0.753
3	1.031	1.000	0.970	0.941	0.913	0.894	0.877	0.859	0.842	0.825	0.808	0.792	0.784	0.777
4	1.000	1.000	0.800	0.800	0.640	0.621	0.602	0.584	0.567	0.550	0.533	0.517	0.507	0.497
6	1.096	1.063	1.031	1.000	0.970	0.941	0.913	0.885	0.859	0.842	0.825	0.808	0.792	0.776
7	0.941	0.913	0.885	0.868	0.850	0.833	0.817	0.800	0.784	0.769	0.753	0.738	0.731	0.723
8	1.031	1.000	0.970	0.951	0.932	0.913	0.895	0.877	0.859	0.842	0.825	0.809	0.801	0.793
9	1.250	1.000	1.000	0.970	0.941	0.913	0.885	0.859	0.833	0.808	0.784	0.760	0.745	0.730
11	1.563	1.563	1.563	1.563	1.563	1.250	1.250	1.000	0.970	0.941	0.913	0.885	0.859	0.842
12	1.130	1.096	1.063	1.031	1.000	0.970	0.941	0.913	0.894	0.877	0.859	0.842	0.825	0.808
13	1.238	1.201	1.165	1.130	1.096	1.063	1.031	1.000	0.970	0.941	0.913	0.894	0.877	0.859
14	1.563	1.563	1.563	1.563	1.563	1.250	1.250	1.000	1.000	0.800	0.800	0.640	0.621	0.602

Note:
[a] Curves 5 and 10 were generated but subsequently not used so are not included in the table.

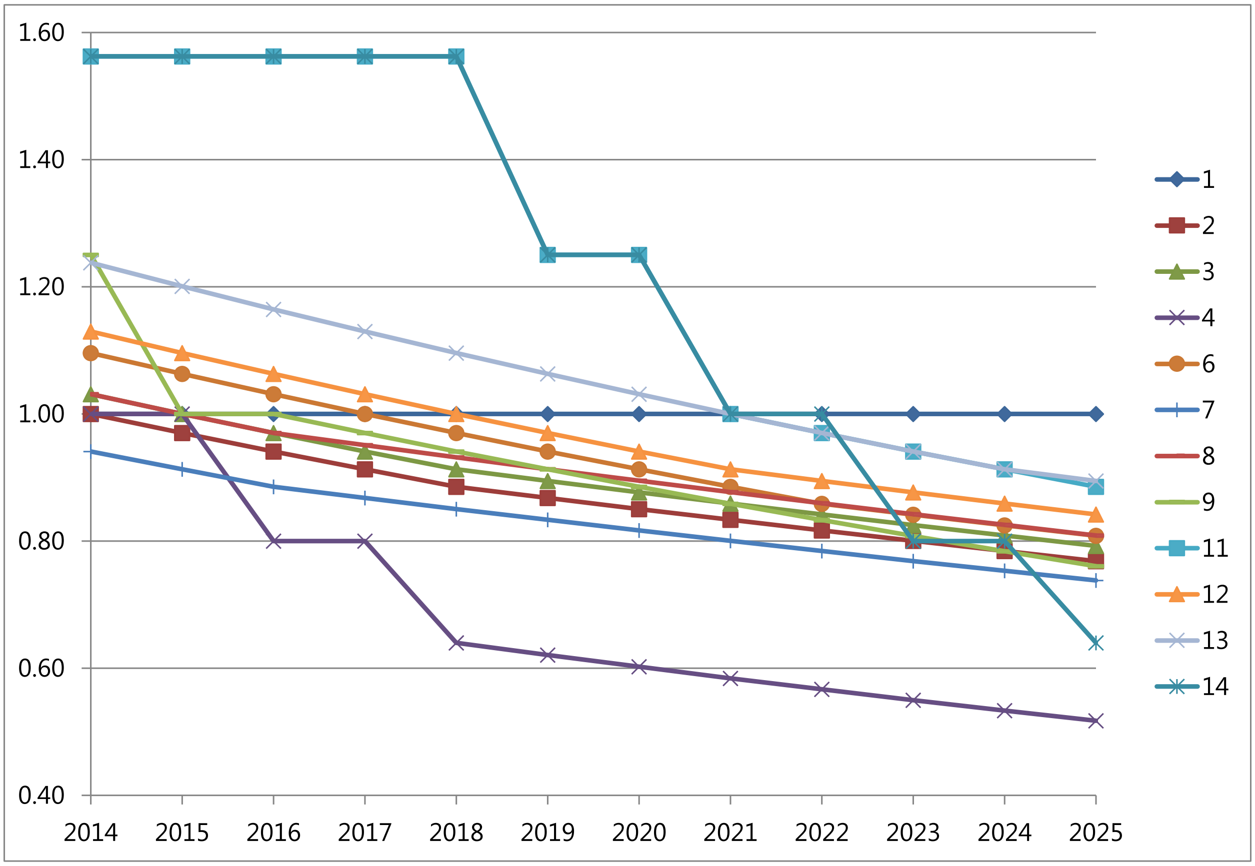


Figure 2-84 Year-by-year Learning Curve Factors for the Learning Curves used in this Analysis

Importantly, where the factors shown in Table 2-122 and, therefore, the curves shown in Figure 2-84 equal "1.00" represents the year for which any particular technology's cost is based. In other words, for example, the cost estimate that we have for cylinder head improvements 2 is "based" in 2021 (curve 13). Therefore, its learning factor equals 1.00 in 2021 and then decreases going forward to represent lower costs due to learning effects. Its learning factors are greater than 1.00 in years before 2021 to represent "reverse" learning, i.e., higher costs than our 2021 estimate since production volumes have, presumably, not yet reached the point where our cost estimate can be considered valid.

2.11.1.4 Technology Penetration Rates and Package Costs

Determining the stringency of the standards involves a balancing of relevant factors – chiefly technology feasibility and effectiveness, costs, and lead time. For each of the standards, the agencies have projected a technology path to achieve the standards reflecting an application rate of those technologies the agencies consider to be available at reasonable cost in the lead times provided. The agencies do not expect each of the technologies for which costs have been developed to be employed by all engines and vehicles across the board. Further, many of today's vehicles are already equipped with some of the technologies and/or are expected to adopt them by MY2018 to comply with the HD Phase 1 standards. Estimated penetration rates in both the reference and control cases are necessary for each vehicle category. The penetration rates for many technologies are zero in the reference case; however, for some technologies—notably aero and tire technologies—the reference case penetration rate is not always zero. These reference and control case penetration rates are then applied to the technology costs with the result being a package cost for each vehicle category. As such, package costs are rarely if ever a simple sum of all the technology costs since each technology would be expected to be adopted at different rates.

For HD pickups and vans, the CAFE model predicts the technology penetration rates that most cost effectively meet the standards being adopted. Similar to vocational vehicles, tractors and trailers, package costs are rarely if ever a simple sum of all the technology costs since each technology would be expected to be adopted at different rates. The methods for estimating technology penetration rates and resultant costs (and other impacts) for HD pickups and vans are discussed in Chapter 10 of this RIA.

2.11.1.5 Conversion of Technology Costs to 2013 U.S. Dollars

As noted above in Section IX.C.1, the agencies are using technology costs from many different sources. These sources, having been published in different years, present costs in different year dollars (i.e., 2009 dollars or 2010 dollars). For this analysis, the agencies sought to have all costs in terms of 2013 dollars to be consistent with the dollars used by AEO in its 2015 Annual Energy Outlook.[204] While the factors used to convert from 2009 dollars (or other) to 2013 dollars are small, the agencies prefer to be overly diligent in this regard to ensure consistency across our benefit-cost analysis. The agencies have used the GDP Implicit Price Deflator for Gross Domestic Product as the converter, with the actual factors used as shown in Table 2-123.[205]

Table 2-123 Implicit Price Deflators and Conversion Factors for Conversion to 2013$

CALENDAR YEAR	2005	2006	2007	2008	2009	2010	2011	2012	2013
Price index for GDP	91.988	94.814	97.337	99.246	100	101.221	103.311	105.214	106.929
Factor applied for 2013$	1.162	1.128	1.099	1.077	1.069	1.056	1.035	1.016	1.000

The sections above describe the technologies expected to be used to enable compliance with the standards and the penetration rates we estimate to be possible. Here we present the cost of each technology, the markups used for each, the learning effect applied, etc. The tables here present the direct manufacturing cost (DMC) we have estimated for each technology, the indirect costs (IC) associated with that technology, and the resultant total cost (TC) of each (where TC=DMC+IC). Each table also presents, where appropriate, the expected adoption rate of each technology in both the reference case (i.e., alternative 1a or the "no new controls" case) and the policy case (the standards). For most technologies, the reference case adoption rate will be shown as 0 percent (or blanks in the tables) since the Phase 2 technologies are expected to be in limited or no use in the regulatory timeframe. However, for some technologies—notably tire and aero technologies—there is expected to considerably adoption of Phase 2 technologies in the reference case. The final row(s) of the tables shown here include the penetration rates applied to the technology costs to arrive at a total cost of each technology as it is applied to the ultimate package (noted as TCp). In Chapter 2.12 of this RIA, we sum these costs (the TCp costs) into total cost applied to the packages presented later in Chapter 7 of this RIA. We also describe how we moved from the total cost applied to the packages developed for the regulatory classes (i.e., Class 8 Sleeper cab, LH vocational medium-speed, etc.) to the MOVES sourcetypes (i.e., transit bus, refuse truck, combination long haul, etc.) in order to develop program costs. This final step—moving from regulatory classes to MOVES sourcetypes, was necessary because MOVES populations, sales, inventory calculations, etc., are based on sourcetypes, not regulatory classes, and to allow for a more granular look at payback as presented in Chapter 7.2.4 of this RIA.

Note that the text surrounding the tables presented here refer to low/medium/high complexity ICMs and to learning curves used. We discuss both the ICMs and the learning effects used in this analysis in Chapter 2.11.1.2 and 2.11.1.3 of this RIA, respectively.

We received some comments on our technology costs, both direct and indirect costs, and on learning impacts. We address those comments in Section 11.3 of the Response to Comments document.

2.11.2 Costs of Engine Technologies

2.11.2.1 Aftertreatment Improvements

We have estimated the cost of aftertreatment improvements based on the aftertreatment improvements technology discussed in the Phase 1 rules. That technology was estimated at $25 (DMC, 2008$, in 2014) for each percentage improvement in fuel consumption, or $100 (DMC, 2008$, in 2014) for the 4 percent improvement expected as a result of that program. In Phase 2, we are expecting only a 0.6 percent improvement in fuel consumption resulting from aftertreatment improvements. Therefore, the cost in Phase 2 including updates to 2013$ is $16 (DMC, 2013$, in 2014). We consider this technology to be on the flat portion of the learning curve (curve 2) and have applied a low complexity ICM with short term markups through 2024. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-124 Costs of Aftertreatment Improvements – Level 2 Light/Medium/Heavy HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aftertreatment improvements – level 2	DMC	$14	$14	$14	$13	$13	$13	$13	$12	$12	$12
Aftertreatment improvements – level 2	IC	$2	$2	$2	$2	$2	$2	$2	$2	$2	$2
Aftertreatment improvements – level 2	TC	$17	$17	$16	$16	$16	$15	$15	$15	$15	$15
Aftertreatment improvements – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aftertreatment improvements – level 2	Alt 3	0%	0%	0%	50%	50%	50%	90%	90%	90%	100%
Aftertreatment improvements – level 2	TCp	$0	$0	$0	$8	$8	$8	$14	$13	$13	$15

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-125 Costs of Aftertreatment Improvements – Level 2 HDD Tractor Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aftertreatment improvements – level 2	DMC	$14	$14	$14	$13	$13	$13	$13	$12	$12	$12
Aftertreatment improvements – level 2	IC	$2	$2	$2	$2	$2	$2	$2	$2	$2	$2
Aftertreatment improvements – level 2	TC	$17	$17	$16	$16	$16	$15	$15	$15	$15	$15
Aftertreatment improvements – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aftertreatment improvements – level 2	Alt 3	0%	0%	0%	45%	45%	45%	95%	95%	95%	100%
Aftertreatment improvements – level 2	TCp	$0	$0	$0	$7	$7	$7	$14	$14	$14	$15

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.2.2 Cylinder Head Improvements

We have estimated the cost of cylinder head improvements based on the cylinder head improvements technology discussed in the Phase 1 rules. That technology was estimated at $9 (DMC, 2008$, in 2014) for light HDD engines and at $5 (DMC, 2008$, in 2014) for medium and heavy HDD engines. In Phase 2, we are estimating equivalent costs for an additional level of cylinder head improvements. With updates to 2013$, we estimate the costs at $10 (DMC, 2013$, in 2021) for light HDD engines and at $6 (DMC, 2013$, in 2021) for medium and heavy HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-126 Costs for Cylinder Head Improvements – Level 2 Light HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Cylinder head improvements – level 2	DMC	$11	$11	$10	$10	$10	$10	$9	$9	$9	$9
Cylinder head improvements – level 2	IC	$2	$2	$2	$2	$2	$2	$2	$2	$2	$2
Cylinder head improvements – level 2	TC	$13	$12	$12	$12	$11	$11	$11	$11	$10	$10
Cylinder head improvements – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cylinder head improvements – level 2	Alt 3	0%	0%	0%	50%	50%	50%	90%	90%	90%	100%
Cylinder head improvements – level 2	TCp	$0	$0	$0	$6	$6	$6	$10	$10	$9	$10

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-127 Costs for Cylinder Head Improvements – Level 2
Medium/Heavy HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Cylinder head improvements – level 2	DMC	$6	$6	$6	$6	$6	$6	$5	$5	$5	$5
Cylinder head improvements – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Cylinder head improvements – level 2	TC	$7	$7	$7	$7	$7	$6	$6	$6	$6	$6
Cylinder head improvements – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cylinder head improvements – level 2	Alt 3	0%	0%	0%	50%	50%	50%	90%	90%	90%	100%
Cylinder head improvements – level 2	TCp	$0	$0	$0	$3	$3	$3	$6	$6	$5	$6

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-128 Costs for Cylinder Head Improvements – Level 2
HDD Tractor Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Cylinder head improvements – level 2	DMC	$6	$6	$6	$6	$6	$6	$5	$5	$5	$5
Cylinder head improvements – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Cylinder head improvements – level 2	TC	$7	$7	$7	$7	$7	$6	$6	$6	$6	$6
Cylinder head improvements – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cylinder head improvements – level 2	Alt 3	0%	0%	0%	45%	45%	45%	95%	95%	95%	100%
Cylinder head improvements – level 2	TCp	$0	$0	$0	$3	$3	$3	$6	$6	$6	$6

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.2.3 Turbocharger Efficiency Improvements

We have estimated the cost of turbo efficiency improvements based on the turbo efficiency improvements technology discussed in the Phase 1 rules. That technology was estimated at $16 (DMC, 2008$, in 2014) for all HDD engines. In Phase 2, we are estimating equivalent costs for an additional level of turbo efficiency improvements. With updates to 2013$, we estimate the costs at $17 (DMC, 2013$, in 2021) for all HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-129 Costs for Turbocharger Efficiency Improvements – Level 2
Light/Medium/Heavy HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Turbo efficiency improvements – level 2	DMC	$18	$18	$17	$17	$16	$16	$15	$15	$15	$14
Turbo efficiency improvements – level 2	IC	$3	$3	$3	$3	$3	$3	$3	$3	$3	$3
Turbo efficiency improvements – level 2	TC	$21	$21	$20	$19	$19	$18	$18	$18	$17	$17
Turbo efficiency improvements – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Turbo efficiency improvements – level 2	Alt 3	0%	0%	0%	50%	50%	50%	90%	90%	90%	100%
Turbo efficiency improvements – level 2	TCp	$0	$0	$0	$10	$9	$9	$16	$16	$16	$17

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-130 Costs for Turbocharger Efficiency Improvements – Level 2
HDD Tractor Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Turbo efficiency improvements – level 2	DMC	$18	$18	$17	$17	$16	$16	$15	$15	$15	$14
Turbo efficiency improvements – level 2	IC	$3	$3	$3	$3	$3	$3	$3	$3	$3	$3
Turbo efficiency improvements – level 2	TC	$21	$21	$20	$19	$19	$18	$18	$18	$17	$17
Turbo efficiency improvements – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Turbo efficiency improvements – level 2	Alt 3	0%	0%	0%	45%	45%	45%	95%	95%	95%	100%
Turbo efficiency improvements – level 2	TCp	$0	$0	$0	$9	$9	$8	$17	$17	$16	$17

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

For HD diesel pickups and vans, we are estimating use of the Phase 1 level of turbo efficiency improvements, or $17 (DMC, 2012$, in 2014). We consider this technology to be on the flat portion of the learning curve (curve 2) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs are shown below.

Table 2-131 Costs for Turbocharger Efficiency Improvements – Level 1
HD Pickups & Vans (2012$)

TECHNOLOGY		2021	2022	2023	2024	2025	2026	2027
Turbo efficiency improvements – level 1	DMC	$14	$14	$13	$13	$13	$13	$12
Turbo efficiency improvements – level 1	IC	$3	$3	$2	$2	$2	$2	$2
Turbo efficiency improvements – level 1	TC	$16	$16	$15	$15	$15	$15	$15

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.11.2.4 Turbo Compounding

We have estimated the cost of turbo compounding based on the turbo compounding technology discussed in the Phase 1 rules. That technology was estimated at $813 (DMC, 2008$, in 2014) for all HDD tractor engines. In Phase 2, we are estimating equivalent costs for an additional level of turbo compounding improvements. With updates to 2013$, we estimate the costs at $875 (DMC, 2013$, in 2021) for all HDD tractor engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-132 Costs for Turbocharger Compounding – Level 2 HDD Tractor Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Turbo compounding – level 2	DMC	$959	$930	$902	$875	$849	$824	$799	$783	$767	$752
Turbo compounding – level 2	IC	$136	$136	$136	$136	$135	$135	$135	$135	$135	$135
Turbo compounding – level 2	TC	$1,095	$1,066	$1,038	$1,011	$985	$959	$934	$918	$902	$887
Turbo compounding – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Turbo compounding – level 2	Alt 3	0%	0%	0%	5%	5%	5%	10%	10%	10%	10%
Turbo compounding – level 2	TCp	$0	$0	$0	$51	$49	$48	$93	$92	$90	$89

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.2.5 Valve Actuation

We have estimated the cost of valve actuation based on the dual cam phasing cost estimate used in the 2017-2025 light-duty rule. In that analysis, we estimated costs at $151 (DMC, 2010$, in 2015) for a large V8 engine. In this HD Phase 2 program, we are estimating equivalent costs for this technology. With updates to 2013$, we estimate the costs at $160 (DMC, 2013$, in 2015) for all HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 8) and have applied a medium complexity ICM with short term markups through 2018. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-133 Costs for Valve Actuation
Light/Medium/Heavy HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Valve actuation	DMC	$149	$146	$143	$140	$137	$135	$132	$129	$128	$127
Valve actuation	IC	$61	$46	$46	$46	$46	$46	$45	$45	$45	$45
Valve actuation	TC	$210	$192	$189	$186	$183	$180	$177	$175	$173	$172
Valve actuation	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Valve actuation	Alt 3	0%	0%	0%	50%	50%	50%	90%	90%	90%	100%
Valve actuation	All	$0	$0	$0	$93	$92	$90	$160	$157	$156	$172

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-134 Costs for Valve Actuation
HDD Tractor Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Valve actuation	DMC	$149	$146	$143	$140	$137	$135	$132	$129	$128	$127
Valve actuation	IC	$61	$46	$46	$46	$46	$46	$45	$45	$45	$45
Valve actuation	TC	$210	$192	$189	$186	$183	$180	$177	$175	$173	$172
Valve actuation	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Valve actuation	Alt 3	0%	0%	0%	45%	45%	45%	95%	95%	95%	100%
Valve actuation	All	$0	$0	$0	$84	$82	$81	$169	$166	$165	$172

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

For HD pickups and vans, we have estimated the costs of dual cam phasing based on the DMC, IC and TC presented above in Table 2-133.

For discrete variable valve lift (DVVL), we have again used the 2017-2025 light-duty FRM values updated to 2012$ to arrive at a cost of $259 (DMC, 2012$, in 2015). We consider this technology to be on the flat portion of the learning curve (curve 8) and have applied medium complexity markups with short term markups through 2024. The resultant costs are presented below.

Table 2-135 Costs for Discrete Variable Valve Lift (DVVL)
Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Discrete variable valve lift (DVVL)	DMC	$227	$223	$218	$214	$210	$207	$205
Discrete variable valve lift (DVVL)	IC	$74	$74	$74	$74	$74	$73	$73
Discrete variable valve lift (DVVL)	TC	$301	$297	$292	$288	$283	$281	$279

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.11.2.6 EGR

We have estimated the cost of EGR cooler improvements based on the EGR cooler improvements technology discussed in the Phase 1 rules. That technology was estimated at $3

(DMC, 2008$, in 2014) for all HDD engines. In Phase 2, we are estimating equivalent costs for an additional level of EGR cooler improvements. With updates to 2013$, we estimate the costs at $3 (DMC, 2013$, in 2021) for all HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-136 Costs for EGR Cooler Improvements – Level 2 Light/Medium/Heavy HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
EGR cooler – level 2	DMC	$4	$4	$3	$3	$3	$3	$3	$3	$3	$3
EGR cooler – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
EGR cooler – level 2	TC	$4	$4	$4	$4	$4	$4	$4	$4	$3	$3
EGR cooler – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
EGR cooler – level 2	Alt 3	0%	0%	0%	50%	50%	50%	90%	90%	90%	100%
EGR cooler – level 2	TCp	$0	$0	$0	$2	$2	$2	$3	$3	$3	$3

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-137 Costs for EGR Cooler Improvements – Level 2 HDD Tractor Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
EGR cooler – level 2	DMC	$4	$4	$3	$3	$3	$3	$3	$3	$3	$3
EGR cooler – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
EGR cooler – level 2	TC	$4	$4	$4	$4	$4	$4	$4	$4	$3	$3
EGR cooler – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
EGR cooler – level 2	Alt 3	0%	0%	0%	45%	45%	45%	95%	95%	95%	100%
EGR cooler – level 2	TCp	$0	$0	$0	$2	$2	$2	$3	$3	$3	$3

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

For HD pickups and vans, we have estimated the costs of adding cooled EGR to a gasoline engine based on the values used in the 2017-2025 light-duty FRM. We have scaled upward the light-duty value by 25 percent and converted to 2012$ to arrive at a cost of $317 (DMC, 2012$, in 2012). We consider this technology to be on the flat portion of the learning curve (curve 7) and have applied medium complexity markups with near term markups through 2024. The resultant costs are presented below.

Table 2-138 Costs for Cooled EGR Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Cooled EGR	DMC	$253	$248	$243	$239	$234	$231	$229
Cooled EGR	IC	$120	$120	$119	$119	$89	$89	$89
Cooled EGR	TC	$373	$368	$363	$358	$323	$321	$318

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.11.2.7 Water Pump Improvements

We have estimated the cost of water pump improvements based on the water pump improvements technology discussed in the Phase 1 rules. That technology was estimated at $78 (DMC, 2008$, in 2014) for all HDD engines. In Phase 2, we are estimating equivalent costs for an additional level of water pump improvements. With updates to 2013$, we estimate the costs at $84 (DMC, 2013$, in 2021) for all HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-139 Costs for Water Pump Improvements – Level 2 Light/Medium/Heavy HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Water pump – level 2	DMC	$92	$89	$87	$84	$82	$79	$77	$75	$74	$72
Water pump – level 2	IC	$13	$13	$13	$13	$13	$13	$13	$13	$13	$13
Water pump – level 2	TC	$105	$103	$100	$97	$95	$92	$90	$88	$87	$85
Water pump – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Water pump – level 2	Alt 3	0%	0%	0%	60%	60%	60%	90%	90%	90%	100%
Water pump – level 2	TCp	$0	$0	$0	$58	$57	$55	$81	$79	$78	$85

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-140 Costs for Water Pump Improvements – Level 2 HDD Tractor Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Water pump – level 2	DMC	$92	$89	$87	$84	$82	$79	$77	$75	$74	$72
Water pump – level 2	IC	$13	$13	$13	$13	$13	$13	$13	$13	$13	$13
Water pump – level 2	TC	$105	$103	$100	$97	$95	$92	$90	$88	$87	$85
Water pump – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Water pump – level 2	Alt 3	0%	0%	0%	45%	45%	45%	95%	95%	95%	100%
Water pump – level 2	TCp	$0	$0	$0	$44	$43	$41	$85	$84	$82	$85

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.2.8 Oil Pump Improvements

We have estimated the cost of oil pump improvements based on the oil pump improvements technology discussed in the Phase 1 rules. That technology was estimated at just under $4 (DMC, 2008$, in 2014) for all HDD engines. In Phase 2, we are estimating equivalent costs for an additional level of oil pump improvements. With updates to 2013$, we estimate the costs at just over $4 (DMC, 2013$, in 2021) for all HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-141 Costs for Oil Pump Improvements – Level 2
Light/Medium/Heavy HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Oil pump – level 2	DMC	$5	$4	$4	$4	$4	$4	$4	$4	$4	$4
Oil pump – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Oil pump – level 2	TC	$5	$5	$5	$5	$5	$5	$4	$4	$4	$4
Oil pump – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Oil pump – level 2	Alt 3	0%	0%	0%	60%	60%	60%	90%	90%	90%	100%
Oil pump – level 2	TCp	$0	$0	$0	$3	$3	$3	$4	$4	$4	$4

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-142 Costs for Oil Pump Improvements – Level 2
HDD Tractor Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Oil pump – level 2	DMC	$5	$4	$4	$4	$4	$4	$4	$4	$4	$4
Oil pump – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Oil pump – level 2	TC	$5	$5	$5	$5	$5	$5	$4	$4	$4	$4
Oil pump – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Oil pump – level 2	Alt 3	0%	0%	0%	45%	45%	45%	95%	95%	95%	100%
Oil pump – level 2	TCp	$0	$0	$0	$2	$2	$2	$4	$4	$4	$4

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.2.9 Fuel Pump Improvements

We have estimated the cost of fuel pump improvements based on the fuel pump improvements technology discussed in the Phase 1 rules. That technology was estimated at just under $4 (DMC, 2008$, in 2014) for all HDD engines. In Phase 2, we are estimating equivalent costs for an additional level of fuel pump improvements. With updates to 2013$, we estimate the costs at just over $4 (DMC, 2013$, in 2021) for all HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-143 Costs for Fuel Pump Improvements – Level 2
Light/Medium/Heavy HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel pump – level 2	DMC	$5	$4	$4	$4	$4	$4	$4	$4	$4	$4
Fuel pump – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Fuel pump – level 2	TC	$5	$5	$5	$5	$5	$5	$4	$4	$4	$4
Fuel pump – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel pump – level 2	Alt 3	0%	0%	0%	60%	60%	60%	90%	90%	90%	100%
Fuel pump – level 2	TCp	$0	$0	$0	$3	$3	$3	$4	$4	$4	$4

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-144 Costs for Fuel Pump Improvements – Level 2
HDD Tractor Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel pump – level 2	DMC	$5	$4	$4	$4	$4	$4	$4	$4	$4	$4
Fuel pump – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Fuel pump – level 2	TC	$5	$5	$5	$5	$5	$5	$4	$4	$4	$4
Fuel pump – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel pump – level 2	Alt 3	0%	0%	0%	45%	45%	45%	95%	95%	95%	100%
Fuel pump – level 2	TCp	$0	$0	$0	$2	$2	$2	$4	$4	$4	$4

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.2.10 Fuel Rail Improvements

We have estimated the cost of fuel rail improvements based on the fuel rail improvements technology discussed in the Phase 1 rules. That technology was estimated at $10 (DMC, 2008$, in 2014) for LHDD engines and just under $9 (DMC, 2008$, in 2014) for MHDD and HHDD engines. In Phase 2, we are estimating equivalent costs for an additional level of fuel rail improvements. With updates to 2013$, we estimate the costs at $11 (DMC, 2013$, in 2021) for LHDD and at just over $9 (DMC, 2013$, in 2021) for MHDD and HHDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-145 Costs for Fuel Rail Improvements – Level 2
Light HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel rail – level 2	DMC	$12	$12	$11	$11	$11	$10	$10	$10	$10	$9
Fuel rail – level 2	IC	$2	$2	$2	$2	$2	$2	$2	$2	$2	$2
Fuel rail – level 2	TC	$14	$13	$13	$13	$12	$12	$12	$11	$11	$11
Fuel rail – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel rail – level 2	Alt 3	0%	0%	0%	60%	60%	60%	90%	90%	90%	100%
Fuel rail – level 2	TCp	$0	$0	$0	$8	$7	$7	$11	$10	$10	$11

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-146 Costs for Fuel Rail Improvements – Level 2
Medium/Heavy HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel rail – level 2	DMC	$10	$10	$10	$9	$9	$9	$8	$8	$8	$8
Fuel rail – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Fuel rail – level 2	TC	$12	$11	$11	$11	$10	$10	$10	$10	$10	$9
Fuel rail – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel rail – level 2	Alt 3	0%	0%	0%	60%	60%	60%	90%	90%	90%	100%
Fuel rail – level 2	TCp	$0	$0	$0	$6	$6	$6	$9	$9	$9	$9

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-147 Costs for Fuel Rail Improvements – Level 2
HDD Tractor Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel rail – level 2	DMC	$10	$10	$10	$9	$9	$9	$8	$8	$8	$8
Fuel rail – level 2	IC	$1	$1	$1	$1	$1	$1	$1	$1	$1	$1
Fuel rail – level 2	TC	$12	$11	$11	$11	$10	$10	$10	$10	$10	$9
Fuel rail – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel rail – level 2	Alt 3	0%	0%	0%	45%	45%	45%	95%	95%	95%	100%
Fuel rail – level 2	TCp	$0	$0	$0	$5	$5	$5	$9	$9	$9	$9

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.2.11 Fuel Injector Improvements

We have estimated the cost of fuel injector improvements based on the fuel injector improvements technology discussed in the Phase 1 rules. That technology was estimated at $13 (DMC, 2008$, in 2014) for LHDD engines and $9 (DMC, 2008$, in 2014) for MHDD and HHDD engines. In Phase 2, we are estimating equivalent costs for an additional level of fuel injector improvements. With updates to 2013$, we estimate the costs at $13 (DMC, 2012$, in 2021) for LHDD and at $10 (DMC, 2013$, in 2021) for MHDD and HHDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-148 Costs for Fuel Injector Improvements – Level 2
Light HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel injectors – level 2	DMC	$15	$14	$14	$13	$13	$13	$12	$12	$12	$12
Fuel injectors – level 2	IC	$2	$2	$2	$2	$2	$2	$2	$2	$2	$2
Fuel injectors – level 2	TC	$17	$16	$16	$16	$15	$15	$14	$14	$14	$14
Fuel injectors – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel injectors – level 2	Alt 3	0%	0%	0%	50%	50%	50%	90%	90%	90%	100%
Fuel injectors – level 2	TCp	$0	$0	$0	$8	$8	$7	$13	$13	$12	$14

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative package; alt=alternative

Table 2-149 Costs for Fuel Injector Improvements – Level 2
Medium/Heavy HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel injectors – level 2	DMC	$11	$11	$10	$10	$10	$10	$9	$9	$9	$9
Fuel injectors – level 2	IC	$2	$2	$2	$2	$2	$2	$2	$2	$2	$2
Fuel injectors – level 2	TC	$13	$12	$12	$12	$11	$11	$11	$11	$10	$10
Fuel injectors – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel injectors – level 2	Alt 3	0%	0%	0%	50%	50%	50%	90%	90%	90%	100%
Fuel injectors – level 2	TCp	$0	$0	$0	$6	$6	$6	$10	$10	$9	$10

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-150 Costs for Fuel Injector Improvements – Level 2
HDD Tractor Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Fuel injectors – level 2	DMC	$11	$11	$10	$10	$10	$10	$9	$9	$9	$9
Fuel injectors – level 2	IC	$2	$2	$2	$2	$2	$2	$2	$2	$2	$2
Fuel injectors – level 2	TC	$13	$12	$12	$12	$11	$11	$11	$11	$10	$10
Fuel injectors – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel injectors – level 2	Alt 3	0%	0%	0%	45%	45%	45%	95%	95%	95%	100%
Fuel injectors – level 2	TCp	$0	$0	$0	$5	$5	$5	$10	$10	$10	$10

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.2.12 Piston Improvements

We have estimated the cost of piston improvements based on the piston improvements technology discussed in the Phase 1 rules. That technology was estimated at just over $2 (DMC, 2008$, in 2014) for all HDD engines. In Phase 2, we are estimating equivalent costs for an additional level of fuel pump improvements. With updates to 2013$, we estimate the costs at $3 (DMC, 2013$, in 2021) for all HDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-151 Costs for Piston Improvements – Level 2
Light/Medium/Heavy HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Piston improvements – level 2	DMC	$3	$3	$3	$3	$2	$2	$2	$2	$2	$2
Piston improvements – level 2	IC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Piston improvements – level 2	TC	$3	$3	$3	$3	$3	$3	$3	$3	$3	$3
Piston improvements – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Piston improvements – level 2	Alt 3	0%	0%	0%	50%	50%	50%	90%	90%	90%	100%
Piston improvements – level 2	TCp	$0	$0	$0	$1	$1	$1	$2	$2	$2	$3

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-152 Costs for Piston Improvements – Level 2
HDD Tractor Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Piston improvements – level 2	DMC	$3	$3	$3	$3	$2	$2	$2	$2	$2	$2
Piston improvements – level 2	IC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Piston improvements – level 2	TC	$3	$3	$3	$3	$3	$3	$3	$3	$3	$3
Piston improvements – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Piston improvements – level 2	Alt 3	0%	0%	0%	45%	45%	45%	95%	95%	95%	100%
Piston improvements – level 2	TCp	$0	$0	$0	$1	$1	$1	$3	$3	$2	$3

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.2.13 Valvetrain Friction Reduction

We have estimated the cost of valvetrain friction reduction based on the valvetrain friction reduction technology discussed in the Phase 1 rules. That technology was estimated at $94 (DMC, 2008$, in 2014) for LHDD engines and $70 (DMC, 2008$, in 2014) for MHDD and HHDD engines. In Phase 2, we are estimating equivalent costs for an additional level of fuel injector improvements. With updates to 2013$, we estimate the costs at $101 (DMC, 2013$, in 2021) for LHDD and at $76 (DMC, 2013$, in 2021) for MHDD and HHDD engines. We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2027. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-153 Costs for Valvetrain Friction Improvements – Level 2
Light HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Valvetrain friction reduction – level 2	DMC	$111	$107	$104	$101	$98	$95	$92	$90	$89	$87
Valvetrain friction reduction – level 2	IC	$16	$16	$16	$16	$16	$16	$16	$16	$16	$16
Valvetrain friction reduction – level 2	TC	$126	$123	$120	$117	$114	$111	$108	$106	$104	$102
Valvetrain friction reduction – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Valvetrain friction reduction – level 2	Alt 3	0%	0%	0%	60%	60%	60%	90%	90%	90%	100%
Valvetrain friction reduction – level 2	TCp	$0	$0	$0	$70	$68	$66	$97	$95	$94	$102

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-154 Costs for Valvetrain Friction Improvements – Level 2
Medium/Heavy HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Valvetrain friction reduction – level 2	DMC	$83	$81	$78	$76	$73	$71	$69	$68	$66	$65
Valvetrain friction reduction – level 2	IC	$12	$12	$12	$12	$12	$12	$12	$12	$12	$12
Valvetrain friction reduction – level 2	TC	$95	$92	$90	$87	$85	$83	$81	$79	$78	$77
Valvetrain friction reduction – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Valvetrain friction reduction – level 2	Alt 3	0%	0%	0%	60%	60%	60%	90%	90%	90%	100%
Valvetrain friction reduction – level 2	TCp	$0	$0	$0	$52	$51	$50	$73	$71	$70	$77

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-155 Costs for Valvetrain Friction Improvements – Level 2 HDD Tractor Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Valvetrain friction reduction – level 2	DMC	$83	$81	$78	$76	$73	$71	$69	$68	$66	$65
Valvetrain friction reduction – level 2	IC	$12	$12	$12	$12	$12	$12	$12	$12	$12	$12
Valvetrain friction reduction – level 2	TC	$95	$92	$90	$87	$85	$83	$81	$79	$78	$77
Valvetrain friction reduction – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Valvetrain friction reduction – level 2	Alt 3	0%	0%	0%	45%	45%	45%	95%	95%	95%	100%
Valvetrain friction reduction – level 2	TCp	$0	$0	$0	$39	$38	$37	$77	$75	$74	$77

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.2.14 "Right-sized" Diesel Engine

We have estimated the cost of a slightly smaller diesel engine at a $500 savings (DMC, 2013$, in any year) for all HDD tractor engines. We believe this represents an opportunity for lower costs because smaller diesel engines contain less materials and are, generally, less costly to produce than a larger diesel engine. As this cost is considered applicable in any year, we have not applied learning effects (curve 1). We have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below. For HD pickups and vans, we estimated the right-sized diesel engine cost as cost neutral to any reference case diesel engine and limited the technology to diesel vans. We have not included any costs associated with lost utility of the smaller diesel engine. We believe that the smaller engine would be attractive to some buyers, but not all, and that those buyers would not be concerned by any possible lost utility. For that reason, we have used a limited application rate for this technology. Note that, for HD pickups and vans, we have considered this technology to be cost neutral.

Table 2-156 Costs for "Right-sized" HDD Tractor Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Right-sized diesel engine	DMC	-$500	-$500	-$500	-$500	-$500	-$500	-$500	-$500	-$500	-$500
Right-sized diesel engine	IC	$89	$89	$89	$89	$89	$89	$89	$89	$89	$89
Right-sized diesel engine	TC	-$411	-$411	-$411	-$411	-$411	-$411	-$411	-$411	-$411	-$411
Right-sized diesel engine	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Right-sized diesel engine	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	30%
Right-sized diesel engine	TCp	$0	$0	$0	-$41	-$41	-$41	-$82	-$82	-$82	-$123

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.2.15 Waste Heat Recovery

In the proposal, we estimated the cost of waste heat recovery based on the estimate from Tetra Tech showing it at $12,000 (retail, 2013$). Using that $12,000 estimate and dividing by a 1.36 RPE (see Chapter 2.11.1.2 of this RIA) and converting to 2012$, we arrived at our estimated DMC of $8,692 (DMC, 2012$, in 2018). For this final rule, we have updated our cost of waste heat recovery based on new understanding of this technology. For this final rule, we have chosen to start with one specific source considered by TetraTech in developing their cost estimate. That source is the NESCCAF/ICCT/TIAX work which estimated the cost of the technology at $15,100 having used an RPE of 2.0.[206] Using the description of the technology by NESCCAF, et al., TetraTech estimated the bill of materials (BOM) costs as shown below. Using that BOM, along with updated understanding of more recent and future waste heat recovery systems, EPA eliminated some of the items as unnecessary for the type of system and effectiveness values that we envision (see Chapter 2.3 and 2.7 of this RIA). As shown in the table below, EPA estimates the costs of waste heat recovery at $5463 (DMC, 2013$, in 2021) and has considered this to be an applicable cost for MY2021.

Table 2-157 Direct Manufacturing Costs (DMC) for Waste Heat Recovery

System	MY2015 Cost estimated by TetraTech (2009$)	EPA updates (2013$)
Turbine generator & flywheel	$2160	$2309
Condenser	$550	$588
EGR boiler	$400	$428
Stack boiler	$1000	Not needed
Packaging, assembly, labor	$2000	$2138
Controls	$400	Not needed
Power electronics	$900	Not needed
Energy storage	$150	Not needed
Subtotal (direct mfg cost DMC)	$7560	$5463
RPE (2x subtotal)	$15120	

We consider this technology to be on the steep portion of the learning curve and have generated a new learning curve in the final rule to accommodate this reworked cost estimate (curve 14). We have applied a medium complexity ICM with short term markups through 2027.

The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-158 Costs for Waste Heat Recovery (WHR)
HDD Tractor Engines (2013$)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
WHR	DMC	$8,536	$6,829	$6,829	$5,463	$5,463	$4,370	$4,370	$3,496	$3,391	$3,290
WHR	IC	$1,807	$1,721	$1,721	$1,652	$1,652	$1,596	$1,596	$1,552	$1,547	$1,541
WHR	TC	$10,343	$8,550	$8,550	$7,115	$7,115	$5,967	$5,967	$5,048	$4,938	$4,831
WHR	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
WHR	Alt 3	0%	0%	0%	1%	1%	1%	5%	5%	5%	25%
WHR	TCp	$0	$0	$0	$71	$71	$60	$298	$252	$247	$1,208

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.2.16 Model-based Control

We have estimated the cost of model-based controls at $100 (DMC, 2013$, in 2021). We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-159 Costs for Model Based Controls
Light/Medium/Heavy HDD Vocational Engines (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Model-based control	DMC	$110	$106	$103	$100	$97	$94	$91	$89	$88	$86
Model-based control	IC	$16	$16	$15	$15	$15	$15	$15	$15	$15	$15
Model-based control	TC	$125	$122	$119	$115	$112	$110	$107	$105	$103	$101
Model-based control	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Model-based control	Alt 3	0%	0%	0%	25%	25%	25%	30%	30%	30%	40%
Model-based control	TCp	$0	$0	$0	$29	$28	$27	$32	$31	$31	$41

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.2.17 Engine Friction Reduction and Accommodating Low Friction Lubes

We have based the costs for accommodating low friction lubes (LUB) on the costs used in the light-duty 2017-2025 FRM but have scaled upward that cost by 50 percent to account for the larger HD engines. Using that cost ($3 DMC, 2006$, in any year) and converting to 2012$ results in a cost of $5 (DMC, 2012$, in any year). We consider this technology to be beyond learning (curve 1) and have applied low complexity markups with near term markups through 2018. The resultant costs for HD pickups and vans are shown in are shown below.

Table 2-160 Costs for Accommodating Low Friction Lubes
Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Engine friction reduction - level 1	DMC	$5	$5	$5	$5	$5	$5	$5
Engine friction reduction - level 1	IC	$1	$1	$1	$1	$1	$1	$1
Engine friction reduction - level 1	TC	$6	$6	$6	$6	$6	$6	$6

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

We have based the costs for engine friction reduction level 1 (EFR1) on the costs used in the light-duty 2017-2025 FRM. That cost is based on an original estimate of $11/cylinder (DMC, 2006$, in any year). Using that cost for an 8 cylinder engine and converting to 2012$ results in a cost of $97 (DMC, 2012$, in any year). We consider this technology to be beyond learning (curve 1) and have applied low complexity markups with near term markups through 2018. The resultant costs for HD pickups and vans are shown in are shown below.

Table 2-161 Costs for Engine Friction Reduction – Level 1
Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Engine friction reduction - level 1	DMC	$97	$97	$97	$97	$97	$97	$97
Engine friction reduction - level 1	IC	$19	$19	$19	$19	$19	$19	$19
Engine friction reduction - level 1	TC	$116	$116	$116	$116	$116	$116	$116

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

For engine friction reduction level 2 (EFR2, which includes costs for accommodating low friction lubes) we have used the same approach as used in the light-duty 2017-2025 rule in that we have doubled the DMC associated with LUB and EFR1. As with those technologies, we consider EFR2 to be beyond learning (curve 1) and have applied low complexity markups but have applied near term markups through 2024. The resultant costs for gasoline HD pickups and vans are shown below.

Table 2-162 Costs for Engine Friction Reduction – Level 2
Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Engine friction reduction - level 2	DMC	$205	$205	$205	$205	$205	$205	$205
Engine friction reduction - level 2	IC	$50	$50	$50	$50	$39	$39	$39
Engine friction reduction - level 2	TC	$254	$254	$254	$254	$244	$244	$244

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

For diesel HD pickups and vans, we have used the above costs for EFR level 2 and added to that costs associated with improvements to other parasitic loads on the engine. For that latter portion of the cost, we have used the light HDD engine DMCs for improved water pump level 1, improved oil pump level 1, improved fuel pump level 1, improved fuel injectors level 1 and valvetrain friction reduction level 1, which together result in a cost of $193 (DMC, 2012$, in and year). We consider this combined set of technologies to be beyond the effects of learning (curve 1) and have applied low complexity markups with near term markups through 2022. The resultant costs for diesel HD pickups and vans are shown below.

Table 2-163 Costs for Engine Friction Reduction & Improvements to Other Parasitics Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Engine friction reduction - diesel	DMC	$397	$397	$397	$397	$397	$397	$397
Engine friction reduction - diesel	IC	$96	$96	$87	$87	$77	$77	$77
Engine friction reduction - diesel	TC	$494	$494	$484	$484	$474	$474	$474

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.11.2.18 Cylinder Deactivation

For cylinder deactivation on HD pickups and vans, we have based the costs on values presented in the light-duty 2017-2025 FRM with updates to 2012$ to arrive at a cost of $169 (DMC, 2012$, in 2015). We consider this technology to be on the flat portion of the learning curve (curve 8) and have applied medium complexity markups with near term markups through 2018. The resultant costs are presented below.

Table 2-164 Costs for Cylinder Deactivation Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Cylinder deactivation	DMC	$148	$145	$142	$139	$137	$135	$134
Cylinder deactivation	IC	$48	$48	$48	$48	$48	$48	$48
Cylinder deactivation	TC	$196	$193	$190	$187	$185	$183	$182

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.11.2.19 Stoichiometric Gasoline Direct Injection (SGDI)

For gasoline direct injection on HD pickups and vans, we have based the costs on values presented in the light-duty 2017-2025 FRM with updates to 2012$ to arrive at a cost of $417 (DMC, 2012$, in 2012). We consider this technology to be on the flat portion of the learning curve (curve 7) and have applied medium complexity markups with near term markups through 2018. The resultant costs are presented below.

Table 2-165 Costs for Direct Injection Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Gasoline direct injection	DMC	$333	$327	$320	$314	$307	$304	$301
Gasoline direct injection	IC	$118	$118	$118	$117	$117	$117	$117
Gasoline direct injection	TC	$451	$445	$438	$431	$425	$422	$418

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost.

2.11.2.20 Turbocharging & Downsizing

For turbocharging and downsizing (TDS) on HD pickups and vans, we have based the costs on values presented in the light-duty 2017-2025 FRM with updates to 2012$. For the twin turbo configuration expected on a V6 engine (downsized from a V8), we estimate the cost at $735 (DMC, 2012$, in 2012). We consider this technology to be on the flat portion of the learning curve (curve 7) and have applied medium complexity markups with near term markups through 2018. For downsizing from an overhead valve (OHV) V8 to an overhead cam (OHC)

V6 valvetrain, we have estimated the cost at $340 (DMC, 2012$, in 2017). We consider this technology to be on the flat portion of the learning curve (curve 6) and have applied medium complexity markups with near term markups through 2018. For downsizing from an OHC V8 to an OHC V6, we have estimated the cost at -$295 (DMC, 2012$, in 2012). We consider this technology to be on the flat portion of the learning curve to arrive at a cost of $417 (DMC, 2012$, in 2012). We consider this technology to be on the flat portion of the learning curve (curve 7) and have applied medium complexity markups with near term markups through 2024. The resultant costs for the turbocharging system and for downsizing from an OHV V8 to an OHC V6 are shown below, and downsizing from an OHC V8 to an OHC V6 are also shown below.

Table 2-166 Costs for Adding Twin Turbos
Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Adding twin turbos	DMC	$588	$576	$565	$553	$542	$537	$531
Adding twin turbos	IC	$208	$208	$208	$207	$207	$207	$207
Adding twin turbos	TC	$796	$784	$772	$761	$749	$744	$738

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

Table 2-167 Costs for Downsizing from an OHV V8 to an OHC V6
Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Downsizing from OHV V8 to OHC V6	DMC	$301	$292	$286	$280	$275	$269	$264
Downsizing from OHV V8 to OHC V6	IC	$97	$97	$97	$97	$96	$96	$96
Downsizing from OHV V8 to OHC V6	TC	$398	$389	$383	$377	$371	$365	$360

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

Table 2-168 Costs for Downsizing from an OHC V8 to an OHC V6
Gasoline HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Downsizing from OHC V8 to OHC V6	DMC	-$236	-$232	-$227	-$223	-$218	-$216	-$214
Downsizing from OHC V8 to OHC V6	IC	$112	$112	$111	$111	$83	$83	$83
Downsizing from OHC V8 to OHC V6	TC	-$125	-$120	-$116	-$111	-$135	-$133	-$131

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.11.3 Transmissions

2.11.3.1 Adding Additional Gears (Vocational)

We have estimated the cost of adding 2 additional gears for vocational vehicles (light/medium HD, heavy HD urban/multipurpose) based on the light-duty cost for an 8 speed automatic transmission relative to a 6 speed automatic of $78 (DMC, 2010$, in 2012).[Q] We have scaled that value by typical torque values of 2000 foot-pounds for vocational and 332 for a light-duty truck. With updates to 2013$, this DMC for vocational vehicles becomes $495 (DMC, 2013$, in 2012). We consider this technology to be on the flat portion of the learning curve (curve 7) and have applied a medium complexity ICM with short term markups through 2018. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-169 Costs for Adding 2 Gears to an Automatic Transmission Vocational Light/Medium HD Urban/Multipurpose/Regional Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Adding additional gears	DMC	$421	$413	$404	$396	$388	$380	$373	$365	$362	$358
Adding additional gears	IC	$146	$109	$109	$108	$108	$108	$107	$107	$107	$107
Adding additional gears	TC	$567	$521	$513	$504	$496	$488	$480	$473	$469	$465
Adding additional gears	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Adding additional gears	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	20%
Adding additional gears	TCp	$0	$0	$0	$50	$50	$49	$96	$95	$94	$93

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-170 Costs for Adding 2 Gears to an Automatic Transmission Vocational Heavy HD Urban/Multipurpose Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Adding additional gears	DMC	$421	$413	$404	$396	$388	$380	$373	$365	$362	$358
Adding additional gears	IC	$146	$109	$109	$108	$108	$108	$107	$107	$107	$107
Adding additional gears	TC	$567	$521	$513	$504	$496	$488	$480	$473	$469	$465
Adding additional gears	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Adding additional gears	Alt 3	0%	0%	0%	5%	5%	5%	10%	10%	10%	10%
Adding additional gears	TCp	$0	$0	$0	$25	$25	$24	$48	$47	$47	$47

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.3.2 Automated/Automated Manual Transmissions (AMT)

We have estimated the cost of an AMT transmission, relative to a manual transmission, based on an estimate by Tetra Tech of $5,100 (retail, 2013$). Using that estimate, we divided by an RPE of 1.36 to arrive at an estimated cost of $3750 (DMC, 2013$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a medium complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

[Q] This cost was updated by FEV in early 2013. We are using the updated cost here, not the value used in the light-duty 2017-2025 final rule.

Table 2-171 Costs for an Automated Transmission
Vocational Heavy HD & Heavy HD Multipurpose Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Manual to AMT	DMC	$3,750	$3,638	$3,528	$3,423	$3,354	$3,287	$3,221	$3,157	$3,094	$3,032
Manual to AMT	IC	$1,134	$1,128	$1,123	$1,117	$1,114	$830	$828	$825	$823	$821
Manual to AMT	TC	$4,884	$4,766	$4,651	$4,540	$4,468	$4,117	$4,049	$3,982	$3,917	$3,853
Manual to AMT	Alt 1a	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
Manual to AMT	Alt 3	80%	80%	80%	85%	85%	85%	100%	100%	100%	100%
Manual to AMT	TCp	$0	$0	$0	$227	$223	$206	$810	$796	$783	$771

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-172 Costs for an Automated Transmission
Vocational Heavy HD Regional Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Manual to AMT	DMC	$3,750	$3,638	$3,528	$3,423	$3,354	$3,287	$3,221	$3,157	$3,094	$3,032
Manual to AMT	IC	$1,134	$1,128	$1,123	$1,117	$1,114	$830	$828	$825	$823	$821
Manual to AMT	TC	$4,884	$4,766	$4,651	$4,540	$4,468	$4,117	$4,049	$3,982	$3,917	$3,853
Manual to AMT	Alt 1a	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Manual to AMT	Alt 3	5%	5%	5%	35%	35%	35%	55%	55%	55%	85%
Manual to AMT	TCp	$0	$0	$0	$1,362	$1,340	$1,235	$2,024	$1,991	$1,958	$3,082

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-173 Costs for an AMT Transmission
Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Manual to AMT	DMC	$3,750	$3,638	$3,528	$3,423	$3,354	$3,287	$3,221	$3,157	$3,094	$3,032
Manual to AMT	IC	$1,134	$1,128	$1,123	$1,117	$1,114	$830	$828	$825	$823	$821
Manual to AMT	TC	$4,884	$4,766	$4,651	$4,540	$4,468	$4,117	$4,049	$3,982	$3,917	$3,853
Manual to AMT	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Manual to AMT	Alt 3	0%	0%	0%	40%	40%	40%	50%	50%	50%	50%
Manual to AMT	TCp	$0	$0	$0	$1,816	$1,787	$1,647	$2,024	$1,991	$1,958	$1,926

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.3.3 Automatic Transmission Powershift

We have estimated the cost of a powershift automatic transmission, relative to a manual transmission, based on an estimate by Tetra Tech of $15000 (retail, 2013$). Using that estimate, we divided by an RPE of 1.36 to arrive at an estimated cost of $11883 (DMC, 2013$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a medium complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-174 Costs for a Powershift Automatic Transmission Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Manual to AT powershift	DMC	$11,883	$11,527	$11,181	$10,846	$10,629	$10,416	$10,208	$10,004	$9,803	$9,607
Manual to AT powershift	IC	$3,593	$3,575	$3,557	$3,540	$3,529	$2,630	$2,623	$2,616	$2,608	$2,602
Manual to AT powershift	TC	$15,476	$15,101	$14,738	$14,386	$14,158	$13,046	$12,830	$12,619	$12,412	$12,209
Manual to AT powershift	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Manual to AT powershift	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	30%
Manual to AT powershift	TCp	$0	$0	$0	$1,439	$1,416	$1,305	$2,566	$2,524	$2,482	$3,663

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.3.4 Dual-clutch Transmissions (DCT)

For tractors, we have based our estimated cost of a DCT relative to a manual transmission on a Tetra Tech estimate of $17,500 (retail, 2013$). Using that estimate, we divided by an RPE of 1.36 to arrive at an estimated cost of $12,868 (DMC, 2013$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a medium complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-175 Costs for a Dual Clutch Transmission (DCT) Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Manual to DCT	DMC	$12,868	$12,482	$12,107	$11,744	$11,509	$11,279	$11,053	$10,832	$10,616	$10,403
Manual to DCT	IC	$3,890	$3,871	$3,852	$3,833	$3,821	$2,848	$2,840	$2,832	$2,825	$2,817
Manual to DCT	TC	$16,758	$16,352	$15,959	$15,577	$15,331	$14,127	$13,893	$13,664	$13,440	$13,220
Manual to DCT	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Manual to DCT	Alt 3	0%	0%	0%	5%	5%	5%	10%	10%	10%	10%
Manual to DCT	TCp	$0	$0	$0	$779	$767	$706	$1,389	$1,366	$1,344	$1,322

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.3.5 High Efficiency Gearbox (HEG)

For this technology, we have relied on our light-duty technology referred to as high efficiency gearbox (HEG). This technology was estimated at $200(DMC, in 2010$, in 2015). For this analysis, we have used that estimate but have scaled upward the cost of HEG by 25 percent to account for differences between light-duty and HD. Converting to 2013$ results in costs for this technology of $267 (DMC, 2013$, in 2021). We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-176 Costs of Improved Transmissions
Vocational Light/Medium/Heavy HD Urban/Multipurpose Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
HEG	DMC	$293	$284	$276	$267	$259	$252	$244	$239	$234	$230
HEG	IC	$48	$48	$48	$48	$48	$37	$37	$37	$37	$37
HEG	TC	$341	$332	$323	$315	$307	$289	$281	$276	$272	$267
HEG	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
HEG	Alt 3	0%	0%	0%	50%	50%	50%	60%	60%	60%	62%
HEG	TCp	$0	$0	$0	$158	$153	$144	$169	$166	$163	$165

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-177 Costs of Improved Transmissions
Vocational Light/Medium/Heavy HD Regional Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
HEG	DMC	$293	$284	$276	$267	$259	$252	$244	$239	$234	$230
HEG	IC	$48	$48	$48	$48	$48	$37	$37	$37	$37	$37
HEG	TC	$341	$332	$323	$315	$307	$289	$281	$276	$272	$267
HEG	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
HEG	Alt 3	0%	0%	0%	50%	50%	50%	60%	60%	60%	70%
HEG	TCp	$0	$0	$0	$158	$153	$144	$169	$166	$163	$187

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-178 Costs for High Efficiency Gearbox (HEG) on Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
HEG	DMC	$293	$284	$276	$267	$259	$252	$244	$239	$234	$230
HEG	IC	$48	$48	$48	$48	$48	$37	$37	$37	$37	$37
HEG	TC	$341	$332	$323	$315	$307	$289	$281	$276	$272	$267
HEG	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
HEG	Alt 3	0%	0%	0%	20%	20%	20%	40%	40%	40%	70%
HEG	TCp	$0	$0	$0	$63	$61	$58	$113	$111	$109	$187

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.3.6 Early Torque Converter Lockup (TORQ) – Vocational Vehicles

For this technology, we have relied on our light-duty technology of the same. This technology was estimated at $25 (DMC, in 2010$, in 2015). For this analysis, we have used that estimate converted to 2013$ resulting in a cost for this technology of $26 (DMC, 2013$, in 2021). We consider this technology to be on the flat portion of the learning curve (curve 8) and have applied a low complexity ICM with short term markups through 2018. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-179 Costs of Early Torque Converter Lockup (TORQ)
Vocational Light/Medium HD Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
TORQ	DMC	$28	$28	$27	$26	$25	$24	$24	$23	$23	$22
TORQ	IC	$5	$5	$5	$5	$5	$4	$4	$4	$4	$4
TORQ	TC	$33	$32	$31	$31	$30	$28	$27	$27	$26	$26
TORQ	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
TORQ	Alt 3	0%	0%	0%	30%	30%	30%	40%	40%	40%	50%
TORQ	TCp	$0	$0	$0	$9	$9	$8	$11	$11	$11	$13

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-180 Costs of Early Torque Converter Lockup (TORQ)
Vocational Heavy HD Urban/Multipurpose Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
TORQ	DMC	$28	$28	$27	$26	$25	$24	$24	$23	$23	$22
TORQ	IC	$5	$5	$5	$5	$5	$4	$4	$4	$4	$4
TORQ	TC	$33	$32	$31	$31	$30	$28	$27	$27	$26	$26
TORQ	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
TORQ	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	30%
TORQ	TCp	$0	$0	$0	$3	$3	$3	$5	$5	$5	$8

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.3.7 Driveline Integration – Vocational Vehicles

We have estimated the cost of driveline integration on comments regarding the cost of neutral idle.[207] While the comment was not speaking to driveline integration, we believe that the rationale of the comment and the cost estimate made by the commenter are applicable to the driveline integration technology in terms of sensors and calibration required. We have divided this cost by 1.36 to arrive at a direct manufacturing cost of $74 (DMC, 2013$, in 2021). We consider this technology to be on the flat portion of the learning curve (curve 13) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-181 Costs of Driveline Integration
Vocational Light/Medium/Heavy HD Urban/Multipurpose Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Improved trans	DMC	$81	$78	$76	$74	$71	$69	$67	$66	$64	$63
Improved trans	IC	$13	$13	$13	$13	$13	$10	$10	$10	$10	$10
Improved trans	TC	$94	$91	$89	$87	$84	$79	$77	$76	$75	$73
Improved trans	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Improved trans	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	24%
Improved trans	TCp	$0	$0	$0	$9	$8	$8	$15	$15	$15	$18

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-182 Costs of Driveline Integration
Vocational Light/Medium/Heavy HD Regional Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Improved trans	DMC	$81	$78	$76	$74	$71	$69	$67	$66	$64	$63
Improved trans	IC	$13	$13	$13	$13	$13	$10	$10	$10	$10	$10
Improved trans	TC	$94	$91	$89	$87	$84	$79	$77	$76	$75	$73
Improved trans	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Improved trans	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	30%
Improved trans	TCp	$0	$0	$0	$9	$8	$8	$15	$15	$15	$22

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.3.8 8 Speed Transmission Relative to a 6 Speed, HD Pickups & Vans

We have based the cost of this technology on several values used in the light-duty 2017-2025 final rule. In that rule, we presented costs for 6 to 8 speed automatic transmission, high efficiency gearbox (HEG) and aggressive shift logic (ASL1) as separate technologies. Here we are treating these technologies as separate for costing (since some metrics differ for each) but considering them as being applied together as a complete group. As such, the cost for moving to an 8 speed transmission from the base 6 would always be the summation within any given year of the total costs shown in the tables that follow. For adding 2 gears, we have estimated the cost at $121 (DMC, 2012$, in 2012). We consider that technology to be on the flat portion of the learning curve (curve 7) and have applied medium complexity markups with near term markups through 2018. For HEG, we have estimated the cost at $263 (DMC, 2012$, in 2017). We consider this technology to be on the flat portion of the learning curve (curve 6) and have applied low complexity markups with near term markups through 2024. For shift logic, we have estimated the cost at $28 (DMC, 2012$, in 2015). We consider this technology to be on the flat portion of the learning curve (curve 8) and have applied low complexity markups with near term markups through 2018. The resultant costs for these technologies are shown below.

Table 2-183 Costs to Add 2 Transmission Gears
HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Move from 6 to 8 gears	DMC	$97	$95	$93	$91	$89	$88	$88
Move from 6 to 8 gears	IC	$34	$34	$34	$34	$34	$34	$34
Move from 6 to 8 gears	TC	$131	$129	$127	$125	$123	$123	$122

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

Table 2-184 Costs for High Efficiency Gearbox (HEG)
HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
High efficiency gearbox	DMC	$232	$225	$221	$217	$212	$208	$204
High efficiency gearbox	IC	$63	$63	$63	$63	$50	$50	$50
High efficiency gearbox	TC	$296	$288	$284	$279	$262	$258	$254

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

Table 2-185 Costs for Aggressive Shift Logic Level 1
HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Aggressive shift logic 1	DMC	$25	$24	$24	$23	$23	$22	$22
Aggressive shift logic 1	IC	$5	$5	$5	$5	$5	$5	$5
Aggressive shift logic 1	TC	$30	$30	$29	$29	$28	$28	$28

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

Table 2-186 Complete Cost of Moving from the Base 6 Speed to 8 Speed Transmission
2 Gears+HEG+ASL1
HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Move from 6speed to 8speed Transmission	TC	$457	$447	$440	$433	$414	$409	$403

Notes: TC=total cost.

2.11.4 Air Conditioning

2.11.4.1 Direct AC Controls – Vocational (all)

We have estimated the cost of this technology based on an estimate from TetraTech of $30 (retail, 2013$). Using that estimate we divided by a 1.36 RPE to arrive at a cost of $22 (DMC, 2013$, in 2014). We consider this technology to be on the flat portion of the learning curve (curve 2) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-187 Costs for Direct Air Conditioning Controls
All Vocational HD Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
A/C direct	DMC	$20	$19	$19	$18	$18	$18	$17	$17	$17	$17
A/C direct	IC	$4	$4	$4	$4	$4	$3	$3	$3	$3	$3
A/C direct	TC	$23	$23	$23	$22	$22	$21	$20	$20	$20	$20
A/C direct	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
A/C direct	Alt 3	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%
A/C direct	TCp	$0	$0	$0	$22	$22	$21	$20	$20	$20	$20

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.4.2 Indirect AC Controls – Tractors (all)

We have estimated the cost of this technology based on an estimate from TetraTech of $218 (retail, 2013$). Using that estimate we divided by a 1.36 RPE to arrive at a cost of $160 (DMC, 2013$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-188 Costs for Indirect AC Controls
Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
A/C indirect	DMC	$160	$155	$150	$146	$143	$140	$137	$135	$132	$129
A/C indirect	IC	$29	$28	$28	$28	$28	$22	$22	$22	$22	$22
A/C indirect	TC	$188	$184	$179	$174	$171	$162	$160	$157	$154	$152
A/C indirect	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
A/C indirect	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	30%
A/C indirect	TCp	$0	$0	$0	$17	$17	$16	$32	$31	$31	$45

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.5 Axles

2.11.5.1 6x2 Axle

We have estimated the cost of this technology based on an estimate from TetraTech of $250 (retail, 2013$). Using that estimate we divided by a 1.36 RPE to arrive at a cost of $184 (DMC, 2013$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-189 Costs for 6x2 Axles
Class 8 Day Cab and Sleeper Cab Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Axle 6x2	DMC	$184	$178	$173	$168	$164	$161	$158	$155	$152	$149
Axle 6x2	IC	$33	$33	$33	$33	$33	$26	$26	$26	$26	$26
Axle 6x2	TC	$217	$211	$206	$200	$197	$187	$183	$180	$177	$174
Axle 6x2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Axle 6x2	Alt 3	0%	0%	0%	15%	15%	15%	25%	25%	25%	30%
Axle 6x2	TCp	$0	$0	$0	$30	$30	$28	$46	$45	$44	$52

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.5.2 Axle Disconnect

We have estimated the cost of this technology based on an estimate from TetraTech of $140 (retail, 2013$). Using that estimate we divided by a 1.36 RPE to arrive at a cost of $103 (DMC, 2013$, in all years). We consider this technology to be on the flat portion of the learning curve with no additional learning to occur (curve 1) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-190 Costs for Axle Disconnect
Vocational Heavy HD Multipurpose Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Axle disconnect	DMC	$103	$103	$103	$103	$103	$103	$103	$103	$103	$103
Axle disconnect	IC	$18	$18	$18	$18	$18	$14	$14	$14	$14	$14
Axle disconnect	TC	$121	$121	$121	$121	$121	$117	$117	$117	$117	$117
Axle disconnect	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Axle disconnect	Alt 3	0%	0%	0%	5%	5%	5%	15%	15%	15%	25%
Axle disconnect	TCp	$0	$0	$0	$6	$6	$6	$18	$18	$18	$29

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-191 Costs for Axle Disconnect
Vocational Heavy HD Regional Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Axle disconnect	DMC	$103	$103	$103	$103	$103	$103	$103	$103	$103	$103
Axle disconnect	IC	$18	$18	$18	$18	$18	$14	$14	$14	$14	$14
Axle disconnect	TC	$121	$121	$121	$121	$121	$117	$117	$117	$117	$117
Axle disconnect	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Axle disconnect	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	30%
Axle disconnect	TCp	$0	$0	$0	$12	$12	$12	$23	$23	$23	$35

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.5.3 Axle Downspeed

We have estimated the cost of this technology based on engineering judgment at $50 (DMC, 2013$, in 2018). This DMC is expected to cover development and some testing and integration work since there is no real hardware required for this technology. We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-192 Costs for Axle Downspeeding
Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Axle downspeed	DMC	$50	$49	$47	$46	$45	$44	$43	$42	$41	$40
Axle downspeed	IC	$9	$9	$9	$9	$9	$7	$7	$7	$7	$7
Axle downspeed	TC	$59	$57	$56	$54	$54	$51	$50	$49	$48	$47
Axle downspeed	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Axle downspeed	Alt 3	0%	0%	0%	20%	20%	20%	40%	40%	40%	60%
Axle downspeed	TCp	$0	$0	$0	$11	$11	$10	$20	$20	$19	$28

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.5.4 High Efficiency Axle (Axle HE)

We have estimated the cost of this technology based on an estimate from TetraTech of $250 (retail, 2013$), an estimate applicable to tractors having 3 axles. Using that estimate we divided by a 1.36 RPE to arrive at a cost of $184 (DMC, 2013$, in 2018). We consider this estimate to be applicable also to vocational HH vehicles since these generally have 3 axles. For vocational light/medium HD vehicles, which generally have 2 axles, we have estimated the DMC at 2/3 the vocational heavy HD/tractor cost, or $123 (DMC, 2013$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-193 Costs for High Efficiency Axles
Vocational Light/Medium HD Urban/Multipurpose/Regional Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Axle low friction lubes	DMC	$123	$119	$115	$112	$110	$107	$105	$103	$101	$99
Axle low friction lubes	IC	$22	$22	$22	$22	$22	$17	$17	$17	$17	$17
Axle low friction lubes	TC	$144	$141	$137	$134	$131	$124	$122	$120	$118	$116
Axle low friction lubes	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Axle low friction lubes	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	30%
Axle low friction lubes	TCp	$0	$0	$0	$13	$13	$12	$24	$24	$24	$35

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-194 Costs for High Efficiency Axles
Vocational Heavy HD Urban/Multipurpose/Regional Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Axle low friction lubes	DMC	$184	$178	$173	$168	$164	$161	$158	$155	$152	$149
Axle low friction lubes	IC	$33	$33	$33	$33	$33	$26	$26	$26	$26	$26
Axle low friction lubes	TC	$217	$211	$206	$200	$197	$187	$183	$180	$177	$174
Axle low friction lubes	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Axle low friction lubes	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	30%
Axle low friction lubes	TCp	$0	$0	$0	$20	$20	$19	$37	$36	$35	$52

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-195 Costs for High Efficiency Axles
Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Axle low friction lubes	DMC	$184	$178	$173	$168	$164	$161	$158	$155	$152	$149
Axle low friction lubes	IC	$33	$33	$33	$33	$33	$26	$26	$26	$26	$26
Axle low friction lubes	TC	$217	$211	$206	$200	$197	$187	$183	$180	$177	$174
Axle low friction lubes	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Axle low friction lubes	Alt 3	0%	0%	0%	30%	30%	30%	65%	65%	65%	80%
Axle low friction lubes	TCp	$0	$0	$0	$60	$59	$56	$119	$117	$115	$139

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.6 Idle Reduction

2.11.6.1 Auxiliary Power Units (APU)

We have estimated the cost of the APU technology at $8000 retail (2013$). We divided that by 1.36 to arrive at a cost of $5882 (DMC, 2013$, in 2014). We consider this technology to be on the flat portion of the learning curve (curve 2) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-196 Costs for Auxiliary Power Units (APU) On Sleeper Cab Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
APU	DMC	$5,208	$5,103	$5,001	$4,901	$4,803	$4,707	$4,613	$4,521	$4,476	$4,431
APU	IC	$1,041	$1,039	$1,038	$1,037	$1,035	$817	$816	$816	$815	$815
APU	TC	$6,248	$6,143	$6,039	$5,938	$5,839	$5,524	$5,429	$5,336	$5,291	$5,246
APU	Alt 1a	9%	9%	9%	9%	9%	9%	0%	0%	0%	0%
APU	Alt 3	9%	9%	9%	30%	30%	30%	0%	0%	0%	0%
APU	TCp	$0	$0	$0	$1,247	$1,226	$1,160	$0	$0	$0	$0

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.6.2 Auxiliary Power Units, Battery Powered (APU_B)

We have estimated the cost of the battery powered APU technology at $6400 retail (2013$). We divided that by 1.36 to arrive at a cost of $5070 (DMC, 2013$, in 2014). We consider this technology to be on the flat portion of the learning curve (curve 2) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-197 Costs for Battery Powered Auxiliary Power Units (APU_B) on Sleeper Cab Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
APU_B	DMC	$4,489	$4,399	$4,311	$4,225	$4,140	$4,057	$3,976	$3,897	$3,858	$3,819
APU_B	IC	$897	$896	$895	$894	$893	$704	$703	$703	$703	$702
APU_B	TC	$5,386	$5,295	$5,206	$5,118	$5,033	$4,761	$4,680	$4,600	$4,560	$4,522
APU_B	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
APU_B	Alt 3	0%	0%	0%	10%	10%	10%	10%	10%	10%	15%
APU_B	TCp	$0	$0	$0	$512	$503	$476	$468	$460	$456	$678

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.6.3 Auxiliary Power Units with Diesel Particulate Filters (APUwDPF)

We have estimated the cost of the DPF equipped APU technology at $10,000 retail (2013$). See Preamble Section III.C for an explanation of the estimate for the cost of the APU. We divided that by 1.36 to arrive at a cost of $7922 (DMC, 2013$, in 2014). We consider this technology to be on the flat portion of the learning curve (curve 2) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-198 Costs for Auxiliary Power Units with Diesel Particulate Filters (APUwDPF) on Sleeper Cab Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
APUwDPF	DMC	$7,013	$6,873	$6,736	$6,601	$6,469	$6,340	$6,213	$6,089	$6,028	$5,967
APUwDPF	IC	$1,402	$1,400	$1,398	$1,396	$1,395	$1,100	$1,099	$1,098	$1,098	$1,098
APUwDPF	TC	$8,415	$8,273	$8,134	$7,997	$7,864	$7,439	$7,312	$7,187	$7,126	$7,065
APUwDPF	Alt 1a	0%	0%	0%	0%	0%	0%	9%	9%	9%	9%
APUwDPF	Alt 3	0%	0%	0%	0%	0%	0%	40%	40%	40%	40%
APUwDPF	TCp	$0	$0	$0	$0	$0	$0	$2,267	$2,228	$2,209	$2,190

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.6.4 Fuel Operated Heater (FOH)

We have estimated the cost of the FOH technology at $1200 retail (2013$). We divided that by 1.36 to arrive at a cost of $882 (DMC, 2013$, in 2014). We consider this technology to be on the flat portion of the learning curve (curve 2) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-199 Costs for Fuel Operated Heaters (FOH) on Sleeper Cab Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
FOH	DMC	$781	$766	$750	$735	$720	$706	$692	$678	$671	$665
FOH	IC	$156	$156	$156	$156	$155	$122	$122	$122	$122	$122
FOH	TC	$937	$921	$906	$891	$876	$829	$814	$800	$794	$787
FOH	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
FOH	Alt 3	0%	0%	0%	0%	10%	10%	10%	10%	10%	15%
FOH	TCp	$0	$0	$0	$0	$88	$83	$81	$80	$79	$118

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.6.5 Neutral Idle

We have estimated the cost of neutral idle on comments received.[208] A commenter stated that a cost of $100 would be more appropriate than the estimate used in the proposal. We have considered the $100 estimate to be in 2013$ and applicable in all years meaning that we consider this technology to be on the flat portion of the learning curve with no additional learning to occur (curve 1) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are below.

**Table 2-200 Costs for Neutral Idle Technology
Vocational Light/Medium/Heavy HD Urban/Multipurpose Vehicles
(2013$)**

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Neutral idle	DMC	$100	$100	$100	$100	$100	$100	$100	$100	$100	$100
Neutral idle	IC	$18	$18	$18	$18	$18	$14	$14	$14	$14	$14
Neutral idle	TC	$118	$118	$118	$118	$118	$114	$114	$114	$114	$114
Neutral idle	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Neutral idle	Alt 3	0%	0%	0%	50%	50%	50%	70%	70%	70%	60%
Neutral idle	TCp	$0	$0	$0	$59	$59	$57	$80	$80	$80	$68

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.6.6 Stop-start with Enhancements (Stop-start_enhanced)

We have estimated the cost of this technology based on several cost estimates. First, an estimate from TetraTech of $700 (retail, 2013$) for gasoline HD pickups and vans and $1500 (retail, 2013$) for diesel HD pickups and vans. Using these values, we divided by a 1.36 RPE to arrive at $515 (DMC, 2013$, in 2021) and $1103 (DMC, 2013$, in 2021) which were considered appropriate for vocational MH and HH vehicles, respectively. To these estimates, we have added the costs for improved accessories used for HD pickups and vans of $126 (DMC, 2013$, in 2015) which is based on values from the 2017-2025 light-duty FRM. However, to account for the heavier vocational vehicles relative to the HD pickup and vans, we have scaled upward the improved accessory value by 50 percent to arrive at a cost of $189 (DMC, 2013$, in 2015). We have then added these values to arrive at costs of $704 (DMC, 2013$, in 2021) and $1292 (DMC, 2013$, in 2021) and have applied the lower cost to vocational medium HD vehicles and the higher cost to vocational heavy HD vehicles. For vocational light HD, we have used the stop-start cost for the 2017-2025 rule for LD pickups ($377 DMC, 2012$, in 2015) but have scaled upward that value by 25 percent to account for the weight difference between the LD and vocational light HD vehicles. Doing this results in a cost of $479 (DMC, 2013$, in 2021). Adding to that the $189 value for improved accessories mentioned earlier gives the resultant vocational light HD cost of $669 (DMC, 2013$, in 2021). We consider all of these technologies to be on the flat portion of the learning curve (curve 13) and have applied a medium complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

**Table 2-201 Costs for Enhanced Stop-start with Enhancements
Vocational Light HD Urban/Multipurpose Vehicles (2013$)**

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Stop-start_enhanced	DMC	$733	$711	$689	$669	$648	$629	$610	$598	$586	$574
Stop-start_enhanced	IC	$205	$204	$203	$202	$201	$149	$149	$148	$148	$148
Stop-start_enhanced	TC	$938	$915	$892	$871	$850	$779	$759	$746	$734	$722
Stop-start_enhanced	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Stop-start_enhanced	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	30%
Stop-start_enhanced	TCp	$0	$0	$0	$87	$85	$78	$152	$149	$147	$217

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-202 Costs for Enhanced Stop-start Vocational Medium HD Urban/Multipurpose Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Stop-start_enhanced	DMC	$771	$748	$726	$704	$683	$662	$642	$630	$617	$605
Stop-start_enhanced	IC	$216	$215	$214	$213	$212	$157	$157	$156	$156	$155
Stop-start_enhanced	TC	$987	$963	$939	$917	$894	$820	$799	$786	$773	$760
Stop-start_enhanced	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Stop-start_enhanced	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	30%
Stop-start_enhanced	TCp	$0	$0	$0	$92	$89	$82	$160	$157	$155	$228

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-203 Costs for Enhanced Stop-start Vocational Heavy HD Urban/Multipurpose Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Stop-start_enhanced	DMC	$1,416	$1,373	$1,332	$1,292	$1,253	$1,216	$1,179	$1,156	$1,133	$1,110
Stop-start_enhanced	IC	$397	$395	$393	$391	$389	$289	$288	$287	$286	$285
Stop-start_enhanced	TC	$1,813	$1,768	$1,725	$1,683	$1,642	$1,505	$1,467	$1,442	$1,419	$1,395
Stop-start_enhanced	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Stop-start_enhanced	Alt 3	0%	0%	0%	0%	0%	0%	10%	10%	10%	20%
Stop-start_enhanced	TCp	$0	$0	$0	$0	$0	$0	$147	$144	$142	$279

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

For HD pickups and vans, we have based our costs for stop-start systems on the values used in the light-duty 2017-2025 final rule, but have scaled upward those costs by 25 percent to account for the larger and harder starting HD engines. Using this approach and converting to 2012$ results in a cost of $471 (DMC, 2012$, in 2015). We consider this technology to be on the steep portion of the learning curve (curve 9, note the different year of cost-applicability relative to the vocational cost discussed above) and have applied medium complexity markups with near term markups through 2018. The resultant costs for HD pickups and vans are shown below.

Table 2-204 Costs of Stop-start HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Stop-start	DMC	$404	$392	$380	$369	$358	$351	$344
Stop-start	IC	$134	$134	$134	$133	$133	$133	$132
Stop-start	TC	$539	$526	$514	$502	$491	$483	$476

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.11.6.7 Automatic Engine Shutdown System (AESS)

We have estimated the cost of an AESS at $50 retail (2013$). This system should be low cost since the engine control software already features the necessary code. The cost here is simply meant to cover the costs of setting the software correctly to take advantage of the already existing feature. We have divided the $50 by 1.36 to arrive at a cost of $40 (DMC, 2013$, in 2014). We have placed this technology on the steep portion of the learning curve today but flat by the 2019 timeframe (curve 4) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-205 Costs for Automatic Engine Shutdown System on Vocational Light/Medium/Heavy HD Urban/Multipurpose Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
AESS	DMC	$25	$25	$24	$23	$22	$22	$21	$20	$20	$20
AESS	IC	$7	$7	$7	$7	$7	$5	$5	$5	$5	$5
AESS	TC	$32	$31	$31	$30	$29	$27	$27	$26	$26	$25
AESS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
AESS	Alt 3	0%	0%	0%	30%	30%	30%	60%	60%	60%	70%
AESS	TCp	$0	$0	$0	$9	$9	$8	$16	$16	$15	$18

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-206 Costs for Automatic Engine Shutdown System on Vocational Light/Medium/Heavy HD Regional Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
AESS	DMC	$25	$25	$24	$23	$22	$22	$21	$20	$20	$20
AESS	IC	$7	$7	$7	$7	$7	$5	$5	$5	$5	$5
AESS	TC	$32	$31	$31	$30	$29	$27	$27	$26	$26	$25
AESS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
AESS	Alt 3	0%	0%	0%	40%	40%	40%	80%	80%	80%	90%
AESS	TCp	$0	$0	$0	$12	$12	$11	$21	$21	$20	$23

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-207 Costs for Automatic Engine Shutdown System on Sleeper Cab Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
AESS	DMC	$25	$25	$24	$23	$22	$22	$21	$20	$20	$20
AESS	IC	$7	$7	$7	$7	$7	$5	$5	$5	$5	$5
AESS	TC	$32	$31	$31	$30	$29	$27	$27	$26	$26	$25
AESS	Alt 1a	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
AESS	Alt 3	80%	80%	80%	40%	40%	40%	30%	30%	30%	15%
AESS	TCp	$0	$0	$0	-$12	-$12	-$11	-$13	-$13	-$13	-$16

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.6.8 Automatic Engine Shutdown System with Auto-Start (AESS_wAutoStart)

We have estimated the cost of an AESS with auto-start at $2700 retail (2013$). We have divided this value by 1.36 to arrive at a cost of $2139 (DMC, 2013$, in 2014). We have placed this technology on the steep portion of the learning curve (curve 4) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-208 Costs for Automatic Engine Shutdown System with Auto-Start on Sleeper Cab Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
AESS_wAutoStart	DMC	$1,369	$1,328	$1,288	$1,249	$1,212	$1,176	$1,140	$1,106	$1,084	$1,062
AESS_wAutoStart	IC	$372	$371	$370	$370	$369	$294	$293	$293	$293	$293
AESS_wAutoStart	TC	$1,740	$1,699	$1,659	$1,619	$1,581	$1,469	$1,434	$1,399	$1,377	$1,355
AESS_wAutoStart	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
AESS_wAutoStart	Alt 3	0%	0%	0%	10%	10%	10%	10%	10%	10%	15%
AESS_wAutoStart	TCp	$0	$0	$0	$162	$158	$147	$143	$140	$138	$203

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.7 Electrification (strong/mild HEV, full EV)

2.11.7.1 Strong Hybrid Electric Vehicle (strong HEV)

We have estimated the cost of this technology using the costs estimated in the 2017-2025 light-duty rule for a light-duty pickup strong HEV. There we estimated the cost at $2729 (DMC, 2010$, in 2021) for a LD truck with a 5200 pound curb weight. We have then scaled upward that value using the ratio of test weights for HD pickups in our MY2014 market file (8739 pounds) to the test weight of the 5200 pound LD truck (5500 pounds). The resultant strong hybrid costs become $4335 (DMC, 2012$, in 2021) for HD pickups and vans. We consider this technology to be on the steep portion of the learning curve today but on the flat portion by 2021 (curve 11) and have applied high complexity level 1 with short term markups through 2024. The resultant technology costs are shown below for HD pickups and vans.

Table 2-209 Costs of Strong Hybrid HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Strong HEV	DMC	$4,335	$4,205	$4,079	$3,957	$3,838	$3,723	$3,648
Strong HEV	IC	$2,443	$2,435	$2,427	$2,419	$1,482	$1,478	$1,476
Strong HEV	TC	$6,779	$6,640	$6,506	$6,376	$5,320	$5,201	$5,124

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.11.7.2 Mild hybrid Electric Vehicle (mild HEV)

We have estimated the cost of this technology using the costs estimated in the 2017-2025 light-duty rule for a light-duty pickup mild HEV. There we estimated the cost at $983 (DMC, 2010$, in 2021) for a LD truck with a 3500 pound curb weight. We have then scaled upward that value using the ratio of curb weights for HD pickups of 6500 pounds to the 3500 pound curb weight. The resultant mild hybrid costs become $1894 (DMC, 2012$, in 2017) for HD pickups and vans. We consider this technology to be on the flat portion of the learning curve (curve 6) and have applied high complexity level 1 with short term markups through 2024. The resultant technology costs are shown below for HD pickups and vans.

Table 2-210 Costs of Mild Hybrid HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Mild HEV	DMC	$1,677	$1,626	$1,594	$1,562	$1,531	$1,500	$1,470
Mild HEV	IC	$1,053	$1,050	$1,048	$1,046	$643	$642	$641
Mild HEV	TC	$2,730	$2,677	$2,642	$2,608	$2,173	$2,142	$2,111

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

For vocational vehicle mild hybrids, we have scaled upward from the HD pickup and van values using best estimates of curb weights. For vocational vehicles, we have used curb weights of 16,000 for light HD, 25,150 for medium HD and 42,000 for heavy HD relative to a 6500 pound value for HD pickups. Scaling based on curb weight here should provide an acceptable scaling of costs with battery and motor sizes since those are generally directly correlated with the weight of the vehicle itself. Using these scaling factors results in costs for complete mild hybrid systems for light, medium and heavy HD, respectively, of $4747, $7462 and $12461 (DMC, 2012$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied high complexity level 1 with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown are shown below.

Table 2-211 Costs for Mild Hybrid Vocational Light HD Urban/Multipurpose Vehicles (2013$)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Mild HEV	DMC	$4,747	$4,605	$4,467	$4,333	$4,246	$4,161	$4,078	$3,996	$3,916	$3,838
Mild HEV	IC	$2,018	$2,007	$1,997	$1,987	$1,981	$1,975	$1,969	$1,963	$1,247	$1,244
Mild HEV	TC	$6,765	$6,612	$6,464	$6,320	$6,227	$6,136	$6,046	$5,959	$5,164	$5,082
Mild HEV	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mild HEV	Alt 3	0%	0%	0%	0%	0%	0%	3%	3%	3%	6%
Mild HEV	TCp	$0	$0	$0	$0	$0	$0	$181	$179	$155	$305

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-212 Costs for Mild Hybrid Vocational Medium HD Urban/Multipurpose Vehicles (2013$)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Mild HEV	DMC	$7,462	$7,238	$7,021	$6,810	$6,674	$6,541	$6,410	$6,282	$6,156	$6,033
Mild HEV	IC	$3,171	$3,155	$3,139	$3,124	$3,114	$3,104	$3,094	$3,085	$1,961	$1,956
Mild HEV	TC	$10,633	$10,393	$10,160	$9,934	$9,788	$9,645	$9,504	$9,367	$8,116	$7,989
Mild HEV	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mild HEV	Alt 3	0%	0%	0%	0%	0%	0%	3%	3%	3%	6%
Mild HEV	TCp	$0	$0	$0	$0	$0	$0	$285	$281	$243	$479

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-213 Costs for Mild Hybrid Vocational Heavy HD Urban/Multipurpose Vehicles (2013$)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Mild HEV	DMC	$12,461	$12,087	$11,725	$11,373	$11,146	$10,923	$10,704	$10,490	$10,280	$10,075
Mild HEV	IC	$5,296	$5,269	$5,242	$5,217	$5,200	$5,184	$5,168	$5,152	$3,274	$3,267
Mild HEV	TC	$17,757	$17,356	$16,967	$16,590	$16,345	$16,106	$15,872	$15,642	$13,554	$13,341
Mild HEV	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mild HEV	Alt 3	0%	0%	0%	0%	0%	0%	3%	3%	3%	6%
Mild HEV	TCp	$0	$0	$0	$0	$0	$0	$476	$469	$407	$800

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.7.3 Hybrid electric Vehicle without Stop-Start (HEVnoSS)

We have estimated the cost of a hybrid electric system without any stop-start technology at $8500 retail (2013$). We have divided this value by 1.36 to arrive at a cost of $6250 (DMC, 2013$, in 2021). We have placed this technology on the steep portion of the learning curve (curve 11) and have applied high complexity level 1 ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-214 Costs for Hybrid Electric without Stop-start, Vocational Light/Medium/Heavy HD Urban/Multipurpose Vehicles (2013$)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
HEVnoSS	DMC	$9,766	$7,813	$7,813	$6,250	$6,063	$5,881	$5,704	$5,533	$5,367	$5,260
HEVnoSS	IC	$2,914	$2,771	$2,771	$2,656	$2,643	$1,669	$1,662	$1,656	$1,650	$1,646
HEVnoSS	TC	$12,679	$10,583	$10,583	$8,906	$8,705	$7,549	$7,366	$7,189	$7,017	$6,906
HEVnoSS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
HEVnoSS	Alt 3	0%	0%	0%	2%	2%	2%	5%	5%	5%	8%
HEVnoSS	TCp	$0	$0	$0	$178	$174	$151	$368	$359	$351	$552

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.8 Tires

2.11.8.1 Lower Rolling Resistance Tires ($/tire)

We have estimated the cost of lower rolling resistance tires based on an estimate from TetraTech of $30 (retail, 2013$). Using that estimate we divided by a 1.36 RPE to arrive at a cost of $22 (DMC, 2013$) but consider that cost valid in different years depending on the level of rolling resistance. For LRR tires level 1 and 2, we consider that $22 value valid in 2014, level 3 in 2018, level 4 and level 5 (new for this FRM analysis) in 2021. We consider this technology to be on the flat portion of the curve with LRR tires level 1 and 2 on curve 2, LRR tires level 3 on curve 12 and LRR tires level 4 and 5 on curve 13. We have applied a low complexity markup to LRR tires levels 1 and 2 with short term markups through 2022. For LRR tires level 3, we have applied a medium complexity markup with short term markups through 2025, for LRR tires level 4, we have applied a medium complexity markup with short term markups through 2028, and for LRR tires level 5, and we have applied a medium complexity markup with short term markups through 2031. As a result, despite using the same DMC for each level of rolling resistance, our tire costs can vary year-over-year for each of the 5 levels of rolling resistance considered. The resultant costs on a per-tire basis are shown in Table 2-215. Table 2-216 through Table 2-239 show the costs per vocational vehicle, tractor or trailer depending on the number of tires present.

Table 2-215 Costs for Lower Rolling Resistance Tires at each LRR Level (2013$/tire)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	DMC	$20	$19	$19	$18	$18	$18	$17	$17	$17	$17
LRR – level 2	DMC	$20	$19	$19	$18	$18	$18	$17	$17	$17	$17
LRR – level 3	DMC	$22	$21	$21	$20	$20	$19	$19	$19	$18	$18
LRR – level 4	DMC	$24	$23	$23	$22	$21	$21	$20	$20	$19	$19
LRR – level 5	DMC	$24	$23	$23	$22	$21	$21	$20	$20	$19	$19
LRR – level 1	IC	$4	$4	$4	$4	$4	$3	$3	$3	$3	$3
LRR – level 2	IC	$4	$4	$4	$4	$4	$3	$3	$3	$3	$3
LRR – level 3	IC	$7	$7	$7	$7	$7	$7	$7	$6	$5	$5
LRR – level 4	IC	$7	$7	$7	$7	$7	$7	$7	$7	$7	$7
LRR – level 5	IC	$7	$7	$7	$7	$7	$7	$7	$7	$7	$7
LRR – level 1	TC	$23	$23	$23	$22	$22	$21	$20	$20	$20	$20
LRR – level 2	TC	$23	$23	$23	$22	$22	$21	$20	$20	$20	$20
LRR – level 3	TC	$29	$28	$27	$27	$26	$26	$25	$25	$23	$23
LRR – level 4	TC	$31	$30	$29	$29	$28	$27	$27	$26	$26	$25
LRR – level 5	TC	$31	$30	$29	$29	$28	$27	$27	$26	$26	$25

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.11.8.2 Lower RR Steer Tires, Vocational Vehicles

Table 2-216 Costs for Lower Rolling Resistance Steer Tires
Vocational Light/Medium HD Urban Vehicles
(2013$/vehicle @ 2 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$47	$46	$45	$45	$44	$41	$41	$40	$40	$39
LRR – level 2	TC	$47	$46	$45	$45	$44	$41	$41	$40	$40	$39
LRR – level 3	TC	$57	$56	$55	$53	$53	$52	$51	$50	$46	$45
LRR – level 4	TC	$62	$60	$59	$57	$56	$55	$53	$53	$52	$51
LRR – level 5	TC	$62	$60	$59	$57	$56	$55	$53	$53	$52	$51
LRR – level 1	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	100%	100%	100%	0%	0%	0%	0%	0%	0%	0%
LRR – level 2	Alt 3	0%	0%	0%	100%	100%	100%	100%	100%	100%	0%
LRR – level 3	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	-$45	-$44	-$41	-$41	-$40	-$40	-$39
LRR – level 2	TCp	$0	$0	$0	$45	$44	$41	$41	$40	$40	$0
LRR – level 3	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$45
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

**Table 2-217 Costs for Lower Rolling Resistance Steer Tires
Vocational Light/Medium/Heavy HD Multipurpose/Regional and Heavy HD Urban Vehicles
(2013$/vehicle @ 2 tires/vehicle)**

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$47	$46	$45	$45	$44	$41	$41	$40	$40	$39
LRR – level 2	TC	$47	$46	$45	$45	$44	$41	$41	$40	$40	$39
LRR – level 3	TC	$57	$56	$55	$53	$53	$52	$51	$50	$46	$45
LRR – level 4	TC	$62	$60	$59	$57	$56	$55	$53	$53	$52	$51
LRR – level 5	TC	$62	$60	$59	$57	$56	$55	$53	$53	$52	$51
LRR – level 1	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	100%	100%	100%	0%	0%	0%	0%	0%	0%	0%
LRR – level 2	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 3	Alt 3	0%	0%	0%	100%	100%	100%	0%	0%	0%	0%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 3	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%
LRR – level 1	TCp	$0	$0	$0	-$45	-$44	-$41	-$41	-$40	-$40	-$39
LRR – level 2	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 3	TCp	$0	$0	$0	$53	$53	$52	$0	$0	$0	$0
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 5	TCp	$0	$0	$0	$0	$0	$0	$53	$53	$52	$51

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.8.3 Lower RR Drive Tires, Vocational Vehicles

Table 2-218 Costs for Lower Rolling Resistance Drive Tires, Vocational Light HD Urban Vehicles (2013$ @ 4 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 2	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 3	TC	$115	$112	$109	$107	$105	$103	$102	$100	$92	$91
LRR – level 4	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR – level 5	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR – level 1	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	100%	100%	100%	0%	0%	0%	0%	0%	0%	0%
LRR – level 2	Alt 3	0%	0%	0%	100%	100%	100%	100%	100%	100%	50%
LRR – level 3	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	50%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	-$89	-$88	-$83	-$81	-$80	-$79	-$79
LRR – level 2	TCp	$0	$0	$0	$89	$88	$83	$81	$80	$79	$39
LRR – level 3	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$45
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-219 Costs for Lower Rolling Resistance Drive Tires, Vocational Light HD Multipurpose Vehicles (2013$ @ 4 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 2	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 3	TC	$115	$112	$109	$107	$105	$103	$102	$100	$92	$91
LRR – level 4	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR – level 5	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR – level 1	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	100%	100%	100%	0%	0%	0%	0%	0%	0%	0%
LRR – level 2	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 3	Alt 3	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	-$89	-$88	-$83	-$81	-$80	-$79	-$79
LRR – level 2	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 3	TCp	$0	$0	$0	$107	$105	$103	$102	$100	$92	$91
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-220 Costs for Lower Rolling Resistance Drive Tires, Vocational Light HD Regional Vehicles (2013$ @ 4 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 2	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 3	TC	$115	$112	$109	$107	$105	$103	$102	$100	$92	$91
LRR – level 4	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR – level 5	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR – level 1	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	100%	100%	100%	0%	0%	0%	0%	0%	0%	0%
LRR – level 2	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 3	Alt 3	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	-$89	-$88	-$83	-$81	-$80	-$79	-$79
LRR – level 2	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 3	TCp	$0	$0	$0	$107	$105	$103	$102	$100	$92	$91
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-221 Costs for Lower Rolling Resistance Drive Tires, Vocational Medium HD Urban Vehicles (2013$ @ 4 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 2	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 3	TC	$115	$112	$109	$107	$105	$103	$102	$100	$92	$91
LRR – level 4	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR – level 5	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR – level 1	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	100%	100%	100%	100%	100%	100%	100%	100%	100%	50%
LRR – level 2	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	50%
LRR – level 3	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$39
LRR – level 2	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$39
LRR – level 3	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-222 Costs for Lower Rolling Resistance Drive Tires, Vocational Medium HD Multipurpose Vehicles (2013$ @ 4 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 2	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 3	TC	$115	$112	$109	$107	$105	$103	$102	$100	$92	$91
LRR – level 4	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR – level 5	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR – level 1	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	100%	100%	100%	100%	100%	100%	50%	50%	50%	0%
LRR – level 2	Alt 3	0%	0%	0%	0%	0%	0%	50%	50%	50%	0%
LRR – level 3	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	$0	$0	$0	-$41	-$40	-$40	-$79
LRR – level 2	TCp	$0	$0	$0	$0	$0	$0	$41	$40	$40	$0
LRR – level 3	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$91
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-223 Costs for Lower Rolling Resistance Drive Tires, Vocational Medium HD Regional Vehicles (2013$ @ 4 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 2	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 3	TC	$115	$112	$109	$107	$105	$103	$102	$100	$92	$91
LRR – level 4	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR – level 5	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR – level 1	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	100%	100%	100%	100%	100%	100%	0%	0%	0%	0%
LRR – level 2	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 3	Alt 3	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	$0	$0	$0	-$81	-$80	-$79	-$79
LRR – level 2	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 3	TCp	$0	$0	$0	$0	$0	$0	$102	$100	$92	$91
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-224 Costs for Lower Rolling Resistance Drive Tires, Vocational Heavy HD Urban Vehicles (2013$ @ 8 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR – level 2	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR – level 3	TC	$230	$224	$219	$214	$210	$207	$204	$200	$184	$181
LRR – level 4	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR – level 5	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR – level 1	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%
LRR – level 2	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
LRR – level 3	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$157
LRR – level 2	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$157
LRR – level 3	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-225 Costs for Lower Rolling Resistance Drive Tires, Vocational Heavy HD Multipurpose Vehicles (2013$ @ 8 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR – level 2	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR – level 3	TC	$230	$224	$219	$214	$210	$207	$204	$200	$184	$181
LRR – level 4	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR – level 5	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR – level 1	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	100%	100%	100%	0%	0%	0%	0%	0%	0%	0%
LRR – level 2	Alt 3	0%	0%	0%	100%	100%	100%	100%	100%	100%	0%
LRR – level 3	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	-$178	-$175	-$166	-$163	-$160	-$159	-$157
LRR – level 2	TCp	$0	$0	$0	$178	$175	$166	$163	$160	$159	$0
LRR – level 3	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$181
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-226 Costs for Lower Rolling Resistance Drive Tires, Vocational Heavy HD Regional Vehicles (2013$ @ 8 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR – level 2	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR – level 3	TC	$230	$224	$219	$214	$210	$207	$204	$200	$184	$181
LRR – level 4	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR – level 5	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR – level 1	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR – level 2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	100%	100%	100%	0%	0%	0%	0%	0%	0%	0%
LRR – level 2	Alt 3	0%	0%	0%	100%	100%	100%	0%	0%	0%	0%
LRR – level 3	Alt 3	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	-$178	-$175	-$166	-$163	-$160	-$159	-$157
LRR – level 2	TCp	$0	$0	$0	$178	$175	$166	$0	$0	$0	$0
LRR – level 3	TCp	$0	$0	$0	$0	$0	$0	$204	$200	$184	$181
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.8.4 Lower RR Steer Tires, Tractors

Table 2-227 Costs for Lower Rolling Resistance Steer Tires Day Cab Low Roof & Sleeper Cab Low/Medium Roof Tractors (2013$/vehicle @ 2 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$47	$46	$45	$45	$44	$41	$41	$40	$40	$39
LRR – level 2	TC	$47	$46	$45	$45	$44	$41	$41	$40	$40	$39
LRR – level 3	TC	$57	$56	$55	$53	$53	$52	$51	$50	$46	$45
LRR – level 4	TC	$62	$60	$59	$57	$56	$55	$53	$53	$52	$51
LRR – level 1	Alt 1a	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
LRR – level 2	Alt 1a	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	50%	50%	50%	35%	35%	35%	25%	25%	25%	20%
LRR – level 2	Alt 3	10%	10%	10%	50%	50%	50%	55%	55%	55%	50%
LRR – level 3	Alt 3	0%	0%	0%	10%	10%	10%	15%	15%	15%	25%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	-$7	-$7	-$6	-$10	-$10	-$10	-$12
LRR – level 2	TCp	$0	$0	$0	$18	$18	$17	$18	$18	$18	$16
LRR – level 3	TCp	$0	$0	$0	$5	$5	$5	$8	$8	$7	$11
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-228 Costs for Lower Rolling Resistance Steer Tires
Day & Sleeper Cab High Roof Tractors
(2013$/vehicle @ 2 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$47	$46	$45	$45	$44	$41	$41	$40	$40	$39
LRR – level 2	TC	$47	$46	$45	$45	$44	$41	$41	$40	$40	$39
LRR – level 3	TC	$57	$56	$55	$53	$53	$52	$51	$50	$46	$45
LRR – level 4	TC	$62	$60	$59	$57	$56	$55	$53	$53	$52	$51
LRR – level 1	Alt 1a	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
LRR – level 2	Alt 1a	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	70%	70%	70%	35%	35%	35%	15%	15%	15%	10%
LRR – level 2	Alt 3	20%	20%	20%	50%	50%	50%	60%	60%	60%	50%
LRR – level 3	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	35%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	-$16	-$15	-$15	-$22	-$22	-$22	-$24
LRR – level 2	TCp	$0	$0	$0	$13	$13	$12	$16	$16	$16	$12
LRR – level 3	TCp	$0	$0	$0	$5	$5	$5	$10	$10	$9	$16
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.8.5 Lower RR Drive Tires, Tractors

Table 2-229 Costs for Lower Rolling Resistance Drive Tires
Class 7 Day Cab Low Roof Tractors
(2013$/vehicle @ 4 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 2	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 3	TC	$115	$112	$109	$107	$105	$103	$102	$100	$92	$91
LRR – level 4	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR – level 1	Alt 1a	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
LRR – level 2	Alt 1a	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	50%	50%	50%	35%	35%	35%	25%	25%	25%	10%
LRR – level 2	Alt 3	10%	10%	10%	50%	50%	50%	65%	65%	65%	85%
LRR – level 3	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	-$13	-$13	-$12	-$20	-$20	-$20	-$31
LRR – level 2	TCp	$0	$0	$0	$36	$35	$33	$45	$44	$44	$59
LRR – level 3	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-230 Costs for Lower Rolling Resistance Drive Tires
Class 7 Day Cab High Roof Tractors
(2013$/vehicle @ 4 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 2	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR – level 3	TC	$115	$112	$109	$107	$105	$103	$102	$100	$92	$91
LRR – level 4	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR – level 1	Alt 1a	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
LRR – level 2	Alt 1a	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	70%	70%	70%	35%	35%	35%	15%	15%	15%	10%
LRR – level 2	Alt 3	20%	20%	20%	50%	50%	50%	60%	60%	60%	50%
LRR – level 3	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	35%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	-$31	-$31	-$29	-$45	-$44	-$44	-$47
LRR – level 2	TCp	$0	$0	$0	$27	$26	$25	$33	$32	$32	$24
LRR – level 3	TCp	$0	$0	$0	$11	$11	$10	$20	$20	$18	$32
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-231 Costs for Lower Rolling Resistance Drive Tires
Class 8 Day Cab Low & Sleeper Cab Low/Medium Roof Tractors
(2013$/vehicle @ 8 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR – level 2	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR – level 3	TC	$230	$224	$219	$214	$210	$207	$204	$200	$184	$181
LRR – level 4	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR – level 1	Alt 1a	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
LRR – level 2	Alt 1a	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	50%	50%	50%	35%	35%	35%	25%	25%	25%	10%
LRR – level 2	Alt 3	10%	10%	10%	50%	50%	50%	65%	65%	65%	85%
LRR – level 3	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	-$27	-$26	-$25	-$41	-$40	-$40	-$63
LRR – level 2	TCp	$0	$0	$0	$71	$70	$66	$90	$88	$87	$118
LRR – level 3	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-232 Costs for Lower Rolling Resistance Drive Tires
Class 8 Day & Sleeper Cab High Roof Tractors
(2013$/vehicle @ 8 tires/vehicle)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR – level 1	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR – level 2	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR – level 3	TC	$230	$224	$219	$214	$210	$207	$204	$200	$184	$181
LRR – level 4	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR – level 1	Alt 1a	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
LRR – level 2	Alt 1a	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
LRR – level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	Alt 3	70%	70%	70%	35%	35%	35%	15%	15%	15%	10%
LRR – level 2	Alt 3	20%	20%	20%	50%	50%	50%	60%	60%	60%	50%
LRR – level 3	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	35%
LRR – level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR – level 1	TCp	$0	$0	$0	-$62	-$61	-$58	-$90	-$88	-$87	-$94
LRR – level 2	TCp	$0	$0	$0	$53	$53	$50	$65	$64	$63	$47
LRR – level 3	TCp	$0	$0	$0	$21	$21	$21	$41	$40	$37	$63
LRR – level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.8.6 Lower RR Tires, Trailers

Table 2-233 Costs for Lower Rolling Resistance Tires
Long Van, Full Aero Highway Trailers
(2013$/trailer @ 8 tires/trailer)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR–level 1	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR–level 2	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR-level 3	TC	$230	$224	$219	$214	$210	$207	$204	$200	$184	$181
LRR-level 4	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR-level 5	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR–level 1	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 2	Alt 1a	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
LRR-level 3	Alt 1a	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
LRR-level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR-level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 1	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 2	Alt 3	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
LRR-level 3	Alt 3	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%
LRR-level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR-level 5	Alt 3	0%	0%	0%	95%	95%	95%	95%	95%	95%	95%
LRR–level 1	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR–level 2	TCp	-$9	-$9	-$9	-$9	-$9	-$8	-$8	-$8	-$8	-$8
LRR-level 3	TCp	$11	$11	$11	-$192	-$189	-$186	-$183	-$180	-$166	-$163
LRR-level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR-level 5	TCp	$0	$0	$0	$218	$213	$208	$203	$200	$197	$193

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

**Table 2-234 Costs for Lower Rolling Resistance Tires
Long Van, Partial Aero Highway Trailers
(2013$/trailer @ 8 tires/trailer)**

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR–level 1	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR–level 2	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR-level 3	TC	$230	$224	$219	$214	$210	$207	$204	$200	$184	$181
LRR-level 4	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR-level 5	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR–level 1	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 2	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR-level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR-level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR-level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 1	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 2	Alt 3	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
LRR-level 3	Alt 3	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%
LRR-level 4	Alt 3	0%	0%	0%	95%	95%	95%	95%	95%	95%	95%
LRR-level 5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 1	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR–level 2	TCp	-$178	-$175	-$172	-$169	-$166	-$157	-$155	-$152	-$151	-$150
LRR-level 3	TCp	$218	$213	$208	$0	$0	$0	$0	$0	$0	$0
LRR-level 4	TCp	$0	$0	$0	$218	$213	$208	$203	$200	$197	$193
LRR-level 5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

**Table 2-235 Costs for Lower Rolling Resistance Tires
Short Van, Full Aero Highway Trailers
(2013$/trailer @ 4 tires/trailer)**

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR–level 1	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR–level 2	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR-level 3	TC	$115	$112	$109	$107	$105	$103	$102	$100	$92	$91
LRR-level 4	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR-level 5	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR–level 1	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 2	Alt 1a	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
LRR-level 3	Alt 1a	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
LRR-level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR-level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 1	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 2	Alt 3	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
LRR-level 3	Alt 3	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%
LRR-level 4	Alt 3	0%	0%	0%	95%	95%	95%	0%	0%	0%	0%
LRR-level 5	Alt 3	0%	0%	0%	0%	0%	0%	95%	95%	95%	95%
LRR–level 1	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR–level 2	TCp	-$5	-$5	-$5	-$4	-$4	-$4	-$4	-$4	-$4	-$4
LRR-level 3	TCp	$6	$6	$5	-$96	-$95	-$93	-$92	-$90	-$83	-$82
LRR-level 4	TCp	$0	$0	$0	$109	$107	$104	$0	$0	$0	$0
LRR-level 5	TCp	$0	$0	$0	$0	$0	$0	$101	$100	$98	$97

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-236 Costs for Lower Rolling Resistance Tires
Short Van, Partial Aero Highway Trailers
(2013$/trailer @ 4 tires/trailer)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR–level 1	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR–level 2	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR-level 3	TC	$115	$112	$109	$107	$105	$103	$102	$100	$92	$91
LRR-level 4	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR-level 5	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR–level 1	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 2	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR-level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR-level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR-level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 1	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 2	Alt 3	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
LRR-level 3	Alt 3	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%
LRR-level 4	Alt 3	0%	0%	0%	95%	95%	95%	95%	95%	95%	95%
LRR-level 5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 1	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR–level 2	TCp	-$89	-$88	-$86	-$85	-$83	-$79	-$77	-$76	-$75	-$75
LRR-level 3	TCp	$109	$107	$104	$0	$0	$0	$0	$0	$0	$0
LRR-level 4	TCp	$0	$0	$0	$109	$107	$104	$101	$100	$98	$97
LRR-level 5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-237 Costs for Lower Rolling Resistance Tires
Long Van, No Aero Highway Trailers
(2013$/trailer @ 8 tires/trailer)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR–level 1	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR–level 2	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR-level 3	TC	$230	$224	$219	$214	$210	$207	$204	$200	$184	$181
LRR-level 4	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR-level 5	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR–level 1	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 2	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR-level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR-level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR-level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 1	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 2	Alt 3	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
LRR-level 3	Alt 3	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%
LRR-level 4	Alt 3	0%	0%	0%	95%	95%	95%	95%	95%	95%	95%
LRR-level 5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 1	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR–level 2	TCp	-$178	-$175	-$172	-$169	-$166	-$157	-$155	-$152	-$151	-$150
LRR-level 3	TCp	$218	$213	$208	$0	$0	$0	$0	$0	$0	$0
LRR-level 4	TCp	$0	$0	$0	$218	$213	$208	$203	$200	$197	$193
LRR-level 5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-238 Costs for Lower Rolling Resistance Tires
Short Van, No Aero Highway Trailers
(2013$/trailer @ 4 tires/trailer)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR–level 1	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR–level 2	TC	$94	$92	$91	$89	$88	$83	$81	$80	$79	$79
LRR-level 3	TC	$115	$112	$109	$107	$105	$103	$102	$100	$92	$91
LRR-level 4	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR-level 5	TC	$124	$121	$118	$115	$112	$109	$107	$105	$103	$102
LRR–level 1	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 2	Alt 1a	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LRR-level 3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR-level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR-level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 1	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 2	Alt 3	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
LRR-level 3	Alt 3	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%
LRR-level 4	Alt 3	0%	0%	0%	95%	95%	95%	95%	95%	95%	95%
LRR-level 5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 1	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR–level 2	TCp	-$89	-$88	-$86	-$85	-$83	-$79	-$77	-$76	-$75	-$75
LRR-level 3	TCp	$109	$107	$104	$0	$0	$0	$0	$0	$0	$0
LRR-level 4	TCp	$0	$0	$0	$109	$107	$104	$101	$100	$98	$97
LRR-level 5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-239 Costs for Lower Rolling Resistance Tires
Non-Box Highway Trailers
(2013$/trailer @ 8 tires/trailer)

ITEM		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LRR–level 1	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR–level 2	TC	$187	$184	$181	$178	$175	$166	$163	$160	$159	$157
LRR-level 3	TC	$230	$224	$219	$214	$210	$207	$204	$200	$184	$181
LRR-level 4	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR-level 5	TC	$248	$241	$236	$230	$224	$219	$214	$210	$207	$204
LRR–level 1	Alt 1a	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%
LRR–level 2	Alt 1a	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
LRR-level 3	Alt 1a	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
LRR-level 4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR-level 5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 1	Alt 3	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
LRR–level 2	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR-level 3	Alt 3	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%
LRR-level 4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR-level 5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LRR–level 1	TCp	-$66	-$65	-$63	-$62	-$61	-$58	-$57	-$56	-$56	-$55
LRR–level 2	TCp	-$56	-$55	-$54	-$53	-$53	-$50	-$49	-$48	-$48	-$47
LRR-level 3	TCp	$149	$146	$142	$139	$137	$135	$132	$130	$120	$118
LRR-level 4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LRR-level 5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.8.7 Lower RR Tires, HD Pickup & Van ($/tire)

We have estimated the costs of lower rolling resistance tires for HD pickups and vans using the costs used in the 2017-2025 light-duty FRM. In that rule, we estimated the costs of lower rolling resistance tires level 1 at $5/vehicle including a spare (DMC, 2010$, in all years) and level 2 at $40/vehicle assuming no spare (DMC, 2010$, in 2021). For HD pickups and vans, we have scaled upward both of those costs by 50 percent to account for the heavier and larger HD tires. We consider the level 1 tires to be learned out (curve 1) and the level 2 tires to be on the steep portion of the curve until 2021 after which it is on the flatter portion of the curve (curve 11). We have applied a low complexity markup to both with short term markups through 2018 for level 1 and through 2024 for level 2. With the exception of the 50 percent scaling factor, all LRR tire costs for HD pickups and vans are identical to the 2017-2025 light-duty FRM. The resultant costs are presented below.

Table 2-240 Costs for Lower Rolling Resistance Tires HD Pickups & Vans (2012$ @ 4 tires/vehicle)

ITEM		2021	2022	2023	2024	2025	2026	2027
LRR – level 1	DMC	$8	$8	$8	$8	$8	$8	$8
LRR – level 2	DMC	$63	$61	$59	$58	$56	$54	$53
LRR – level 1	IC	$2	$2	$2	$2	$2	$2	$2
LRR – level 2	IC	$15	$15	$15	$15	$12	$12	$12
LRR – level 1	TC	$10	$10	$10	$10	$10	$10	$10
LRR – level 2	TC	$78	$76	$74	$73	$68	$66	$65

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.11.8.8 Automatic Tire Inflation Systems (ATIS)

For tractors, we have estimated the cost of ATIS technology based on an estimate from TetraTech of $1143 (retail, 2013$). Using that estimate we divided by a 1.36 RPE to arrive at a cost of $840 (DMC, 2013$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below for tractors.

Table 2-241 Costs for Automatic Tire Inflation Systems Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
ATIS	DMC	$840	$815	$790	$767	$751	$736	$722	$707	$693	$679
ATIS	IC	$150	$150	$149	$149	$149	$117	$117	$117	$117	$117
ATIS	TC	$990	$964	$940	$916	$900	$853	$839	$824	$810	$796
ATIS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
ATIS	Alt 3	0%	0%	0%	20%	20%	20%	25%	25%	25%	30%
ATIS	TCp	$0	$0	$0	$183	$180	$171	$210	$206	$202	$239

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

For trailers, we have estimated the cost of this technology based on an estimate from TetraTech of $800 (retail, 2013$). We consider this estimate to be valid for all trailers except short vans. For short vans, we have used an estimate of $600 (retail, 2013$) since they have just one axle. Using these estimates we divided by a 1.36 RPE to arrive at a cost of $588 (DMC, 2013$, in 2018) for all but short vans and $441 (DMC, 2013$, in 2018) for short vans. We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below for trailers.

Table 2-242 Costs for Automatic Tire Inflation Systems
Long Van, Full Aero Trailers (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
ATIS	DMC	$588	$571	$553	$537	$526	$516	$505	$495	$485	$476
ATIS	IC	$105	$105	$105	$104	$104	$82	$82	$82	$82	$82
ATIS	TC	$693	$675	$658	$641	$630	$598	$587	$577	$567	$557
ATIS	Alt 1a	45%	45%	45%	45%	45%	45%	45%	45%	45%	45%
ATIS	Alt 3	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%
ATIS	TCp	$347	$338	$329	$321	$315	$299	$294	$289	$284	$279

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-243 Costs for Automatic Tire Inflation Systems
Long Van, Partial Aero Trailers (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
ATIS	DMC	$588	$571	$553	$537	$526	$516	$505	$495	$485	$476
ATIS	IC	$105	$105	$105	$104	$104	$82	$82	$82	$82	$82
ATIS	TC	$693	$675	$658	$641	$630	$598	$587	$577	$567	$557
ATIS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
ATIS	Alt 3	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%
ATIS	TCp	$659	$642	$625	$609	$599	$568	$558	$548	$539	$529

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-244 Costs for Automatic Tire Inflation Systems
Short Van, Full Aero Trailers (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
ATIS	DMC	$441	$428	$415	$403	$395	$387	$379	$371	$364	$357
ATIS	IC	$79	$79	$78	$78	$78	$61	$61	$61	$61	$61
ATIS	TC	$520	$506	$493	$481	$473	$448	$440	$433	$425	$418
ATIS	Alt 1a	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
ATIS	Alt 3	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%
ATIS	TCp	$338	$329	$321	$313	$307	$291	$286	$281	$276	$272

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-245 Costs for Automatic Tire Inflation Systems
Short Van, Partial Aero Trailers (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
ATIS	DMC	$441	$428	$415	$403	$395	$387	$379	$371	$364	$357
ATIS	IC	$79	$79	$78	$78	$78	$61	$61	$61	$61	$61
ATIS	TC	$520	$506	$493	$481	$473	$448	$440	$433	$425	$418
ATIS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
ATIS	Alt 3	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%
ATIS	TCp	$494	$481	$469	$457	$449	$426	$418	$411	$404	$397

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.8.9 Tire Pressure Monitoring System (TPMS)

We have estimated the cost of TPMS technology based on price data from Ryder.[209] These price data showed a price of $94/pair of tire pressure monitoring sensors along with a price of $65 for a repeater. Using these values as DMCs in 2013$ and applicable in 2018, we have costed 10 sensors per class 8 tractor, 6 per class 7 tractor, 10 sensors per heavy HD vocational vehicle, 6 per light and medium HD vocational vehicle, 8 per long van and non-box trailer, and 4 per short van trailer. We have also included a $65 repeater for all tractors. We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown in the tables below.

Table 2-246 Costs for Tire Pressure Monitoring Systems (TPMS)
Vocational Light/Medium HD Urban Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
TPMS	DMC	$282	$274	$265	$257	$252	$247	$242	$237	$233	$228
TPMS	IC	$50	$50	$50	$50	$50	$39	$39	$39	$39	$39
TPMS	TC	$332	$324	$315	$307	$302	$286	$281	$277	$272	$267
TPMS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
TPMS	Alt 3	0%	0%	0%	40%	40%	40%	55%	55%	55%	70%
TPMS	TCp	$0	$0	$0	$123	$121	$115	$155	$152	$150	$187

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-247 Costs for Tire Pressure Monitoring Systems (TPMS)
Vocational Light/Medium HD Multipurpose Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
TPMS	DMC	$282	$274	$265	$257	$252	$247	$242	$237	$233	$228
TPMS	IC	$50	$50	$50	$50	$50	$39	$39	$39	$39	$39
TPMS	TC	$332	$324	$315	$307	$302	$286	$281	$277	$272	$267
TPMS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
TPMS	Alt 3	0%	0%	0%	50%	50%	50%	65%	65%	65%	80%
TPMS	TCp	$0	$0	$0	$154	$151	$143	$183	$180	$177	$214

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-248 Costs for Tire Pressure Monitoring Systems (TPMS)
Vocational Light/Medium HD Regional Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
TPMS	DMC	$282	$274	$265	$257	$252	$247	$242	$237	$233	$228
TPMS	IC	$50	$50	$50	$50	$50	$39	$39	$39	$39	$39
TPMS	TC	$332	$324	$315	$307	$302	$286	$281	$277	$272	$267
TPMS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
TPMS	Alt 3	0%	0%	0%	60%	60%	60%	75%	75%	75%	90%
TPMS	TCp	$0	$0	$0	$184	$181	$172	$211	$207	$204	$240

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-249 Costs for Tire Pressure Monitoring Systems (TPMS)
Vocational Heavy HD Urban Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
TPMS	DMC	$535	$519	$503	$488	$479	$469	$460	$450	$441	$433
TPMS	IC	$95	$95	$95	$95	$95	$75	$74	$74	$74	$74
TPMS	TC	$630	$614	$598	$583	$573	$543	$534	$525	$516	$507
TPMS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
TPMS	Alt 3	0%	0%	0%	40%	40%	40%	55%	55%	55%	70%
TPMS	TCp	$0	$0	$0	$233	$229	$217	$294	$289	$284	$355

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-250 Costs for Tire Pressure Monitoring Systems (TPMS)
Vocational Heavy HD Multipurpose Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
TPMS	DMC	$535	$519	$503	$488	$479	$469	$460	$450	$441	$433
TPMS	IC	$95	$95	$95	$95	$95	$75	$74	$74	$74	$74
TPMS	TC	$630	$614	$598	$583	$573	$543	$534	$525	$516	$507
TPMS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
TPMS	Alt 3	0%	0%	0%	50%	50%	50%	65%	65%	65%	80%
TPMS	TCp	$0	$0	$0	$292	$287	$272	$347	$341	$335	$405

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-251 Costs for Tire Pressure Monitoring Systems (TPMS)
Vocational Heavy HD Regional Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
TPMS	DMC	$535	$519	$503	$488	$479	$469	$460	$450	$441	$433
TPMS	IC	$95	$95	$95	$95	$95	$75	$74	$74	$74	$74
TPMS	TC	$630	$614	$598	$583	$573	$543	$534	$525	$516	$507
TPMS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
TPMS	Alt 3	0%	0%	0%	60%	60%	60%	75%	75%	75%	90%
TPMS	TCp	$0	$0	$0	$350	$344	$326	$401	$394	$387	$456

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-252 Costs for Tire Pressure Monitoring Systems (TPMS)
Class 7 Day Cab Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
TPMS	DMC	$347	$337	$326	$317	$310	$304	$298	$292	$286	$281
TPMS	IC	$62	$62	$62	$62	$61	$48	$48	$48	$48	$48
TPMS	TC	$409	$398	$388	$378	$372	$352	$346	$340	$334	$329
TPMS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
TPMS	Alt 3	0%	0%	0%	20%	20%	20%	50%	50%	50%	70%
TPMS	TCp	$0	$0	$0	$76	$74	$70	$173	$170	$167	$230

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-253 Costs for Tire Pressure Monitoring Systems (TPMS)
Class 8 Day & Sleeper Cab Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
TPMS	DMC	$535	$519	$503	$488	$479	$469	$460	$450	$441	$433
TPMS	IC	$95	$95	$95	$95	$95	$75	$74	$74	$74	$74
TPMS	TC	$630	$614	$598	$583	$573	$543	$534	$525	$516	$507
TPMS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
TPMS	Alt 3	0%	0%	0%	20%	20%	20%	50%	50%	50%	70%
TPMS	TCp	$0	$0	$0	$117	$115	$109	$267	$262	$258	$355

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-254 Costs for Tire Pressure Monitoring Systems (TPMS)
Long Van, No Aero and Non-Box Trailers (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
TPMS	DMC	$376	$365	$354	$343	$336	$330	$323	$317	$310	$304
TPMS	IC	$67	$67	$67	$67	$67	$52	$52	$52	$52	$52
TPMS	TC	$443	$432	$421	$410	$403	$382	$375	$369	$362	$356
TPMS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
TPMS	Alt 3	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%
TPMS	TCp	$421	$410	$400	$389	$383	$363	$357	$350	$344	$338

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-255 Costs for Tire Pressure Monitoring Systems (TPMS)
Short Van, No Aero Trailers (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
TPMS	DMC	$188	$182	$177	$172	$168	$165	$161	$158	$155	$152
TPMS	IC	$34	$33	$33	$33	$33	$26	$26	$26	$26	$26
TPMS	TC	$222	$216	$210	$205	$201	$191	$188	$184	$181	$178
TPMS	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
TPMS	Alt 3	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%
TPMS	TCp	$210	$205	$200	$195	$191	$181	$178	$175	$172	$169

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.9 Aerodynamic Improvements (Aero)

The agencies' estimates for cost of tractor aero features are based the work done by ICF in support of the Phase 1 HD rules. For trailers, we have based our estimates on the work presented in the ICCT trailer technology report.[210]

2.11.9.1 Aero Improvements, Day Cab Low Roof Tractors

For low roof day cab tractors, Aero Bin 2 costs are estimated at $1020, Bin 3 at $2059 and Bin 4 at $2625 (all are DMC, in 2013$, and applicable in 2014). We consider Bin 2 technologies to be beyond the effects of learning (curve 1), Bin 3 technologies to be on the flat portion of the curve (curve 2) and Bin 4 technologies to be on the steep portion of the curve (curve 4). We have applied a low complexity ICMs to each with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

**Table 2-256 Costs of Aero Technologies
Day Cab Low Roof Tractors (2013$)**

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aero Bin2	DMC	$1,020	$1,020	$1,020	$1,020	$1,020	$1,020	$1,020	$1,020	$1,020	$1,020
Aero Bin3	DMC	$1,823	$1,787	$1,751	$1,716	$1,681	$1,648	$1,615	$1,583	$1,567	$1,551
Aero Bin4	DMC	$1,680	$1,630	$1,581	$1,534	$1,488	$1,443	$1,400	$1,358	$1,331	$1,304
Aero Bin2	IC	$182	$182	$182	$182	$182	$143	$143	$143	$143	$143
Aero Bin3	IC	$364	$364	$363	$363	$362	$286	$286	$285	$285	$285
Aero Bin4	IC	$456	$455	$455	$454	$454	$360	$360	$360	$360	$360
Aero Bin2	TC	$1,201	$1,201	$1,201	$1,201	$1,201	$1,162	$1,162	$1,162	$1,162	$1,162
Aero Bin3	TC	$2,187	$2,150	$2,114	$2,079	$2,044	$1,934	$1,901	$1,868	$1,852	$1,836
Aero Bin4	TC	$2,136	$2,085	$2,036	$1,988	$1,941	$1,803	$1,760	$1,718	$1,690	$1,663
Aero Bin2	Alt 1a	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Aero Bin3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin2	Alt 3	90%	90%	90%	95%	95%	95%	80%	80%	80%	50%
Aero Bin3	Alt 3	0%	0%	0%	5%	5%	5%	20%	20%	20%	50%
Aero Bin4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin2	TCp	$0	$0	$0	$60	$60	$58	-$116	-$116	-$116	-$465
Aero Bin3	TCp	$0	$0	$0	$104	$102	$97	$380	$374	$370	$918
Aero Bin4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.9.2 Aero Improvements, Day Cab High Roof Tractors

For high roof day cab tractors, Aero Bin 3 costs are estimated at $1046, Bin 4 at $2086, Bin 5 at $2660, Bin 6 at $3234 and Bin 7 at $3807 (all are DMC, in 2013$, and applicable in 2014; note that the table below makes clear that we do not project use of aero improvements above Bin 5). We consider Bin 3 technologies to be on the flat portion of the curve (curve 2) and Bin 4 through 7 technologies to be on the steep portion of the curve (curve 4). We have applied a low complexity ICMs to Bins 3 and 4 with short term markups through 2022. We have applied medium complexity ICMs to Bins 5 through 7 with short term markups through 2025. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-257 Costs of Aero Technologies
Day Cab High Roof Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aero Bin3	DMC	$926	$908	$890	$872	$854	$837	$821	$804	$796	$788
Aero Bin4	DMC	$1,335	$1,295	$1,256	$1,219	$1,182	$1,147	$1,112	$1,079	$1,057	$1,036
Aero Bin5	DMC	$1,702	$1,651	$1,602	$1,554	$1,507	$1,462	$1,418	$1,375	$1,348	$1,321
Aero Bin6	DMC	$2,069	$2,007	$1,947	$1,889	$1,832	$1,777	$1,724	$1,672	$1,639	$1,606
Aero Bin7	DMC	$2,437	$2,364	$2,293	$2,224	$2,157	$2,092	$2,030	$1,969	$1,929	$1,891
Aero Bin3	IC	$185	$185	$185	$184	$184	$145	$145	$145	$145	$145
Aero Bin4	IC	$362	$362	$361	$361	$360	$286	$286	$286	$286	$286
Aero Bin5	IC	$756	$753	$750	$748	$746	$743	$741	$739	$554	$553
Aero Bin6	IC	$919	$915	$912	$909	$907	$904	$901	$898	$673	$672
Aero Bin7	IC	$1,082	$1,078	$1,074	$1,071	$1,067	$1,064	$1,061	$1,058	$793	$792
Aero Bin3	TC	$1,112	$1,093	$1,074	$1,056	$1,039	$983	$966	$949	$941	$933
Aero Bin4	TC	$1,697	$1,657	$1,618	$1,579	$1,542	$1,433	$1,398	$1,365	$1,343	$1,322
Aero Bin5	TC	$2,458	$2,404	$2,352	$2,302	$2,253	$2,205	$2,159	$2,114	$1,902	$1,874
Aero Bin6	TC	$2,988	$2,923	$2,860	$2,798	$2,739	$2,681	$2,625	$2,571	$2,312	$2,278
Aero Bin7	TC	$3,518	$3,441	$3,367	$3,295	$3,224	$3,156	$3,091	$3,027	$2,722	$2,682
Aero Bin3	Alt 1a	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
Aero Bin4	Alt 1a	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Aero Bin5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin6	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin7	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin3	Alt 3	80%	80%	80%	60%	60%	60%	40%	40%	40%	30%
Aero Bin4	Alt 3	10%	10%	10%	35%	35%	35%	40%	40%	40%	30%
Aero Bin5	Alt 3	0%	0%	0%	5%	5%	5%	20%	20%	20%	40%
Aero Bin6	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin7	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin3	TCp	$0	$0	$0	-$211	-$208	-$197	-$386	-$380	-$376	-$467
Aero Bin4	TCp	$0	$0	$0	$395	$386	$358	$419	$409	$403	$264
Aero Bin5	TCp	$0	$0	$0	$115	$113	$110	$432	$423	$380	$750
Aero Bin6	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin7	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.9.3 Aero Improvements, Sleeper Cab Low/Mid Roof Tractors

For low and mid roof sleeper cab tractors, Aero Bin 2 costs are estimated at $1244, Bin 3 at $2356 and Bin 4 at $3003 (all are DMC, in 2013$, and applicable in 2014). We consider Bin 2 technologies to be beyond the effects of learning (curve 1), Bin 3 technologies to be on the flat portion of the curve (curve 2) and Bin 4 technologies to be on the steep portion of the curve (curve 4). We have applied a low complexity ICMs to each with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-258 Costs of Aero Technologies
Sleeper Cab Low/Mid Roof Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aero Bin2	DMC	$1,244	$1,244	$1,244	$1,244	$1,244	$1,244	$1,244	$1,244	$1,244	$1,244
Aero Bin3	DMC	$2,085	$2,044	$2,003	$1,963	$1,923	$1,885	$1,847	$1,810	$1,792	$1,774
Aero Bin4	DMC	$1,922	$1,864	$1,808	$1,754	$1,702	$1,651	$1,601	$1,553	$1,522	$1,492
Aero Bin2	IC	$222	$222	$222	$222	$222	$174	$174	$174	$174	$174
Aero Bin3	IC	$417	$416	$416	$415	$415	$327	$327	$327	$326	$326
Aero Bin4	IC	$522	$521	$520	$519	$519	$412	$412	$412	$412	$411
Aero Bin2	TC	$1,466	$1,466	$1,466	$1,466	$1,466	$1,419	$1,419	$1,419	$1,419	$1,419
Aero Bin3	TC	$2,502	$2,460	$2,418	$2,378	$2,338	$2,212	$2,174	$2,137	$2,119	$2,101
Aero Bin4	TC	$2,444	$2,385	$2,329	$2,274	$2,220	$2,063	$2,013	$1,965	$1,933	$1,903
Aero Bin2	Alt 1a	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Aero Bin3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin2	Alt 3	90%	90%	90%	90%	90%	90%	90%	90%	90%	60%
Aero Bin3	Alt 3	0%	0%	0%	5%	5%	5%	10%	10%	10%	40%
Aero Bin4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin2	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	-$426
Aero Bin3	TCp	$0	$0	$0	$119	$117	$111	$217	$214	$212	$840
Aero Bin4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.9.4 Aero Improvements, Sleeper Cab High Roof Tractors

For high roof sleeper cab tractors, Aero Bin 3 costs are estimated at $1413, Bin 4 at $2423, Bin 5 at $3089, Bin 6 at $3755 and Bin 7 at $4422 (all are DMC, in 2013$, and applicable in 2014; note that the table below makes clear that we do not project use of aero improvements above Bin 5). We consider Bin 3 technologies to be on the flat portion of the curve (curve 2) and Bin 4 through 7 technologies to be on the steep portion of the curve (curve 4). We have applied a low complexity ICMs to Bins 3 and 4 with short term markups through 2022. We have applied medium complexity ICMs to Bins 5 through 7 with short term markups through 2025. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-259 Costs of Aero Technologies
Sleeper Cab High Roof Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aero Bin3	DMC	$1,251	$1,226	$1,201	$1,177	$1,154	$1,131	$1,108	$1,086	$1,075	$1,064
Aero Bin4	DMC	$1,551	$1,504	$1,459	$1,415	$1,373	$1,332	$1,292	$1,253	$1,228	$1,203
Aero Bin5	DMC	$1,977	$1,918	$1,860	$1,804	$1,750	$1,698	$1,647	$1,597	$1,565	$1,534
Aero Bin6	DMC	$2,403	$2,331	$2,261	$2,194	$2,128	$2,064	$2,002	$1,942	$1,903	$1,865
Aero Bin7	DMC	$2,830	$2,745	$2,663	$2,583	$2,505	$2,430	$2,357	$2,286	$2,241	$2,196
Aero Bin3	IC	$250	$250	$249	$249	$249	$196	$196	$196	$196	$196
Aero Bin4	IC	$421	$420	$420	$419	$418	$333	$332	$332	$332	$332
Aero Bin5	IC	$878	$875	$872	$869	$866	$863	$861	$858	$643	$642
Aero Bin6	IC	$1,067	$1,063	$1,060	$1,056	$1,053	$1,050	$1,046	$1,043	$782	$781
Aero Bin7	IC	$1,256	$1,252	$1,248	$1,244	$1,240	$1,236	$1,232	$1,229	$921	$919
Aero Bin3	TC	$1,501	$1,475	$1,450	$1,426	$1,402	$1,327	$1,304	$1,282	$1,271	$1,260
Aero Bin4	TC	$1,971	$1,924	$1,879	$1,834	$1,791	$1,664	$1,624	$1,585	$1,560	$1,535
Aero Bin5	TC	$2,855	$2,792	$2,732	$2,673	$2,616	$2,561	$2,508	$2,456	$2,209	$2,176
Aero Bin6	TC	$3,470	$3,395	$3,321	$3,250	$3,181	$3,114	$3,048	$2,985	$2,685	$2,646
Aero Bin7	TC	$4,086	$3,997	$3,910	$3,826	$3,745	$3,666	$3,589	$3,515	$3,162	$3,115
Aero Bin3	Alt 1a	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
Aero Bin4	Alt 1a	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Aero Bin5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin6	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin7	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin3	Alt 3	80%	80%	80%	60%	60%	60%	40%	40%	40%	20%
Aero Bin4	Alt 3	10%	10%	10%	30%	30%	30%	40%	40%	40%	30%
Aero Bin5	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	50%
Aero Bin6	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin7	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin3	TCp	$0	$0	$0	-$285	-$280	-$265	-$522	-$513	-$508	-$756
Aero Bin4	TCp	$0	$0	$0	$367	$358	$333	$487	$476	$468	$307
Aero Bin5	TCp	$0	$0	$0	$267	$262	$256	$502	$491	$442	$1,088
Aero Bin6	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin7	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.9.5 Aero Improvements, Trailers

For long van trailers, Aero Bin 3 costs are based on and ICCT estimate of $700 (retail, 2013$), Bin 4 costs are based on an ICCT estimate of $1000 (retail, 2013$), Bin 5 costs are based on an ICCT estimate of $1600 (retail, 2013$), Bin 6 costs are based on an ICCT estimate of $1900 (retail, 2013$), Bin 7 costs are based on an ICCT estimate of $2200 (retail, 2013$), and Bin 8 costs are based on an ICCT estimate of $2900 (retail, 2013$). We have used these costs and divided by a 1.36 RPE to arrive at direct manufacturing costs of $515, $735, $1176, $1397, $1617 and $2132 for Bins 3 through 8, respectively (all are DMC, in 2013$, applicable in 2014). We consider each of these technologies to be on the flat portion of the learning curve (curve 2) and have applied low complexity ICMs with short term markups through 2018. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-260 Costs of Aero Technologies
Long Van, Full Aero Trailers (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aero Bin3	DMC	$456	$447	$438	$429	$420	$412	$404	$396	$392	$388
Aero Bin4	DMC	$651	$638	$625	$613	$600	$588	$577	$565	$559	$554
Aero Bin5	DMC	$1,042	$1,021	$1,000	$980	$961	$941	$923	$904	$895	$886
Aero Bin6	DMC	$1,237	$1,212	$1,188	$1,164	$1,141	$1,118	$1,096	$1,074	$1,063	$1,052
Aero Bin7	DMC	$1,432	$1,403	$1,375	$1,348	$1,321	$1,294	$1,269	$1,243	$1,231	$1,218
Aero Bin8	DMC	$1,888	$1,850	$1,813	$1,777	$1,741	$1,706	$1,672	$1,639	$1,622	$1,606
Aero Bin3	IC	$91	$72	$72	$72	$72	$71	$71	$71	$71	$71
Aero Bin4	IC	$130	$102	$102	$102	$102	$102	$102	$102	$102	$102
Aero Bin5	IC	$208	$164	$164	$164	$163	$163	$163	$163	$163	$163
Aero Bin6	IC	$247	$195	$194	$194	$194	$194	$194	$194	$194	$194
Aero Bin7	IC	$286	$225	$225	$225	$225	$225	$224	$224	$224	$224
Aero Bin8	IC	$377	$297	$297	$296	$296	$296	$296	$296	$296	$295
Aero Bin3	TC	$547	$518	$509	$500	$492	$483	$475	$467	$463	$459
Aero Bin4	TC	$781	$740	$727	$715	$703	$690	$679	$667	$661	$656
Aero Bin5	TC	$1,250	$1,185	$1,164	$1,144	$1,124	$1,105	$1,086	$1,067	$1,058	$1,049
Aero Bin6	TC	$1,484	$1,407	$1,382	$1,358	$1,335	$1,312	$1,289	$1,267	$1,257	$1,246
Aero Bin7	TC	$1,718	$1,629	$1,600	$1,573	$1,546	$1,519	$1,493	$1,467	$1,455	$1,443
Aero Bin8	TC	$2,265	$2,147	$2,110	$2,073	$2,037	$2,002	$1,968	$1,934	$1,918	$1,902
Aero Bin3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin4	Alt 1a	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%
Aero Bin5	Alt 1a	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Aero Bin6	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin7	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin8	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin3	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin4	Alt 3	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%
Aero Bin5	Alt 3	0%	0%	0%	95%	95%	95%	0%	0%	0%	0%
Aero Bin6	Alt 3	0%	0%	0%	0%	0%	0%	95%	95%	95%	30%
Aero Bin7	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	70%
Aero Bin8	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin3	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin4	TCp	$430	$407	$400	-$286	-$281	-$276	-$271	-$267	-$265	-$262
Aero Bin5	TCp	-$62	-$59	-$58	$1,029	$1,012	$994	-$54	-$53	-$53	-$52
Aero Bin6	TCp	$0	$0	$0	$0	$0	$0	$1,225	$1,204	$1,194	$374
Aero Bin7	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$1,010
Aero Bin8	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-261 Costs of Aero Technologies
Long Van, Partial Aero Trailers (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aero Bin3	DMC	$456	$447	$438	$429	$420	$412	$404	$396	$392	$388
Aero Bin4	DMC	$651	$638	$625	$613	$600	$588	$577	$565	$559	$554
Aero Bin5	DMC	$1,042	$1,021	$1,000	$980	$961	$941	$923	$904	$895	$886
Aero Bin6	DMC	$1,237	$1,212	$1,188	$1,164	$1,141	$1,118	$1,096	$1,074	$1,063	$1,052
Aero Bin7	DMC	$1,432	$1,403	$1,375	$1,348	$1,321	$1,294	$1,269	$1,243	$1,231	$1,218
Aero Bin8	DMC	$1,888	$1,850	$1,813	$1,777	$1,741	$1,706	$1,672	$1,639	$1,622	$1,606
Aero Bin3	IC	$91	$72	$72	$72	$72	$71	$71	$71	$71	$71
Aero Bin4	IC	$130	$102	$102	$102	$102	$102	$102	$102	$102	$102
Aero Bin5	IC	$208	$164	$164	$164	$163	$163	$163	$163	$163	$163
Aero Bin6	IC	$247	$195	$194	$194	$194	$194	$194	$194	$194	$194
Aero Bin7	IC	$286	$225	$225	$225	$225	$225	$224	$224	$224	$224
Aero Bin8	IC	$377	$297	$297	$296	$296	$296	$296	$296	$296	$295
Aero Bin3	TC	$547	$518	$509	$500	$492	$483	$475	$467	$463	$459
Aero Bin4	TC	$781	$740	$727	$715	$703	$690	$679	$667	$661	$656
Aero Bin5	TC	$1,250	$1,185	$1,164	$1,144	$1,124	$1,105	$1,086	$1,067	$1,058	$1,049
Aero Bin6	TC	$1,484	$1,407	$1,382	$1,358	$1,335	$1,312	$1,289	$1,267	$1,257	$1,246
Aero Bin7	TC	$1,718	$1,629	$1,600	$1,573	$1,546	$1,519	$1,493	$1,467	$1,455	$1,443
Aero Bin8	TC	$2,265	$2,147	$2,110	$2,073	$2,037	$2,002	$1,968	$1,934	$1,918	$1,902
Aero Bin3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin6	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin7	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin8	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin3	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin4	Alt 3	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%
Aero Bin5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin6	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin7	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin8	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin3	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin4	TCp	$742	$703	$691	$679	$667	$656	$645	$634	$628	$623
Aero Bin5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin6	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin7	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin8	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-262 Costs of Aero Technologies
Short Van, Full Aero Trailers (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aero Bin2	DMC	$456	$447	$438	$429	$420	$412	$404	$396	$392	$388
Aero Bin3	DMC	$911	$893	$875	$858	$841	$824	$807	$791	$783	$775
Aero Bin4	DMC	$1,107	$1,084	$1,063	$1,042	$1,021	$1,000	$980	$961	$951	$942
Aero Bin5	DMC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin6	DMC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin7	DMC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin8	DMC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin2	IC	$91	$72	$72	$72	$72	$71	$71	$71	$71	$71
Aero Bin3	IC	$182	$143	$143	$143	$143	$143	$143	$143	$143	$143
Aero Bin4	IC	$221	$174	$174	$174	$174	$174	$173	$173	$173	$173
Aero Bin5	IC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin6	IC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin7	IC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin8	IC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin2	TC	$547	$518	$509	$500	$492	$483	$475	$467	$463	$459
Aero Bin3	TC	$1,093	$1,036	$1,018	$1,001	$984	$967	$950	$934	$926	$918
Aero Bin4	TC	$1,328	$1,259	$1,237	$1,215	$1,194	$1,174	$1,154	$1,134	$1,124	$1,115
Aero Bin5	TC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin6	TC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin7	TC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin8	TC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin2	Alt 1a	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Aero Bin3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin6	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin7	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin8	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin2	Alt 3	5%	5%	5%	95%	95%	95%	0%	0%	0%	0%
Aero Bin3	Alt 3	0%	0%	0%	0%	0%	0%	95%	95%	95%	30%
Aero Bin4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	60%
Aero Bin5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%
Aero Bin6	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin7	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin8	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin2	TCp	$0	$0	$0	$450	$443	$435	-$24	-$23	-$23	-$23
Aero Bin3	TCp	$0	$0	$0	$0	$0	$0	$903	$887	$880	$275
Aero Bin4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$669
Aero Bin5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin6	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin7	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin8	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-263 Costs of Aero Technologies
Short Van, Partial Aero Trailers (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Aero Bin2	DMC	$456	$447	$438	$429	$420	$412	$404	$396	$392	$388
Aero Bin3	DMC	$911	$893	$875	$858	$841	$824	$807	$791	$783	$775
Aero Bin4	DMC	$1,107	$1,084	$1,063	$1,042	$1,021	$1,000	$980	$961	$951	$942
Aero Bin5	DMC	$1,107	$1,084	$1,063	$1,042	$1,021	$1,000	$980	$961	$951	$942
Aero Bin6	DMC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin7	DMC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin8	DMC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin2	IC	$91	$72	$72	$72	$72	$71	$71	$71	$71	$71
Aero Bin3	IC	$182	$143	$143	$143	$143	$143	$143	$143	$143	$143
Aero Bin4	IC	$221	$174	$174	$174	$174	$174	$173	$173	$173	$173
Aero Bin5	IC	$221	$174	$174	$174	$174	$174	$173	$173	$173	$173
Aero Bin6	IC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin7	IC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin8	IC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin2	TC	$547	$518	$509	$500	$492	$483	$475	$467	$463	$459
Aero Bin3	TC	$1,093	$1,036	$1,018	$1,001	$984	$967	$950	$934	$926	$918
Aero Bin4	TC	$1,328	$1,259	$1,237	$1,215	$1,194	$1,174	$1,154	$1,134	$1,124	$1,115
Aero Bin5	TC	$1,328	$1,259	$1,237	$1,215	$1,194	$1,174	$1,154	$1,134	$1,124	$1,115
Aero Bin6	TC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin7	TC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin8	TC	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin2	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin3	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin4	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin5	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin6	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin7	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin8	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin2	Alt 3	0%	0%	0%	95%	95%	95%	95%	95%	95%	95%
Aero Bin3	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin4	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin5	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin6	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin7	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin8	Alt 3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Aero Bin2	TCp	$0	$0	$0	$475	$467	$459	$451	$444	$440	$436
Aero Bin3	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin4	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin5	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin6	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin7	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Aero Bin8	TCp	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.9.6 Aero Improvements, HD Pickups and Vans

For HD pickups and vans, we have based our aero improvement costs on values used in our light-duty 2017-2025 final rule. Using those values updated to 2012$ results in costs for aero 1 (passive aero treatments) and active aero treatments of $47 and $142 (both are DMC, in 2012$, in 2015). Note that the aero 2 costs are the passive aero 1 plus the active aero costs. We consider both of these technologies to be on the flat portion of the learning curve (curve 8) and, to aero 1, have applied low complexity markups with near term markups through 2018 and, to active aero, and have applied medium complexity markups with near term markups through 2024. The resultant costs for HD pickups and vans are shown below for aero 1 and active aero and then for aero 2 (the two combined, passive+active aero).

Table 2-264 Costs for Passive Aero Treatments – Aero 1
Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Aero 1 – passive aero	DMC	$42	$41	$40	$39	$38	$38	$38
Aero 1 – passive aero	IC	$9	$9	$9	$9	$9	$9	$9
Aero 1 – passive aero	TC	$51	$50	$49	$48	$47	$47	$47

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

Table 2-265 Costs for Active Aero Treatments
Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Aero 2 – active aero	DMC	$125	$122	$120	$118	$115	$114	$113
Aero 2 – active aero	IC	$54	$54	$54	$54	$40	$40	$40
Aero 2 – active aero	TC	$179	$177	$174	$172	$156	$154	$153

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

Table 2-266 Costs for Aero 2 (passive plus active aero)
Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Aero 2 – active aero	DMC	$166	$163	$160	$157	$154	$152	$151
Aero 2 – active aero	IC	$63	$63	$63	$63	$50	$49	$49
Aero 2 – active aero	TC	$230	$227	$223	$220	$203	$201	$200

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.11.10 Other Technologies

2.11.10.1 Advanced Cruise Controls, Tractors

We have estimated the cost of this technology based on an estimate from TetraTech of $1100 (retail, 2013$). Using that estimate we divided by a 1.36 RPE to arrive at a cost of $809 (DMC, 2013$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022.

The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-267 Costs for Advanced Cruise Controls Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Advanced cruise control	DMC	$809	$785	$761	$738	$723	$709	$695	$681	$667	$654
Advanced cruise control	IC	$144	$144	$144	$143	$143	$113	$113	$112	$112	$112
Advanced cruise control	TC	$953	$929	$905	$882	$867	$822	$807	$793	$780	$766
Advanced cruise control	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Advanced cruise control	Alt 3	0%	0%	0%	20%	20%	20%	40%	40%	40%	40%
Advanced cruise control	TCp	$0	$0	$0	$176	$173	$164	$323	$317	$312	$307

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.10.2 Improved Accessories

For vocational vehicles, we have estimated the cost of this technology based on an estimate from TIAX of $530 (retail) for light HD, $1000 for medium HD and $2000 for heavy HD vocational vehicles. These estimates include costs of upgrading to a 42 Volt electrical system, electric power steering and electric air conditioning. Using these estimates, we divided by a 1.36 RPE to arrive at cost of $390, $735 and $1471, respectively (DMC, 2013$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-268 Costs for Improved Accessories Vocational Light HD Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Improved accessories	DMC	$390	$378	$367	$356	$349	$342	$335	$328	$322	$315
Improved accessories	IC	$70	$69	$69	$69	$69	$54	$54	$54	$54	$54
Improved accessories	TC	$459	$447	$436	$425	$418	$396	$389	$382	$376	$369
Improved accessories	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Improved accessories	Alt 3	0%	0%	0%	5%	5%	5%	10%	10%	10%	15%
Improved accessories	TCp	$0	$0	$0	$21	$21	$20	$39	$38	$38	$55

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-269 Costs for Improved Accessories Vocational Medium HD Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Improved accessories	DMC	$735	$713	$692	$671	$658	$645	$632	$619	$607	$594
Improved accessories	IC	$131	$131	$131	$130	$130	$102	$102	$102	$102	$102
Improved accessories	TC	$867	$844	$822	$801	$788	$747	$734	$721	$709	$697
Improved accessories	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Improved accessories	Alt 3	0%	0%	0%	5%	5%	5%	10%	10%	10%	15%
Improved accessories	TCp	$0	$0	$0	$40	$39	$37	$73	$72	$71	$104

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

Table 2-270 Costs for Improved Accessories
Vocational Heavy HD Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Improved accessories	DMC	$1,471	$1,426	$1,384	$1,342	$1,315	$1,289	$1,263	$1,238	$1,213	$1,189
Improved accessories	IC	$262	$262	$261	$261	$260	$205	$205	$205	$204	$204
Improved accessories	TC	$1,733	$1,688	$1,645	$1,603	$1,576	$1,494	$1,468	$1,443	$1,418	$1,393
Improved accessories	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Improved accessories	Alt 3	0%	0%	0%	5%	5%	5%	10%	10%	10%	15%
Improved accessories	TCp	$0	$0	$0	$80	$79	$75	$147	$144	$142	$209

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

For tractors, we have estimated the cost of this technology based on an estimate from TetraTech of $350 (retail, 2013$). Using that estimate we divided by a 1.36 RPE to arrive at a cost of $257 (DMC, 2013$, in 2018). We consider this technology to be on the flat portion of the learning curve (curve 12) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below for tractors.

Table 2-271 Costs for Improved Accessories
Tractors (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Improved accessories	DMC	$257	$250	$242	$235	$230	$226	$221	$217	$212	$208
Improved accessories	IC	$46	$46	$46	$46	$46	$36	$36	$36	$36	$36
Improved accessories	TC	$303	$295	$288	$281	$276	$261	$257	$252	$248	$244
Improved accessories	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Improved accessories	Alt 3	0%	0%	0%	10%	10%	10%	20%	20%	20%	30%
Improved accessories	TCp	$0	$0	$0	$28	$28	$26	$51	$50	$50	$73

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

For HD pickups and vans, we have estimated the costs for two levels of improved accessories based on estimates presented in the light-duty 2017-2025 final rule. In that rule, we estimated the costs of IACC1 and IACC2 at $73 and $118, respectively (both are DMC, 2009$, in 2015). With updates to 2012$, these costs become $77 and $124, respectively (both are DMC, 2012$, in 2015). Note that IACC2 includes IACC1. We consider these technologies to be on the flat portion of the learning curve (curve 8) and have applied low complexity markups with near term markups through 2018. The resultant cost for both are shown below.

Table 2-272 Costs for Improved Accessories
Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Improved accessories 1 (IACC1)	DMC	$67	$66	$64	$63	$62	$61	$61
Improved accessories 1 (IACC2)	DMC	$109	$106	$104	$102	$100	$99	$98
Improved accessories 1 (IACC1)	IC	$15	$15	$15	$15	$15	$15	$15
Improved accessories 1 (IACC2)	IC	$24	$24	$24	$24	$24	$24	$24
Improved accessories 1 (IACC1)	TC	$82	$80	$79	$78	$77	$76	$75
Improved accessories 1 (IACC2)	TC	$132	$130	$128	$126	$124	$123	$122

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.11.10.3 Weight Reduction, Vocational Vehicles

We have estimated the cost of a 200 pound weight reduction on vocational vehicles at $4/pound (retail, 2013$). Using that cost we have divided by a 1.36 RPE to arrive at costs of $588 (DMC, in 2013$, applicable in 2021). We consider this weight reduction level to be on the flat portion of the learning curve (curve 13) and have applied low complexity ICMs with short term markups through 2022. We have applied the 200 pound weight reduction level to light and medium HD vocational vehicles. The resultant technology costs, penetration rates and total cost applied to the package are shown below.

Table 2-273 Costs for a 200 Pound Weight Reduction Vocational Light/Medium HD Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Weight reduction, 200 lbs	DMC	$645	$625	$606	$588	$571	$553	$537	$526	$516	$505
Weight reduction, 200 lbs	IC	$106	$105	$105	$105	$105	$82	$82	$82	$82	$82
Weight reduction, 200 lbs	TC	$750	$731	$712	$693	$675	$636	$619	$608	$598	$587
Weight reduction, 200 lbs	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Weight reduction, 200 lbs	Alt 3	0%	0%	0%	10%	10%	10%	30%	30%	30%	50%
Weight reduction, 200 lbs	TCp	$0	$0	$0	$69	$68	$64	$186	$182	$179	$294

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

We have estimated the cost of weight reduction from use of aluminum wheels based on the aluminum steer wheel technology discussed in the Phase 1 rules. That technology was estimated at $459 for two wheels (DMC, 2008$, in 2014). With updates to 2013$, we estimate the costs at $494 (DMC, 2013$, in 2014). We consider this technology to be on the flat portion of the learning curve (curve 2) and have applied a low complexity ICM with short term markups through 2022. The resultant technology costs, penetration rates and total cost applied to the package are shown below. We apply this technology to heavy HD vocational vehicles having 10 wheels per vehicle.

Table 2-274 Costs for Weight Reduction via use of Aluminum Wheels Vocational Heavy HD Vehicles (2013$)

TECHNOLOGY		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Weight reduction, Al wheels	DMC	$2,188	$2,144	$2,102	$2,060	$2,018	$1,978	$1,938	$1,900	$1,881	$1,862
Weight reduction, Al wheels	IC	$437	$437	$436	$436	$435	$343	$343	$343	$343	$342
Weight reduction, Al wheels	TC	$2,626	$2,581	$2,538	$2,495	$2,453	$2,321	$2,281	$2,242	$2,223	$2,204
Weight reduction, Al wheels	Alt 1a	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Weight reduction, Al wheels	Alt 3	0%	0%	0%	10%	10%	10%	30%	30%	30%	50%
Weight reduction, Al wheels	TCp	$0	$0	$0	$250	$245	$232	$684	$673	$667	$1,102

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost; TCp=total cost applied to the package; alt=alternative

2.11.10.4 Weight Reduction in HD Pickups and Vans

For this rule, we are estimating weight reduction costs for HD pickups and vans using the same cost curve used in support of the 2017-2025 light-duty GHG/CAFE FRM. That curve can be expressed as:

Mass Reduction Direct Manufacturing Cost (DMC) ($/lb) = 4.55 x Percentage of Mass Reduction (2012$)

For example, this results in an estimated $80 (2012$) DMC increase for a 5 percent mass reduction of a 7,000 pound vehicle and $318 (2012$) DMC increase for a 10 percent mass reduction of a 7,000 pound vehicle, or $0.227 $/lb and $0.455/lb, respectively (both in 2012$).

Consistent with the 2017-2025 light-duty FRM, the agencies consider this DMC to be applicable to MY2017 and consider mass reduction technology to be on the flat portion of the learning curve in the 2017-2025MY timeframe. To estimate indirect costs for applied mass reduction of up to 10 percent, the agencies have applied a low complexity ICM with near term markups through 2018.

2.11.10.5 Electric Power Steering, HD Pickups and Vans

We have based the costs for electric power steering on the costs used in the light-duty 2017-2025 FRM but have scaled upward that cost by 50 percent to account for the larger HD vehicles. Using that cost and converting to 2012$ results in a cost of $141 (DMC, 2012$, in 2015). We consider this technology to be on the flat portion of the learning curve (curve 8) and have applied low complexity markups with near term markups through 2018. The resultant costs for HD pickups and vans are shown in are shown below.

Table 2-275 Costs for Electric Power Steering Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Electric power steering (EPS)	DMC	$124	$121	$119	$117	$114	$113	$112
Electric power steering (EPS)	IC	$27	$27	$27	$27	$27	$27	$27
Electric power steering (EPS)	TC	$151	$148	$146	$144	$141	$140	$139

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.11.10.6 Low Drag Brakes, HD Pickups and Vans

We have based the costs for low drag brakes on the costs used in the light-duty 2017-2025 FRM but have scaled upward that cost by 50 percent to account for the larger HD vehicles. Using that cost and converting to 2012$ results in a cost of $91 (DMC, 2012$, in any year). We consider this technology to be beyond the learning curve (curve 1) and have applied low complexity markups with near term markups through 2018. The resultant costs for HD pickups and vans are shown in are shown below.

Table 2-276 Costs for Low Drag Brakes
Gasoline & Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Low drag brakes	DMC	$91	$91	$91	$91	$91	$91	$91
Low drag brakes	IC	$18	$18	$18	$18	$18	$18	$18
Low drag brakes	TC	$109	$109	$109	$109	$109	$109	$109

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.11.10.7 Driveline Friction Reduction, Diesel HD Pickups & Vans

We have estimated the cost of driveline friction reduction based on the cost of secondary axle disconnect in the light-duty 2017-2025 final rule. Using that cost of $80 (DMC, 2009$, in 2015), we have scaled upward by 50 percent to account for the larger HD componentry to arrive at a cost of $126 (DMC, 2012$, in 2015). We consider this technology to be on the flat portion of the learning curve (curve 3) and have applied low complexity markups with near term markups through 2022. The resultant costs for driveline friction reduction (applied only to diesel HD pickups & vans) are shown below.

Table 2-277 Costs for Driveline Friction Reduction
Diesel HD Pickups and Vans (2012$)

ITEM		2021	2022	2023	2024	2025	2026	2027
Driveline friction reduction	DMC	$108	$106	$104	$102	$100	$99	$98
Driveline friction reduction	IC	$30	$30	$24	$24	$24	$24	$24
Driveline friction reduction	TC	$139	$136	$128	$126	$124	$123	$122

Notes: DMC=direct manufacturing cost; IC=indirect cost; TC=total cost

2.12 Package Costs

Chapter 2.11 presents detailed technology costs along with penetration rates to illustrate how each technology is accounted for in the package costs. Here we present package costs by regulated sector (i.e., vocational heavy HD, urban vehicles) and package costs by MOVES sourcetype (i.e., diesel refuse trucks). We determine package costs by MOVES sourcetype so that we can calculate total program costs (i.e., package costs multiplied by vehicle sales) since sourcetypes are the sales figures that we can glean from MOVES. As a result, the sourcetype package costs presented here are the costs used in our program cost estimations.

2.12.1 Package Costs by Regulated Sector

2.12.1.1 Vocational Vehicles

We have estimated costs for 9 vocational segments and 2 fuels. We present package costs in the tables below for these for alternative 3 relative to alternatives 1a and 1b and separately for diesel and gasoline vehicles.

Table 2-278 Package Costs for Regulated Vocational Segment Alternative 3 Incremental to Alternative 1a & 1b Diesel (2013$)

WEIGHT CLASS	SPEED	2021	2022	2023	2024	2025	2026	2027
Light HD	Urban	$1,106	$1,083	$1,020	$1,959	$1,925	$1,873	$2,533
Light HD	Multipurpose	$1,164	$1,140	$1,079	$2,018	$1,983	$1,919	$2,571
Light HD	Regional	$873	$855	$825	$1,272	$1,251	$1,224	$1,486
Medium HD	Urban	$1,116	$1,092	$1,030	$2,082	$2,046	$1,977	$2,727
Medium HD	Multipurpose	$1,146	$1,123	$1,058	$2,110	$2,074	$2,004	$2,771
Medium HD	Regional	$851	$833	$800	$1,274	$1,252	$1,226	$1,500
Heavy HD	Urban	$1,334	$1,308	$1,236	$2,932	$2,882	$2,785	$4,151
Heavy HD	Multipurpose	$1,625	$1,595	$1,502	$3,813	$3,749	$3,638	$5,025
Heavy HD	Regional	$2,562	$2,517	$2,359	$4,009	$3,942	$3,869	$5,670

Table 2-279 Package Costs for Regulated Vocational Segment Alternative 3 Incremental to Alternative 1a & 1b Gasoline (2013$)

WEIGHT CLASS	SPEED	2021	2022	2023	2024	2025	2026	2027
Light HD	Urban	$947	$930	$872	$1,649	$1,616	$1,569	$2,177
Light HD	Multipurpose	$1,004	$986	$931	$1,708	$1,673	$1,615	$2,215
Light HD	Regional	$714	$701	$677	$962	$941	$921	$1,130
Medium HD	Urban	$979	$961	$904	$1,805	$1,770	$1,705	$2,406
Medium HD	Multipurpose	$1,010	$991	$932	$1,833	$1,797	$1,732	$2,450
Medium HD	Regional	$715	$702	$674	$997	$975	$954	$1,179
Heavy HD	Urban	$1,198	$1,177	$1,110	$2,655	$2,606	$2,513	$3,830
Heavy HD	Multipurpose	$1,489	$1,464	$1,376	$3,536	$3,472	$3,366	$4,704
Heavy HD	Regional	$2,426	$2,386	$2,233	$3,732	$3,665	$3,598	$5,349

2.12.1.2 Tractors

We have estimated costs for 7 tractor segments and 1 fuel. We present package costs in the tables below for these for alternative 3 relative to alternatives 1a and 1b.

Table 2-280 Package Costs for Regulated Tractor Segment Alternative 3 Incremental to Alternative 1a Diesel (2013$)

CLASS	TYPE	2021	2022	2023	2024	2025	2026	2027
7	Day cab, low roof	$5,134	$5,052	$4,682	$8,037	$7,859	$7,728	$10,235
7	Day cab, high roof	$5,240	$5,151	$4,772	$8,210	$8,026	$7,852	$10,298
8	Day cab, low roof	$5,228	$5,143	$4,769	$8,201	$8,020	$7,887	$10,439
8	Day cab, high roof	$5,317	$5,227	$4,844	$8,358	$8,172	$7,993	$10,483
8	Sleeper cab, low roof	$7,181	$7,061	$6,580	$11,100	$10,871	$10,714	$13,535
8	Sleeper cab, mid roof	$7,175	$7,056	$6,574	$11,100	$10,871	$10,714	$13,574
8	Sleeper cab, high roof	$7,276	$7,239	$6,751	$11,306	$11,068	$10,857	$13,749

Table 2-281 Package Costs for Regulated Tractor Segment
Alternative 3 Incremental to Alternative 1b
Diesel (2013$)

CLASS	TYPE	2021	2022	2023	2024	2025	2026	2027
7	Day cab, low roof	$5,267	$5,112	$4,659	$7,944	$7,705	$7,536	$9,937
7	Day cab, high roof	$5,093	$4,977	$4,594	$8,016	$7,816	$7,621	$10,042
8	Day cab, low roof	$5,360	$5,203	$4,745	$8,108	$7,866	$7,695	$10,141
8	Day cab, high roof	$5,170	$5,053	$4,667	$8,164	$7,962	$7,763	$10,227
8	Sleeper cab, low roof	$7,195	$6,988	$6,438	$10,883	$10,614	$10,404	$13,140
8	Sleeper cab, mid roof	$7,102	$6,886	$6,337	$10,800	$10,514	$10,306	$13,043
8	Sleeper cab, high roof	$7,115	$7,057	$6,577	$11,122	$10,871	$10,656	$13,515

2.12.1.3 Trailers

We have estimated costs for seven trailer types (i.e. for each of the subcategories). The dry and refrigerated vans have identical stringency and technology packages, so costs are presented by length category only. The tire-based design standards for non-aero box vans are a single category, but separate non-aero costs were considered for long vans and short vans, because we assumed all short vans have a single axle, which results in fewer wheels and tires and lower costs. We present package costs in the tables below for these for alternative 3 relative to alternative 1a and 1b.

Table 2-282 Costs for Trailers
Alternative 3 Incremental to Alternative 1a (2013$)

TYPE	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Long van, Full aero	$716	$688	$673	$1,081	$1,061	$1,030	$1,204	$1,184	$1,183	$1,370
Long van, Partial aero	$1,441	$1,383	$1,352	$1,337	$1,313	$1,274	$1,251	$1,229	$1,213	$1,196
Long van, No aero	$461	$448	$435	$438	$429	$413	$405	$398	$390	$382
Short van, Full aero	$339	$330	$322	$772	$757	$733	$1,171	$1,151	$1,144	$1,204
Short van, Partial aero	$514	$500	$487	$957	$940	$910	$894	$879	$867	$855
Short van, No aero	$231	$224	$218	$219	$215	$207	$202	$199	$195	$191
Non-box	$448	$436	$424	$412	$406	$390	$383	$377	$361	$354

Table 2-283 Costs for Trailers
Alternative 3 Incremental to Alternative 1b (2013$)

TYPE	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Long van, Full aero	$716	$676	$650	$1,047	$1,016	$975	$1,139	$1,109	$1,098	$1,276
Long van, Partial aero	$1,441	$1,383	$1,352	$1,337	$1,313	$1,274	$1,251	$1,229	$1,213	$1,196
Long van, No aero	$461	$448	$435	$438	$429	$413	$405	$398	$390	$382
Short van, Full aero	$339	$330	$322	$772	$757	$733	$1,171	$1,151	$1,144	$1,204
Short van, Partial aero	$514	$500	$487	$957	$940	$910	$894	$879	$867	$855
Short van, No aero	$231	$224	$218	$219	$215	$207	$202	$199	$195	$191
Non-box	$448	$436	$424	$412	$406	$390	$383	$377	$361	$354

2.12.1.4 HD Pickups and Vans

The costs presented in the table below are CAFE model outputs used in analysis Method B. We describe the CAFE model and how these costs were generated in Chapter 6 and 11 of this RIA.

Table 2-284 Package Costs for HD Pickups and Vans (2013$)

ALTERNATIVE	BASELINE CASE	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
3	1a	$114	$105	$108	$524	$516	$804	$963	$1,180	$1,244	$1,364
3	1b	$113	$105	$102	$513	$505	$793	$952	$1,168	$1,233	$1,349

2.12.2 Package Costs by MOVES Sourcetype

The package costs by segment can then be used to calculate package costs by MOVES sourcetype. To do this, we need the percentage of the MOVES sourcetype fleet comprised of each regulated sector. Table 2-285 shows this breakout for the vocational sector and Table 2-286 shows it for tractors. Package costs for vocational vehicles make the conservative assumption of full program compliance rather than compliance with the more flexible, less costly custom chassis program.

Table 2-285 Fleet Mix by MOVES Sourcetype and Regulated Sector -- Vocational[a]

ENGINE	FUEL	SPEED	INTERCITY BUS	TRANSIT BUS	SCHOOL BUS	REFUSE TRUCKS	SINGLE UNIT SHORT HAUL	SINGLE UNIT LONG HAUL	MOTOR HOMES
Light HD	Gasoline	Urban	0%	27%	1%	0%	41%	0%	0%
Light HD	Gasoline	Multipurpose	0%	0%	0%	0%	33%	0%	0%
Light HD	Gasoline	Regional	0%	0%	0%	0%	7%	0%	54%
Medium HD	Gasoline	Urban	0%	10%	85%	0%	7%	0%	0%
Medium HD	Gasoline	Multipurpose	0%	0%	9%	0%	9%	0%	0%
Medium HD	Gasoline	Regional	0%	0%	0%	0%	3%	0%	41%
Heavy HD	Gasoline	Urban	0%	63%	4%	0%	0%	0%	0%
Heavy HD	Gasoline	Multipurpose	0%	0%	0%	0%	0%	0%	0%
Heavy HD	Gasoline	Regional	0%	0%	0%	0%	0%	0%	5%
Light HD	Diesel	Urban	0%	0%	1%	0%	21%	0%	0%
Light HD	Diesel	Multipurpose	0%	0%	0%	0%	17%	0%	0%
Light HD	Diesel	Regional	2%	0%	0%	0%	4%	25%	54%
Medium HD	Diesel	Urban	0%	0%	85%	2%	12%	0%	0%
Medium HD	Diesel	Multipurpose	0%	0%	9%	0%	17%	0%	0%
Medium HD	Diesel	Regional	15%	0%	0%	0%	5%	37%	41%
Heavy HD	Diesel	Urban	0%	100%	4%	88%	5%	0%	0%
Heavy HD	Diesel	Multipurpose	0%	0%	0%	10%	15%	0%	0%
Heavy HD	Diesel	Regional	83%	0%	0%	0%	5%	37%	5%
Heavy HD	CNG	Urban	0%	100%	0%	0%	0%	0%	0%
Heavy HD	CNG	Multipurpose	0%	0%	0%	0%	0%	0%	0%
Heavy HD	CNG	Regional	0%	0%	0%	0%	0%	0%	0%

Note:
[a] Columns add to 100% or 0% within each fuel type.

Table 2-286 Fleet Mix by MOVES Sourcetype and Regulated Sector – Tractors[a]

ENGINE	MOVES SOURCETYPE	CLASS 7 DAY CAB LOW ROOF	CLASS 7 DAY CAB HIGH ROOF	CLASS 8 DAY CAB LOW ROOF	CLASS 8 DAY CAB HIGH ROOF	CLASS 8 SLEEPER CAB LOW ROOF	CLASS 8 SLEEPER CAB MID ROOF	CLASS 8 SLEEPER CAB HIGH ROOF
Medium HD	Combination Short haul	11%	11%	0%	0%	0%	0%	0%
Heavy HD	Combination Short haul	0%	0%	39%	39%	0%	0%	0%
Heavy HD	Combination Long haul	0%	0%	0%	0%	5%	15%	80%

Note:
[a] Combination short haul adds to 100% and long haul to 100%.

Using the fleet mix information shown in Table 2-285 and Table 2-286, along with the package costs shown in Chapter 2.12.1, we can generate the package costs by MOVES sourcetype (note that package costs by MOVES sourcetype differ from package costs by regulated sector only for vocational vehicles and tractors; trailer and HD pickup and van costs do not change). These costs are shown below.

Table 2-287 Package Costs by MOVES Sourcetype
Alternative 3 Incremental to Alternative 1a (2013$)

SOURCETYPE	FUEL	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Intercity Bus	Diesel	$0	$0	$0	$2,266	$2,225	$2,089	$3,534	$3,475	$3,411	$4,946
Transit Bus	Diesel	$0	$0	$0	$1,334	$1,308	$1,236	$2,932	$2,882	$2,785	$4,151
School Bus	Diesel	$0	$0	$0	$1,130	$1,106	$1,043	$2,127	$2,090	$2,019	$2,799
Refuse Truck	Diesel	$0	$0	$0	$1,357	$1,330	$1,256	$2,996	$2,945	$2,847	$4,198
SingleUnit ShortHaul	Diesel	$0	$0	$0	$1,270	$1,244	$1,174	$2,392	$2,351	$2,281	$3,142
SingleUnit LongHaul	Diesel	$0	$0	$0	$1,497	$1,468	$1,389	$2,296	$2,258	$2,214	$3,056
MotorHome	Diesel	$0	$0	$0	$954	$934	$896	$1,418	$1,394	$1,365	$1,714
Intercity Bus	Gasoline										
Transit Bus	Gasoline	$0	$0	$0	$1,109	$1,089	$1,026	$2,302	$2,258	$2,181	$3,247
School Bus	Gasoline	$0	$0	$0	$993	$975	$917	$1,850	$1,813	$1,747	$2,477
Refuse Truck	Gasoline										
SingleUnit ShortHaul	Gasoline	$0	$0	$0	$951	$933	$880	$1,628	$1,595	$1,544	$2,126
SingleUnit LongHaul	Gasoline										
MotorHome	Gasoline	$0	$0	$0	$805	$791	$758	$1,123	$1,100	$1,076	$1,374
Transit Bus	CNG	$0	$0	$0	$1,059	$1,039	$973	$2,519	$2,476	$2,384	$3,705
Comb ShortHaul Tractor	Diesel	$0	$0	$0	$5,254	$5,167	$4,789	$8,245	$8,062	$7,907	$10,418
Comb LongHaul Tractor	Diesel	$0	$0	$0	$7,256	$7,203	$6,716	$11,265	$11,029	$10,829	$13,712
Long Van, Full Aero		$716	$688	$673	$1,081	$1,061	$1,030	$1,204	$1,184	$1,183	$1,370
Long Van, Partial Aero		$1,441	$1,383	$1,352	$1,337	$1,313	$1,274	$1,251	$1,229	$1,213	$1,196
Long Van, No Aero		$461	$448	$435	$438	$429	$413	$405	$398	$390	$382
Short Van, Full Aero		$339	$330	$322	$772	$757	$733	$1,171	$1,151	$1,144	$1,204
Short Van, Partial Aero		$514	$500	$487	$957	$940	$910	$894	$879	$867	$855
Short Van, No Aero		$231	$224	$218	$219	$215	$207	$202	$199	$195	$191
Non-Box		$448	$436	$424	$412	$406	$390	$383	$377	$361	$354
Vocational	Weighted Avg	$0	$0	$0	$1,110	$1,088	$1,027	$2,022	$1,986	$1,927	$2,662
Tractor/Trailer	Weighted Avg	$568	$548	$535	$7,352	$7,269	$6,799	$11,134	$10,901	$10,712	$13,550

Note: Blank cells indicate no such vehicles of that sourcetype/fuel combination.

Table 2-288 Package Costs by MOVES Sourcetype
Alternative 3 Incremental to Alternative 1b (2013$)

SOURCETYPE	FUEL	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Intercity Bus	Diesel	$0	$0	$0	$2,266	$2,225	$2,089	$3,534	$3,475	$3,411	$4,946
Transit Bus	Diesel	$0	$0	$0	$1,334	$1,308	$1,236	$2,932	$2,882	$2,785	$4,151
School Bus	Diesel	$0	$0	$0	$1,130	$1,106	$1,043	$2,127	$2,090	$2,019	$2,799
Refuse Truck	Diesel	$0	$0	$0	$1,357	$1,330	$1,256	$2,996	$2,945	$2,847	$4,198
SingleUnit ShortHaul	Diesel	$0	$0	$0	$1,270	$1,244	$1,174	$2,392	$2,351	$2,281	$3,142
SingleUnit LongHaul	Diesel	$0	$0	$0	$1,497	$1,468	$1,389	$2,296	$2,258	$2,214	$3,056
MotorHome	Diesel	$0	$0	$0	$954	$934	$896	$1,418	$1,394	$1,365	$1,714
Intercity Bus	Gasoline										
Transit Bus	Gasoline	$0	$0	$0	$1,109	$1,089	$1,026	$2,302	$2,258	$2,181	$3,247
School Bus	Gasoline	$0	$0	$0	$993	$975	$917	$1,850	$1,813	$1,747	$2,477
Refuse Truck	Gasoline										
SingleUnit ShortHaul	Gasoline	$0	$0	$0	$951	$933	$880	$1,628	$1,595	$1,544	$2,126
SingleUnit LongHaul	Gasoline										
MotorHome	Gasoline	$0	$0	$0	$805	$791	$758	$1,123	$1,100	$1,076	$1,374
Transit Bus	CNG	$0	$0	$0	$1,059	$1,039	$973	$2,519	$2,476	$2,384	$3,705
Comb ShortHaul	Diesel	$0	$0	$0	$5,246	$5,110	$4,689	$8,101	$7,880	$7,696	$10,141
Comb LongHaul	Diesel	$0	$0	$0	$7,117	$7,028	$6,534	$11,061	$10,804	$10,591	$13,426
Long Van, Full Aero		$716	$676	$650	$1,047	$1,016	$975	$1,139	$1,109	$1,098	$1,276
Long Van, Partial Aero		$1,441	$1,383	$1,352	$1,337	$1,313	$1,274	$1,251	$1,229	$1,213	$1,196
Long Van, No Aero		$461	$448	$435	$438	$429	$413	$405	$398	$390	$382
Short Van, Full Aero		$339	$330	$322	$772	$757	$733	$1,171	$1,151	$1,144	$1,204
Short Van, Partial Aero		$514	$500	$487	$957	$940	$910	$894	$879	$867	$855
Short Van, No Aero		$231	$224	$218	$219	$215	$207	$202	$199	$195	$191
Non-Box		$448	$436	$424	$412	$406	$390	$383	$377	$361	$354
Vocational	Weighted Avg	$0	$0	$0	$1,110	$1,088	$1,027	$2,022	$1,986	$1,927	$2,662
Tractor/Trailer	Weighted Avg	$639	$548	$482	$7,248	$7,120	$6,624	$10,925	$10,660	$10,447	$13,226

References

[1] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council; Transportation Research Board (2010). “Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles,” (hereafter, “NAS Report”). Washington, D.C., The National Academies Press. Available electronically from the National Academies Press Website at http://www.nap.edu/catalog.php?record_id=12845 (last accessed September 10, 2010).
[2] TIAX, LLC. “Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles,” Final Report to the National Academy of Sciences, November 19, 2009.
[3] U.S. EPA. EPA Lumped Parameter Model HD Version 1.0.0.5, 2010. Docket #EPA-HQ-OAR-2010-0162.
[4] NESCCAF, ICCT, Southwest Research Institute, and TIAX. Reducing Heavy-Duty Long Haul Combination Truck Fuel Consumption and CO_2 Emissions. October 2009.
[5] ICF International. Investigation of Costs for Strategies to Reduce Greenhouse Gas Emissions for Heavy-Duty On-Road Vehicles. July 2010. Docket Identification Number EPA-HQ-OAR-2010-0162-0044.
[6] Reinhart, T.E. (2015, June). Commercial Medium- and Heavy-Duty Truck Fuel Efficiency Technology Study – Report #1. (Report No. DOT HS 812 146). Washington, DC: National Highway Traffic Safety Administration.
[7] Reinhart, T. (February 2016). Commercial Medium- and Heavy-Duty (MD/HD) Truck Fuel Efficiency Technology Study – Report #2. Washington, DC: National Highway Traffic Safety Administration. EPA-HQ-OAR-2014-0827-1623.
[8] Schubert, R., Chan, M., Law, K. (2015). Commercial Medium- and Heavy-Duty Truck Fuel Efficiency Technology Cost Study. Washington, DC: National Highway Traffic Safety Administration.
[9] Northeast States Center for a Clean Air Future. “Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles.” September 2004.
[10] Energy and Environmental Analysis, Inc. “Technology to Improve the Fuel Economy of Light Duty Trucks to 2015.” May 2006.
[11] “Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 - 2014,” EPA-420-R-14-023, October 2014. Available at http://www3.epa.gov/otaq/fetrends.htm (last accessed October 31, 2014).
[12] “Development and Optimization of the Ford 3.5L V6 EcoBoost Combustion System,” Yi,J., Wooldridge, S., Coulson, G., Hilditch, J. Iyer, C.O., Moilanen, P., Papaioannou, G., Reiche, D. Shelby, M., VanDerWege, B., Weaver, C. Xu, Z., Davis, G., Hinds, B. Schamel, A. SAE Technical Paper No. 2009-01-1494, 2009, Docket EPA-HQ-OAR-2009-0472-2860.
[13] David Woldring and Tilo Landenfeld of Bosch, and Mark J. Christie of Ricardo, “DI Boost: Application of a High Performance Gasoline Direct Injection Concept,” SAE 2007-01-1410. Available at http://www.sae.org/technical/papers/2007-01-1410 (last accessed Nov. 9, 2008).
[14] Yves Boccadoro, Loïc Kermanac’h, Laurent Siauve, and Jean-Michel Vincent, Renault Powertrain Division, “The New Renault TCE 1.2L Turbocharged Gasoline Engine,” 28th Vienna Motor Symposium, April 2007.
[15] Tobias Heiter, Matthias Philipp, Robert Bosch, “Gasoline Direct Injection: Is There a Simplified, Cost-Optimal System Approach for an Attractive Future of Gasoline Engines?” AVL Engine & Environment Conference, September 2005.
[16] Stanton, Donald. “Enabling High Efficiency Clean Combustion.” 2009 Semi-Mega Merit Review of the Department of Energy. May 21, 2009. Last accessed on August 25, 2010 at http://www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2009/advanced_combustion/ace_40_stanton.pdf.
[17] Zhang, H. Heavy Truck Engine Development & HECC. 2009 DOE Semi-Mega Merit Review, May 21, 2009. Last accessed on August 25, 2010 at http://www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2009/advanced_combustion/ace_42_zhang.pdf.
[18] de Ojeda, W., SuperTruck – Development and Demonstration of a Fuel-Efficient Class 8 Tractor & Trailer Engine Systems, http://energy.gov/eere/vehicles/downloads/supertruck-development-and-demonstration-fuel-efficient-class-8-tractor-3.
[19] Zhang, H. Detroit Diesel. “High Efficiency Clean Combustion for Heavy-Duty Engine.” August 6, 2008 presentation to DEER Conference. Last accessed on August 25, 2010 at http://www1.eere.energy.gov/vehiclesandfuels/pdfs/deer_2008/session5/deer08_zhang.pdf.

[20] Singh, S., SuperTruck Program: Engine Project Review Recovery Act – Class 8 Truck Freight Efficiency Improvement Project, DOE SuperTruck Merit Review, Department of Energy, 2014.
[21] See the NAS Report, page 53 cites Detroit Diesel Corporation, DD15 Brochure, DDC-EMC-BRO-0003-0408, April 2008
[22] Greszler, A., "View from the Bridge – Commercial Vehicle Perspective," DEER Conference, Department of Energy, 2012. http://www1.eere.energy.gov/vehiclesandfuels/resources/proceedings/2012_deer_presentations.html.
[23] de Ojeda, W., "Development and Demonstration of a Fuel-Efficient HD Engine (Department of Energy SuperTruck Program)," DEER Conference, Department of Energy, 2012. http://www1.eere.energy.gov/vehiclesandfuels/resources/proceedings/2012_deer_presentations.html.
[24] Jadin, D., "SuperTruck – Development and Demonstration of a Fuel-Efficient Class 8 Tractor & Trailer," DOE Supertruck Merit Review, Department of Energy, 2012. http://www1.eere.energy.gov/vehiclesandfuels/resources/proceedings/2012_deer_presentations.html.
[25] Koeberlein, D., Technology and System Level Demonstration of Highly Efficient and Clean, Diesel Powered Class 8 Trucks, 2012, http://energy.gov/sites/prod/files/2014/03/f10/ace057_koeberlein_2012_o.pdf.
[26] Sisken, K., Rotz, D., "Recovery Act – Class 8 Truck Freight Efficiency Improvement Project," DOE Supertruck Merit Review, Department of Energy, 2012. http://www1.eere.energy.gov/vehiclesandfuels/resources/proceedings/2012_deer_presentations.html.
[27] de Ojeda, W., "Development and Demonstration of a Fuel-Efficient HD Truck," DEER Conference, Department of Energy, 2011, http://www1.eere.energy.gov/vehiclesandfuels/resources/proceedings/2011_deer_presentations.html.
[28] SAE Off-Highway Magazine. Federal-Mogul's Latest Piston Ring Developments help reduce friction in heavy-duty engines. October 2, 2014. Last accessed on October 3, 2014 at http://www.oemoffhighway.com/press_release/12007334/federal-moguls-latest-piston-ring-developments-help-reduce-friction-in-heavy-duty-engines.
[29] Sisken, K., SuperTruck Program: Engine Project Review Recovery Act – Class 8 Truck Freight Efficiency Improvement Project, DOE Supertruck Merit Review, Department of Energy, 2013.
[30] Amar, P., SuperTruck Development and Demonstration of a Fuel-Efficient Class 8 Highway Vehicle Systems, DOE Supertruck Merit Review, Department of Energy, 2013.
[31] Koeberlein, D., Technology and System Level Demonstration of Highly Efficient and Clean, Diesel Powered Class 8 Trucks, DOE Supertruck Merit Review, Department of Energy, 2013.
[32] Stanton, D. W., Systematic development of highly efficient and clean engines to meet future commercial vehicle greenhouse gas regulations. Presented at SAE Commercial Vehicle Engineering Congress. Chicago, IL, October 2013.
[33] Amar, P., Volvo SuperTruck Powertrain Technologies for Efficiency Improvement, DOE Supertruck Merit Review, Department of Energy, 2014.
[34] Rotz, D., Super Truck Program: Vehicle Project Review, DOE Supertruck Merit Review, Department of Energy, 2014.
[35] Damon, K., DOE SuperTruck Program – Technology and System Level Demonstration of Highly Efficient b and Clean, Diesel Powered Class 8 Trucks, DOE Supertruck Merit Review, Department of Energy, 2014.
[36] 2015 Annual Fleet Fuel Study, report of a study conducted by the North American Council for Freight Efficiency (NACFE), May 6, 2015.
[37] Assumes travel on level road at 65 MPH. (21st Century Truck Partnership Roadmap and Technical White Papers, December 2006. U.S. Department of Energy, Energy Efficiency and Renewable Energy Program. 21CTP-003. p. 36.
[38] Reducing Heavy-Duty Long Haul Combination Truck Fuel Consumption and CO_2 Emissions, ICCT, October 2009.
[39] Overdrive magazine September 2014, "Western Star introduces re-designed on-highway tractor," http://www.overdriveonline.com/photo-video-western-star-unveils-re-designed-on-highway-tractor/?utm_medium=overdrive&utm_campaign=site_click&utm_source=top_stories
[40] Cornelius Pfeifer (Rochling Automotive), Society of Automotive Engineer (SAE) Paper #2014-01-0633: "Evolution of Active Grille Shutters." April 1, 2014.
[41] Jason Leuschen and Kevin R. Cooper (National Research Council of Canada), Society of Automotive Engineer (SAE) Paper #2006-01-3456: "Full-Scale Wind Tunnel Tests of Production and Prototype, Second-Generation Aerodynamic Drag-Reducing Devices for Tractor-Trailers.," November 2, 2006.
[42] http://www.todaystrucking.com/supertruck-flies-to-future-of-fuel-efficiency-at-107-mpg.

[43] "Tires & Truck Fuel Economy," A New Perspective. Bridgestone Firestone, North American Tire, LLC, Special Edition Four, 2008.
[44] "Michelin's Green Meters," Press Kit, October, 30, 2007. http://www.michelin-green-meter.com/main.php?cLang=en (Complete Press File, Viewed March 6, 2010).
[45] Argonne National Laboratory. "Evaluation of Fuel Consumption Potential of Medium and Heavy Duty Vehicles through Modeling and Simulation." October 2009. Page 91.
[46] 21st Century Truck Partnership, "Roadmap and technical White Papers," U.S. Department of Energy, Technical paper: 21CTP-0003, December 2006.
[47] NACFE December 2010 "Executive Report – Wide Base Tires," available at http://nacfe.org/wp-content/uploads/2010/12/NACFE-ER-1002-Wide-Base-Tires-Dec-2010.pdf.
[48] "Energy Efficiency Strategies for Freight Trucking: Potential Impact on Fuel Use and Greenhouse Gas Emissions," J. Ang-Olson, W. Schroer, Transportation Research Record: Journal of the Transportation Research Board, 2002(1815):11-18.
[49] "Effect of Single Wide Tires and Trailer Aerodynamics on Fuel efficiency and NO_X Emissions of Class 8 Line-Haul Tractor-Trailer," J. Bachman, A. Erb, C. Bynum, U.S. Environmental Protection Agency, SAE International, Paper Number 05CV-45, 2005.
[50] "Class 8 Heavy Truck Duty Cycle Project Final Report," U.S. Department of Energy, Oak Ridge National Laboratory, ORNL/TM-2008/122, p. 21, December 2008. Accessed January 19, 2010 at http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2008-122.pdf.
[51] "Are Ultra-Wide, Ultra-Low Aspect Ratio Tires the Next Big Thing?" K. Rohlwing, Today's Tire Industry, Vol. 1, Issue 1, July/August, July 2003.
[52] "New Generation Wide Base Single Tires," American Trucking Association, White paper presented at the International Workshop on the use of wide tires sponsored by Federal Highway Administration, Turner-Fairbank Highway Research Center, October 25-26, 2007, Revision 9, December 21, 2007, Accessed on February 3, 2010 at http://www.arc.unr.edu/Workshops/Wide_Tires/Wide_Base_Summary-v9-ATA-whitepaper.pdf.
[53] HDT Trucking info, March 2014,"Switching to Wide-Base Singles: Keys to Success," Available online: http://www.truckinginfo.com/channel/equipment/article/story/2014/03/switching-to-wide-base-singles-keys-to-success.aspx.
[54] "Recommended Practice: Guidelines for Outset Wide Base Wheels for Drive, Trailer and Auxiliary Axle Applications (Draft)," Technology and Maintenance Council, Council of American Trucking Associations, circulated September 28, 2009.
[55] "Tire Pressure Systems - Confidence Report." North American Council for Freight Efficiency. 2013. Available online: http://nacfe.org/wp-content/uploads/2014/01/TPS-Detailed-Confidence-Report1.pdf.
[56] Technology and Maintenance Council of the American Trucking Associations, Tire Air Pressure Study, Tire Debris Prevention Task Force S.2 Tire & Wheel Study Group; May 2002.
[57] "Commercial Vehicle Tire Condition Sensors," Federal Motor Carrier Safety Administration. Report No. FMCSA-PSV-04-002, November 2003.
[58] U.S. Environmental Protection Agency Office of Transportation and Air Quality SmartWay Transport Partnership, A Glance at Clean Freight Strategies: Automatic Tire Inflation Systems EPA 420-F-04-0010; February 2004.
[59] "A Day in the Life of a Tire," Pressure Systems International, Presented to EPA on August 20, 2014.
[60] "Buses & Retread Tires," The Tire Retread & Repair Information Bureau, Pacific Grove, Ca., Accessed on January 27, 2010 at http://www.retread.org/packet/index.cfm/ID/284.htm.
[61] "What are Retreaders Doing to Improve Fuel Efficiency?" H. Inman, Tire Review, December 11, 2006, Accessed on February 18, 2010 at http://www.tirereview.com/Article/59777/what_are_retreaders_doing_to_improve_fuel_efficiency.aspx.
[62] Modern Tire Dealer, Top Retreaders, ibid.
[63] Tire Industry Association and the Tire Retread and Repair Information Bureau, Understanding Retreading, accessed August 2, 2010, at http://www.retread.org/pdf/UR/UnderstandingRetreading_web.pdf.
[64] Todaystrucking.com, Retread Tires FAQ (07/17/2006), accessed August 2, 2010.
[65] "Better Fuel Efficiency? Start with a Strong Tire Program," H. Inman, Fleet & Tire 2006, Tire Review, December 11, 2006, Accessed on February 18, 2010 at http://www.tirereview.com/better-fuel-economy-start-with-a-strong-tire-program/.
[66] *See* 2010 NAS Report, Note 1, Finding 4-6, page 87.
[67] See NHTSA Technology Report #1 (2015), Note 6.
[68] NACFE. Executive Report – 6x2 (Dead Axle) Tractors. November 2010. See Docket.

[69] Reinhart, T.E. (2015, June). Commercial Medium- and Heavy-Duty Truck Fuel Efficiency Technology Study – Report #1. (Report No. DOT HS 812 146). Washington, DC: National Highway Traffic Safety Administration.
[70] Fleet Owner, "Meritor Expects to offer new tandem axle in 2013," http://fleetowner.com/equipment/meritor-expects-offer-new-tandem-axle-2013, December 2012.
[71] Dana Holding Corporation Patents (8,523,738, 8,795,125, and 8,911,321).
[72] See 4WD Axle Actuator Housing at 1A Auto, accessed November 2014 from http://www.1aauto.com/4wd-axle-actuator-housing/c/264.
[73] DriveAluminum. The Aluminum Advantage in Commercial Vehicle Applications Webinar. 2009. Last accessed on May 21, 2015 at http://www.drivealuminum.org/research-resources/PDF/Webinars/2009/The-Aluminum-Advantage-Commercial-Vehicle-Applications-Webinar-2009-Dec-Commercial-Vehicle-Webinar.pdf/view.
[74] Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy; National Research Council, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles," 2011. Available at http://www.nap.edu/catalog.php?record_id=12924 (last accessed Jun 27, 2012).
[75] Energy Savings through Increased Fuel Economy for Heavy Duty Trucks," Therese Langer, American Council for an Energy-Efficient Economy prepared for the National Commission on Energy Policy, February 11, 2004.
[76] Best practices Guidebook for Greenhouse Gas Reductions in Freight Transportation," H. Christopher Fey, Po-Yao Kuo, North Carolina State University prepared for the U.S. Department of Transportation, October 4, 2007.
[77] U.S. EPA. http://www3.epa.gov/smartway/documents/weightreduction.pdf.
[78] SAE World Congress, "Focus B-pillar 'tailor rolled' to 8 different thicknesses," Feb. 24, 2010. Available at http://www.sae.org/mags/AEI/7695 (last accessed Jun. 10, 2012).
[79] "Preliminary Vehicle Mass Estimation Using Empirical Subsystem Influence Coefficients," Malen, D.E., Reddy, K. Auto-Steel Partnership Report, May 2007, Docket EPA-HQ-OAR-2009-0472-0169. Accessed on the Internet on May 30, 2009 at: http://www.a-sp.org/database/custom/Mass%20Compounding%20-%20Final%20Report.pdf.
[80] "Benefit Analysis: Use of Aluminum Structures in Conjunction with Alternative Powertrain Technologies in Automobiles," Bull, M. Chavali, R., Mascarin, A., Aluminum Association Research Report, May 2008, Docket EPA-HQ-OAR-2009-0472-0168. Accessed on the Internet on April 30, 2009 at: http://www.autoaluminum.org/downloads/IBIS-Powertrain-Study.pdf.
[81] American Trucking Association. Last viewed on January 29, 2010 at http://www.trucksdeliver.org/recommendations/speed-limits.html.
[82] U.S. EPA SmartWay Transport Partnership. Last viewed on January 28, 2010 at http://www3.epa.gov/smartway/transport/documents/tech/reducedspeed.pdf.
[83] Department for Transport, Vehicle and Operator Services Agency. Last viewed on January 6, 2010 at http://www.dft.gov.uk/vosa/newsandevents/pressreleases/2006pressreleases/28-12-06speedlimiterlegislation.htm.
[84] Transport Canada. Summary Report – Assessment of a Heavy Truck Speed Limiter Requirement in Canada. Last viewed on January 6, 2010 at http://www.tc.gc.ca/eng/roadsafety/tp-tp14808-menu-370.htm.
[85] See TIAX 2009, Note 2, at page 4-98.
[86] Gaines, L. and D. Santini. Argonne National Laboratory, Economic Analysis of Commercial Idling Reduction Technologies.
[87] Gaines, L. and D. Santini. Argonne National Laboratory, Economic Analysis of Commercial Idling Reduction Technologies.
[88] ICF International. Investigation of Costs for Strategies to Reduce Greenhouse Gas Emissions for Heavy-Duty On-Road Vehicles. July 2010. Docket Identification Number EPA-HQ-OAR-2010-0162-0044.
[89] National Academy of Science. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. March 2010. Page 124.
[90] Gaines, L., A. Vyas, J. Anderson. Estimation of Fuel Use by Idling Commercial Trucks. 2006. Page 6.
[91] Brodrick, C., T.Lipman, M. Farshchi, H. Dwyer, S. Gouse III, D.B. Harris, and F.King, Jr. Potential Benefits of Utilizing Fuel Cell Auxiliary Power Units in Lieu of Heavy-Duty Truck Engine Idling. 2001. Page 3.
[92] Lim, Han. Study of Exhaust Emissions from Idling Heavy-Duty Diesel Trucks and Commercially Available Idle-Reducing Devices. EPA420-R-02-052. 2002. Page 2.
[93] Kahn, ABM, N. Clark, G. Thompson, W.S. Wayne, M. Gautam, and D. Lyons. Idle Emissions from Heavy-Duty Diesel Vehicles: Review and Recent Data. 2006. Journal of Air and Waste Management Association. Page 1405.

[94] NACFE, June 2014. Confidence Report: Idle-Reduction Solutions. Available at http://www.carbonwarroom.com/sites/default/files/reports/Idle-Reduction_Confidence_Report.pdf (accessed November 2014).
[95] See Vanner battery-inverter Systems at http://www.vanner.com/.
[96] See eNow solar systems. http://www.enowenergy.com/.
[97] Schwarz, W., Harnisch, J. 2003. "Establishing Leakage Rates of Mobile Air Conditioners." Prepared for the European Commission (DG Environment), Doc B4-3040/2002/337136/MAR/C1.
[98] Vincent, R., Cleary, K., Ayala, A., Corey, R. 2004. "Emissions of HFC-134a from Light-Duty Vehicles in California." SAE 2004-01-2256.
[99] Society of Automotive Engineers, "IMAC Team 1 – Refrigerant Leakage Reduction, Final Report to Sponsors," 2006.
[100] California Air Resources Board. Letter from Michael Carter to Matthew Spears dated December 3, 2014. Solar Control: Heavy-Duty Vehicles White Paper. Docket EPA-HA-OAR-2014-0827.
[101] National Renewal Energy Laboratory. Reducing Long-Haul Truck Idle Loads and Resulting Fuel Use. Presented by Jason A. Lustbader to EPA on July 29, 2014. See Docket EPA-HA-OAR-2014-0827.
[102] See NHTSA Technology Report #1 (2015), Note 6.
[103] U.S. EPA and NHTSA, "Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards – Joint Technical Support Document," 2010. Last viewed on June 3, 2010 at http://www3.epa.gov/otaq/climate/regulations/420r10901.pdf.
[104] "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 - 2014," EPA-420-R-14-023, October 2014. Available at http://www3.epa.gov/otaq/fetrends.htm (last accessed October 31, 2014).
[105] "Development and Optimization of the Ford 3.5L V6 EcoBoost Combustion System," Yi, J., Wooldridge, S., Coulson, G., Hilditch, J. Iyer, C.O., Moilanen, P., Papaioannou, G., Reiche, D. Shelby, M., VanDerWege, B., Weaver, C. Xu, Z., Davis, G., Hinds, B. Schamel, A. SAE Technical Paper No. 2009-01-1494, 2009, Docket EPA-HQ-OAR-2009-0472-2860.
[106] David Woldring and Tilo Landenfeld of Bosch, and Mark J. Christie of Ricardo, "DI Boost: Application of a High Performance Gasoline Direct Injection Concept," SAE 2007-01-1410. Available at http://www.sae.org/technical/papers/2007-01-1410 (last accessed Nov. 9, 2008).
[107] Yves Boccadoro, Loïc Kermanac'h, Laurent Siauve, and Jean-Michel Vincent, Renault Powertrain Division, "The New Renault TCE 1.2L Turbocharged Gasoline Engine," 28th Vienna Motor Symposium, April 2007.
[108] Tobias Heiter, Matthias Philipp, Robert Bosch, "Gasoline Direct Injection: Is There a Simplified, Cost-Optimal System Approach for an Attractive Future of Gasoline Engines?" AVL Engine & Environment Conference, September 2005.
[109] U.S. EPA and NHTSA, "Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards – Joint Technical Support Document," 2010. Last viewed on June 3, 2010 at http://www3.epa.gov/otaq/climate/regulations/420r10901.pdf.
[110] "All-new-Ford-engineered, Ford-tested, Ford-built diesel maximizes 2011 Super Duty productivity," Ford press release, August 3, 2010. Available at: http://www.media.ford.com (last accessed June 27, 2011).
[111] Stanton, Donald. "Enabling High Efficiency Clean Combustion." 2009 Semi-Mega Merit Review of the Department of Energy. May 21, 2009. Last accessed on August 25, 2010 at http://www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2009/advanced_combustion/ace_40_stanton.pdf.
[112] Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy; National Research Council, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles," 2011. Available at http://www.nap.edu/catalog.php?record_id=12924 (last accessed Jun 27, 2012).
[113] SAE World Congress, "Focus B-pillar 'tailor rolled' to 8 different thicknesses," Feb. 24, 2010. Available at http://www.sae.org/mags/AEI/7695 (last accessed Jun. 10, 2012).
[114] http://www.techtimes.com/articles/87961/20150925/ford-s-2017-f-250-super-duty-with-an-aluminum-body-is-the-toughest-smartest-and-most-capable-super-duty-ever.htm, September 25, 2015.
[115] https://www.ford.com/trucks/superduty/2017/.
[116] "2008/9 Blueprint for Sustainability," Ford Motor Company. Available at: http:// www.ford.com/go/sustainability (last accessed February 8, 2010).
[117] "2015 North American Light Vehicle Aluminum Content Study – Executive Summary," June 2014, http://www.drivealuminum.org/research-resources/PDF/Research/2014/2014-ducker-report (last accessed February 26, 2015).

[118] http://www.foxnews.com/leisure/2014/09/30/ford-confirms-increased-aluminum-use-on-next-gen-super-duty-pickups/.
[119] See EPA's heavy-duty engine certification database at http://www3.epa.gov/otaq/certdata.htm#largeng.
[120] See Phase 1 Federal Register at 76 FR 57231.
[121] H. Zhang, J, Sanchez, M, Spears, "Alternative Heavy-duty Engine Test Procedure for Full Vehicle Certification," SAE *Int. J. Commer. Veh.* 8(2): 2015, doi:10.4271/2015-01-2768.
[122] EPA Docket Memo, *Fleet Average Fuel Maps Projected for HD Phase 2 Vehicles*, July 2016.
[123] Cummins, 'Cummins visit on Phase 2 Engine standard," Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles - Phase 2 - Docket EPA-HQ-OAR-2014-0827.
[124] NACFE. Confidence Report: Programmable Engine Parameters. February 2015. Page 23.
[125] Ostrander, Robert, et.al. (Meritor). Understanding the Effects of Engine Downspeeding on Drivetrain Components. 2014. Page 2.
[126] NACFE. Confidence Report for Idle Reduction Technologies.
[127] Southwest Research Institute. Aerodynamic Test Report. July 2016. Docket EPA-HQ-OAR-2014-0827.
[128] "Aerodynamic data from EPA's wind tunnel tests performed at Auto Research Center," Supplemental Aerodynamic Data from EPA Testing. Available in the docket to this rulemaking: EPA–HQ–OAR–2014– 0827–1624.
[129] Delgado, Oscar. N. Lutsey. Advanced Tractor-Trailer Efficiency Technology Potential in the 2020-2030 Timeframe. April 2015. Docket EPA-HQ-OAR-2014-0827.
[130] Delgado, Oscar. N. Lutsey. Advanced Tractor-Trailer Efficiency Technology Potential in the 2020-2030 Timeframe. April 2015. Docket EPA-HQ-OAR-2014-0827.
[131] U.S. EPA. Memo to Docket. Coefficient of Rolling Resistance and Coefficient of Drag Certification Data for Tractors. See Docket EPA-HQ-OAR-2014-0827.
[132] Delgado, Oscar. N. Lutsey. Advanced Tractor-Trailer Efficiency Technology Potential in the 2020-2030 Timeframe. April 2015. Docket EPA-HQ-OAR-2014-0827.
[133] North American Council for Freight Efficiency. Confidence Report: Electronically Controlled Transmissions. December 2014.
[134] Oak Ridge National Laboratory. "Powertrain Test Procedure Development for EPA GHG Certification of Medium- and Heavy-Duty Engines and Vehicles." July 2016. Docket # EPA-HQ-OAR-2014-0827.
[135] Stoltz, T and Dorobantu, M. Transmission Potential to Contribute to CO_2 Reduction: 2020 and Beyond Line Haul Perspective. ACEEE/ICCT Workshop on Emerging Technologies for Heavy-Duty Fuel Efficiency. July 2014.
[136] U.S. EPA. Memorandum to the Docket. "Effectiveness of Technology to Increase Transmission Efficiency." July 2016. EPA-HQ-OAR-2014-0827.
[137] Ibid.
[138] *See* the 2010 NAS Report, Note 1, page 67.
[139] U.S. EPA. Memorandum to the Docket. "Effectiveness of Technology to Increase Axle Efficiency." July 2016. EPA Docket # EPA-HQ-OAR-2014-0827.
[140] Delgado, Oscar. N. Lutsey. "Advanced Tractor-Trailer Efficiency Technology Potential in the 2020-2030 Timeframe." April 2015. EPA Docket EPA-HQ-OAR-2014.0827.
[141] U.S. Department of Energy. *Transportation Energy Data Book*, Edition 28-2009. Table 5.7.
[142] U.S. EPA. Memo to Docket. Coefficient of Rolling Resistance and Coefficient of Drag Certification Data for Tractors. See Docket EPA-HQ-OAR-2014-0827.
[143] Memo to Docket. Coefficient of Rolling Resistance and Coefficient of Drag Certification Data for Tractors. Docket EPA-HQ-OAR-2014-0827.
[144] North American Council for Freight Efficiency. Confidence Report: Idle- Reduction Solutions. 2014. Page 13.
[145] EPA Docket Memo, *Fleet Average Fuel Maps Projected for HD Phase 2 Vehicles*, July 2016.
[146] Michael Ross, *Validation Testing for Phase 2 Greenhouse Gas Test Procedures and the Greenhouse Gas Emission Model (GEM) for Medium and Heavy-Duty Engines and Powertrains*, Final Report to EPA, Southwest Research Institute, found in docket of this rulemaking, EPA-HQ-OAR-2014-0827, June, 2016.
[147] Joint Technical Support Document: Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards, August 2012, available at http://www3.epa.gov/otaq/climate/documents/420r12901.pdf.
[148] National Renewable Energy Laboratory July 2016, "The Development of Vocational Vehicle Drive Cycles and Segmentation," NREL/TP-5400-65921.
[149] See memorandum dated July 2016 titled, "Summary of Comments on Vocational Vehicle Baselines."

[150] See Cummins-Eaton partnership at http://smartadvantagepowertrain.com/.
[151] See TIAX 2009, Note 2, Table 4-48.
[152] See http://www.truckinginfo.com/channel/equipment/article/story/2014/10/2015-medium-duty-trucks-the-vehicles-and-trends-to-look-for/page/3.aspx (downloaded November 2014).
[153] For example, see XL Hybrids at http://www.xlhybrids.com/content/assets/Uploads/XL-BoxTruck-US-FLY-8.5x11-0519-LR.pdf, and Crosspoint Kinetics at http://crosspointkinetics.com/members/kinetics-hybrid-partners
[154] See spreadsheet file titled, "HD GHG Simple Hybrid Model v7.xlsx".
[155] Green Fleet Magazine, The Latest Developments in EV Battery Technology, November 2013, available at http://www.greenfleetmagazine.com/article/story/2013/12/the-latest-developments-in-ev-battery-technology-grn/page/1.aspx.
[156] See memorandum on axle efficiency improvements, Note 139.
[157] See Argonne National Laboratory 2009 report, page 91.
[158] See memorandum dated May 2016 on Vocational Vehicle Tire Rolling Resistance Certification Data.
[159] See NREL data at http://www.nrel.gov/vehiclesandfuels/fleettest/research_fleet_dna.html.
[160] See spreadsheet file titled, "Vocational-Standards_GEMpostprocess.xlsx
[161] See Cummins maintenance schedule, available at http://www.cumminsbridgeway.com/pdf/parts/Recommended_Maintenance_Schedule.pdf (accessed March 2016).
[162] NTEA, 2015 Work Truck Electrification and Idle Management Study.
[163] See TIAX 2009, Note 2.
[164] Morton, C. and Spargo, C.M., IET Electrical Systems in Transportation, Electrified hydraulic power steering system in hybrid electric heavy trucks, Sept 2014, accessed June 2016 from https://www.researchgate.net/publication/264983979_Electrified_hydraulic_power_steering_system_in_hybrid_electric_heavy_trucks.
[165] TIAX 2009, Note 2 pp. 3-5.
[166] The Minnesota refrigerant leakage data can be found at http://www.pca.state.mn.us/climatechange/mobileair.html#leakdata.
[167] See Phase 1 RIA, Chapter 2.7.
[168] Society of Automotive Engineers, "IMAC Team 1 – Refrigerant Leakage Reduction, Final Report to Sponsors," 2006.
[169] Society of Automotive Engineers Surface Vehicle Standard J2727, issued August 2008, http://www.sae.org.
[170] See Attachment 1 of public comments from CARB, "Aerodynamic Drag Reduction Technologies Testing for Heavy- Duty Vocational Vehicles— Preliminary Results, July 2015, NREL/TP-5400-64610.
[171] National Renewable Energy Laboratory July 2016, "Characterization of PTO and Idle Behavior for Utility Vehicles" NREL/TP-5400-66747.
[172] See http://westcoastcollaborative.org/files/sector-fleets/WCC-LA-BEVBusinessCase2011-08-15.pdf
[173] Silver, Fred, and Brotherton, Tom. (CalHEAT) Research and Market Transformation Roadmap to 2020 for Medium- and Heavy-Duty Trucks. California Energy Commission, June 2013.
[174] Gallo, Jean-Baptiste, and Jasna Tomic (CalHEAT). 2013. Battery Electric Parcel Delivery Truck Testing and Demonstration. California Energy Commission.
[175] See memorandum titled, Vocational Vehicle Tire Rolling Resistance Certification Data.
[176] American Public Transportation Association, "An Analysis of Transit Bus Axle Weight Issues", November 2014.
[177] See spreadsheet file dated July 2016 titled, "FRM_Vocational-Standards_GEMpostprocess.xls.
[178] Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles: Regulatory Impact Analysis, Environmental Protection Agency, Page 3-42. Available at: https://www3.epa.gov/otaq/climate/documents/420r11901.pdf.
[179] "Improving the Aerodynamic Efficiency of Heavy-Duty Vehicles – Wind Tunnel Test Results of Trailer-Based Drag Reduction Technologies," McAuliffe, Brian R., National Research Council Canada, Report #: LTR-AL-2015-0272. Available online: https://www.tc.gc.ca/eng/programs/environment-etv-menu-eng-2980.html.
[180] "Aerodynamic data from EPA's wind tunnel tests performed at Auto Research Center," Supplemental Aerodynamic Data from EPA Testing. Available in the docket to this rulemaking: EPA–HQ–OAR–2014– 0827–1624.
[181] "Aerodynamic data from EPA's wind tunnel tests performed at Auto Research Center," Supplemental Aerodynamic Data from EPA Testing. Available in the docket to this rulemaking: EPA–HQ–OAR–2014– 0827–1624.

[182] "Tires & Truck Fuel Economy: A New Perspective," The Tire Topic Magazine, Special Edition Four, 2008, Bridgestone Firestone, North American Tire, LLC. Available online: http://www.trucktires.com/bridgestone/us_eng/brochures/pdf/08-Tires_and_Truck_Fuel_Economy.pdf.
[183] Truck Trailer Manufacturers Association letter to EPA. October 16, 2014. Docket EPA-HQ-OAR-2014-0827.
[184] "Tire Pressure Systems - Confidence Report." North American Council for Freight Efficiency. 2013. Available online: http://nacfe.org/wp-content/uploads/2014/01/TPS-Detailed-Confidence-Report1.pdf.
[185] "A Day in the Life of a Tire," Pressure Systems International, Presented to EPA on August 20, 2014.
[186] Federal Motor Carriers Safety Administration, "Commercial Vehicle Tire Condition Sensors," conducted by Booz-Allen-Hamilton, Inc. November, 2003.
[187] TMC Technology & Maintenance Council, "TMC Tire Air Pressure Study," May 2002.
[188] FMCSA "Advanced Sensors and Applications: Commercial Motor Vehicle Tire Pressure Monitoring and Maintenance," February 2014.
[189] "Underinflated Commercial Low Rolling Resistance Truck Tires & It's Impact on Fuel Economy," October 2010. Pressure Systems International, Presentation Material shared with EPA on May 21, 2014.
[190] Scarcelli, Jamie. "Fuel Efficiency for Trailers" Presented at ACEEE/ICCT Workshop: Emerging Technologies for Heavy-Duty Vehicle Fuel Efficiency, Wabash National Corporation. July 22, 2014.
[191] "Weight Reduction: A Glance at Clean Freight Strategies," EPA SmartWay. EPA420F09-043. Available at: http://permanent.access.gpo.gov/gpo38937/EPA420F09-043.pdf.
[192] Memo to docket regarding confidential weight reduction information obtained during SBREFA Panel, June 4, 2015.
[193] Randall Scheps, Aluminum Association, "The Aluminum Advantage: Exploring Commercial Vehicles Applications," presented in Ann Arbor, Michigan, June 18, 2009.
[194] ICF International. Investigation of Costs for Strategies to Reduce Greenhouse Gas Emissions for Heavy-Duty On-Road Vehicles. July 2010. See also, TIAX, LLC. "Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles," Final Report to the National Academy of Sciences, November 19, 2009.
[195] Schubert, R., Chan, M., Law, K. (2015). Commercial Medium- and Heavy-Duty (MD/HD) Truck Fuel Efficiency Cost Study. Washington, DC: National Highway Traffic Safety Administration, Tetra Tech Technology Cost Report (2015).
[196] Schubert, R., Chan, M., Law, K. (2015). Commercial Medium- and Heavy-Duty Truck Fuel Efficiency Technology Cost Study. Washington, DC: National Highway Traffic Safety Administration.
[197] A. Rogozhin et al., Int. J. Production Economics 124 (2010) 360–368.
[198] RTI International. Heavy Duty Truck Retail Price Equivalent and Indirect Cost Multipliers. July 2010.
[199] Rogozhin, A., et al., "Using indirect cost multipliers to estimate the total cost of adding new technology in the automobile industry," International Journal of Production Economics (2009), doi:10.1016/j.ijpe.2009.11.031.
[200] Helfand, Gloria, and Todd Sherwood, "Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies," August 2009.
[201] RTI International. Heavy Duty Truck Retail Price Equivalent and Indirect Cost Multipliers. July 2010.
[202] See "Learning Curves in Manufacturing," L. Argote and D. Epple, Science, Volume 247; "Toward Cost Buy down Via Learning-by-Doing for Environmental Energy Technologies, R. Williams, Princeton University, Workshop on Learning-by-Doing in Energy Technologies, June 2003; "Industry Learning Environmental and the Heterogeneity of Firm Performance, N. Balasubramanian and M. Lieberman, UCLA Anderson School of Management, December 2006, Discussion Papers, Center for Economic Studies, Washington DC.
[203] See "Learning Curves in Manufacturing," L. Argote and D. Epple, Science, Volume 247; "Toward Cost Buy down Via Learning-by-Doing for Environmental Energy Technologies, R. Williams, Princeton University, Workshop on Learning-by-Doing in Energy Technologies, June 2003; "Industry Learning Environments and the Heterogeneity of Firm Performance, N. Balasubramanian and M. Lieberman, UCLA Anderson School of Management, December 2006, Discussion Papers, Center for Economic Studies, Washington DC.
[204] U.S. Energy Information Administration, Annual Energy Outlook 2014, Early Release; Report Number DOE/EIA-0383ER (2014), December 16, 2013.
[205] Bureau of Economic Analysis, Table 1.1.9 Implicit Price Deflators for Gross Domestic Product; as revised on March 27, 2014.
[206] Reducing Heavy-Duty Long Haul Combination Truck Fuel Consumption and CO_2 Emissions; prepared by Northeast States Center for a Clean Air Future (NESCCAF), International Council on Clean Transportation (ICCT), Southwest Research Institute, TIAX, LLC; Final Report October 2009.
[207] Comments to the docket from Allison Transmission, at I.D.2.a, page 6.
[208] Comments to the docket from Allison Transmission, at I.D.2.a, page 6.

[209] Ryder website at http://www.ryderfleetproducts.com/tpms-accessories-c-11434; a PDF version of the site has been placed in the docket.
[210] Ben Sharpe (ICCT) and Mike Roeth (North American Council for Freight Efficiency), "Costs and Adoption Rates of Fuel-Saving Technologies for Trailer in the North American On-Road Freight Sector," Feb 2014.

Chapter 3: Test Procedures

Test procedures are a crucial aspect of the heavy-duty vehicle GHG and fuel consumption program. This rulemaking establishes several new test procedures to be used as part of compliance process for both engine and vehicle compliance. Specifically, these test procedures are used to generate inputs to GEM. This chapter will describe the development process for the test procedures, including the assessment of engines, aerodynamics, rolling resistance, chassis dynamometer testing, powertrain testing, and duty cycles. The final subsection of this chapter (3.10) describes the chassis test procedure used to verify compliance with the standards for heavy duty pickups and vans.

This section focuses on the actual measurements procedures and generally does not address how manufacturers will use this data to certify their engines and vehicles. For example, Chapter 3.2 below discusses how to measure aerodynamic drag, but does not detail how manufacturers will use the data to develop GEM aerodynamic inputs for certification.

3.1 Heavy-Duty Engine Test Procedure

The agencies are controlling heavy-duty engine fuel consumption and greenhouse gas emissions through the use of engine certification. The program will mirror existing engine regulations for the control of both GHG and non-GHG pollutants in many aspects. The following sections provide an overview of the test procedures.

3.1.1 Existing Regulation Reference

Heavy-duty engines currently are certified for GHG and non-GHG pollutants using test procedures developed by EPA. The Heavy-Duty Federal Test Procedure (FTP) is a transient test consisting of second-by-second sequences of engine speed and torque pairs with values given in normalized percent of maximum form. The cycle was computer generated from a dataset of 88 heavy-duty trucks in urban operation in New York and Los Angeles. These procedures are well-defined, mirror in-use operating parameters, and thus we believe appropriate also for the assessment of GHG emissions from heavy duty engines. Further, EPA is concerned that we maintain a regulatory relationship between the non-GHG emissions and GHG emissions, especially for control of CO_2 and NO_X. Therefore, the agencies will continue using the same criteria pollutant test procedures for both the CO_2 and fuel consumption standards.

For 2007 and later Heavy-Duty engines, 40 CFR parts 86 – "Control of Emissions from New and In-Use Highway Vehicles and Engines" and 1065 – "Engine Testing Procedures" detail the certification process. 40 CFR 86.007-11 defines the standard settings of Oxides of Nitrogen, Non-Methane Hydrocarbons, Carbon Monoxide, and Particulate Matter. The duty cycles are defined in 40 CFR part 86. The Federal Test Procedure engine test cycle is defined in 40 CFR part 86 Appendix I. The Supplemental Emissions Test engine cycle is defined in 40 CFR 86.1360(b). All emission measurements and calculations are defined in 40 CFR part 1065, with exceptions as noted in 40 CFR 86.007-11. The data requirements are defined in 40 CFR 86.001-23 and 40 CFR 1065.695.

The measurement method for CO_2 is described in 40 CFR 1065.250. For measurement of CH_4 refer to 40 CFR 1065.260. For measurement of N_2O refer to 40 CFR 1065.275. We recommend that you use an analyzer that meets performance specifications shown in Table 1 of 40 CFR 1065.205. Note that your system must meet the linearity verification of 40 CFR 1065.307. To calculate the brake specific mass emissions for CO_2, CH_4 and N_2O refer to 40 CFR 1065.650.

3.1.2 Engine Dynamometer Test Procedure Modifications

3.1.2.1 Fuel Consumption Calculation

EPA and NHTSA will calculate fuel consumption, as defined as gallons per brake horsepower-hour, from the CO_2 measurement, just as in the Phase 1 rule. The agencies are continuing to use 8,887 grams of CO_2 per gallon of gasoline and 10,180 g CO_2 per gallon of diesel fuel.

3.1.2.2 Regeneration Impact on Fuel Consumption and CO_2 Emissions

The current engine test procedures also require the development of regeneration emission rate and frequency factors to account for the emission changes during a regeneration event.[1] In Phase 1, the agencies adopted provisions to exclude CO_2 emissions and fuel consumption due to regeneration. However, for Phase 2, we will include CO_2 emissions and fuel consumption due to regeneration over the FTP and RMC cycles as determined using the infrequently regenerating aftertreatment devices (IRAF) provisions in 40 CFR 1065.680. However, we are not finalizing the inclusion of fuel consumption due to regeneration in the creation of the steady-state and cycle average fuel maps used in GEM for vehicle compliance. Our assessment of the current non-GHG regulatory program indicates that engine manufacturers have significantly reduced the frequency of regeneration events. In addition, market forces already exist which create incentives to reduce fuel consumption during regeneration.

3.1.2.3 Fuel Heating Value Correction

In the Phase 1 rule, the agencies collected baseline CO_2 performance of diesel engines from testing which used fuels with similar properties. The agencies will continue using a fuel-specific correction factor for the fuel's energy content. This maintains consistency between test labs, as well as prevents potential fuel changes that could occur in the future from changing the effective stringency of the Phase 2 standards. The agencies found the average energy content of the diesel fuel used at EPA's National Vehicle Fuel and Emissions Laboratory was 21,200 BTU per pound of carbon. This value was determined by dividing the Net Heating Value (BTU per pound) by the carbon weight fraction of the fuel used in testing. We will continue using the Phase 1 corrections for diesel fuel, gasoline, natural gas, and liquid petroleum gas in 40 CFR 1036.530. We will also expand the table by adding dimethyl ether.

In addition to the fuel heating value correction, we are finalizing the addition of reference carbon mass fraction values for these fuels to the Table 1 of 40 CFR 1036.530. These reference values are used in the powertrain calculations 40 CFR 1037.550, steady-state engine fuel mapping and fuel consumption at idle in 40 CFR 1036.535, and cycle average engine fuel mapping in 40 CFR 1036.540 to account for the difference in carbon mass fraction between the test fuel and the reference fuel prior to correcting for the test fuel's mass-specific net energy content.

The agencies are not finalizing fuel corrections for alcohols because the fuel chemistry is homogeneous.

3.1.2.4 Urea Derived CO_2 Correction

The agencies will allow manufacturers to correct compression ignition engine and powertrain CO_2 emission results (for engines utilizing urea SCR for NO_X control) to account for the contribution of urea derived CO_2 emissions to the total engine CO_2 emissions.

Urea derived CO_2 can account for up to 1 percent of the total CO_2 emissions. Urea is produced from gaseous NH_3 and gaseous CO_2 that is captured from the atmosphere, thus CO_2 derived from urea decomposition in diesel SCR emission control systems results in a net emission of zero CO_2 to the environment. In our test procedures for Phase 2, we allow manufacturers to determine CO_2 emissions either by measuring the CO_2 emitted from the engine or to determine it by measuring fuel flow rate during the test. If we do not allow for correction of the urea derived CO_2 emissions, this will result in a positive CO_2 bias for CO_2 emissions determined by measuring the CO_2 emitted from the engine. To perform this correction, we are allowing you to determine the mass rate of urea injected over the duty cycle from the engine's J1939 CAN signal or you may measure urea flow rate independently using good engineering judgment. This value is used as an input to an equation that allows you to determine the mass rate of CO_2 from urea during the duty cycle. This resulting CO_2 mass emission rate value is then used as an input to the steady-state engine fuel map and engine fuel consumption at idle fuel mass flow rate calculation in 40 CFR 1036.535, the cycle average engine fuel map calculation in 40 CFR 1036.540, and the total mass of CO_2 emissions over the duty cycle calculations in 40 CFR 1037.550. Note that this correction is only allowed for CO_2 measured from the engine and not CO_2 derived from fuel flow measurement.

The calculation for determination of the mass rate of CO_2 from urea requires the user to input the urea solution urea percent by mass. This calculation uses prescribed molecular weights for CO_2 and urea as given in 40 CFR 1065.1005 of 44.0095 and 60.05526 respectively. A 1:1 molar ratio of urea reactant to CO_2 product is assumed.

To facilitate the ability of the agencies to make this correction, we are requiring that the urea mass flow rate be broadcasted on the non-proprietary J1939 PGN (Parameter Group Number) 61475 (and 61478 if applicable).

3.1.2.5 Multiple Fuel Maps

Engine manufacturers are being required to certify fuel maps to enable vehicle manufacturers to run GEM for each vehicle configuration. However, modern heavy-duty engines often have multiple fuel maps, commonly meant to improve performance or fuel efficiency under certain operating conditions. CO_2 emissions can also be different depending on which map is tested, so it is important to specify a procedure to properly deal with engines with multiple fuel maps. Consistent with criteria-pollutant emissions certification, engine manufacturers will be required to address this during certification, either by declaring worst case maps that cover more than one in-use map, or by submitting multiple fuel maps. The agencies may require the manufacturer to include other fuel map information, such as when the conditions under which a given fuel map is used (*i.e.* transmission gear, vehicle speed, etc.).

3.1.2.6 Measuring GEM Engine Inputs

To recognize the contribution of the engine in GEM, the engine fuel map, full load torque curve and motoring torque curve have to be input into GEM. To insure the robustness of each of those inputs, a standard procedure has to be followed. Both the full load and motoring torque curve procedures are already defined in 40 CFR part 1065 subpart F for engine testing. However, the fuel mapping procedures we are finalizing are new. The agencies have compared the new procedures to other accepted engine mapping procedures with a number of engines at various labs including EPA's NVFEL, Southwest Research Institute, and Environment Canada's laboratory. The procedure was selected because it proved to be accurate and repeatable, while limiting the test burden to create the fuel map. This provision is consistent with NAS's recommendation (3.8).

The agencies are requiring that engine manufacturers must certify fuel maps as part of their certification to the engine standards, and that they provide those maps to vehicle manufacturers. These maps consist of steady-state and cycle average fuel maps. The one exception to this requirement would be for cases in which the engine manufacturer certifies based on powertrain testing, as described in Chapter 3.6. In such cases, engine manufacturers would not be required to also certify the otherwise applicable fuel maps. We are not allowing vehicle manufacturers to develop their own fuel maps for engines they do not manufacture.

In addition to the steady-state engine fuel map procedure for cruise cycles the agencies are also requiring use of the cycle-average engine map test procedure for the transient duty-cycle as defined in 40 CFR 1036.540. The cycle-average approach can optionally be used in place of the steady-state fuel maps by performing cycle-average testing over the cruise cycles. The NPRM to this rule, along with the two journal publications, one from the US EPA and one authored by an industry group, discussed in length the benefits of this test procedure.[2,3] The benefits ranged from capturing transient fueling to protecting intellectual property. We have tested four different engines with two different engine ratings for each engine since the proposal. The results of these tests confirmed our earlier findings that the cycle average engine test procedure is much more accurate than the steady-state mapping procedure with respect to representing the engine over transient engine operation. The results also showed that the cycle average engine map can be applied to the cruise cycles but required that the agencies update the test points to ensure that overlap doesn't occur. Overlap happens when the lower axle ratio causes the vehicle to operate in the next lowest gear at increased engine speed. The agencies updated the test points in 40 CFR 1037.540 to address the overlap issue. The agencies are finalizing the requirement to use the steady-state engine procedure over the cruise cycles and the cycle average engine map procedure for the transient cycle (optional for cruise).

Along with testing additional engines, the agencies have done significant work to define the mathematical form the cycle average engine map data should take in GEM. The first approach the agencies evaluated was an interpolation and extrapolation scheme.[4] Since then we have looked at many different least square fits of the data using different dependent (fuel mass and BSFC) and independent (average engine speed, average engine torque, average engine speed divided by average vehicle speed (N/V) and positive cycle work) variables. The results of this work showed that the cycle average map is most accurately described with fuel mass as the dependent variable and N/V and positive work as the independent variables. The form of the equation is fuel mass ~ 1 + N/V + W.

3.1.3 Engine Family Definition and Test Engine Selection

3.1.3.1 Criteria for Engine Families

The current regulations outline the criteria for grouping engine models into engine families sharing similar emission characteristics. A few of these defining criteria include bore-center dimensions, cylinder block configuration, valve configuration, and combustion cycle; a comprehensive list can be found in 40 CFR 86.096-24(a)(2). While this set of criteria was developed with criteria pollutant emissions in mind, similar effects on CO_2 emissions can be expected. For this reason, this methodology should continue to be followed when considering CO_2 emissions, just as it was in the Phase 1 rules.

3.1.3.2 Emissions Test Engine

Manufacturers must select at least one engine per engine family for emission testing. The methodology for selecting the test engine(s) should be consistent with 40 CFR 86.096-24(b)(2) (for heavy-duty Otto cycle engines) and 40 CFR 86.096-24(b)(3) (for heavy-duty diesel engines). An inherent characteristic of these methodologies is selecting the engine with the highest fuel feed per stroke (primarily at the speed of maximum rated torque and secondarily at rated speed) as the test engine, as this is expected to produce the worst-case criteria pollutant emissions. To be consistent, it is recommended that the same methodology continue to be used for selecting test engines.

3.2 Aerodynamic Assessment

For the Phase 1 rule, the agencies promulgated requirements whereby the coefficient of drag assessment was a product of test data and modeling using good engineering judgment. A group of aerodynamic bins for tractors corresponding to certain known aerodynamic design features (e.g., Classic, Conventional, SmartWay, etc.) were established based on the results of an agency sponsored aerodynamic assessment test program. The rules require tractor manufacturers to take the aerodynamic test result from a tractor and determine the tractor's appropriate bin. To ensure the consistency of the drag assessment results, certain aspects of the truck were defined, including the trailer, location of payload, and tractor-trailer gap. In addition, the agencies specified test procedures for aerodynamic assessment: coastdown testing (also used as the reference method), wind tunnel testing (reduced and full scale), and computational fluid dynamics (CFD). Constant speed testing was also permitted as an alternative test procedure, but the agencies did not develop a specific procedure.

For the Phase 2 rule, we are retaining many of the aspects of the aerodynamic assessment protocols from Phase 1 with the following revisions and additions: enhancement of the analysis methodology for the coastdown test procedure, which we will keep as the reference method for the tractor program; inclusion of trailers in the aerodynamic assessment test protocols; modifications to the standard trailer used for tractor aerodynamic assessment and establishing a reference tractor for trailer aerodynamic assessment; and use of wind-average drag area (C_dA_{wa}) as the required aerodynamic Greenhouse Gas Emissions Model (GEM) input for tractors. Another modification to the aerodynamic assessment for Phase 2 is the use of drag area (coefficient of drag multiplied by the frontal area, or C_dA), rather than the coefficient of drag (C_d), for tractor aerodynamic bin standards. Although this modification will not alter the aerodynamic assessment protocols, it is important to note this since all Phase 2 aerodynamic assessment results will be presented in this format, rather than the C_d format used for Phase 1. The Phase 2 trailer program will also be in the wind-averaged drag area domain, instead of drag coefficient. However, the trailer program will be based on a drag area reduction from a baseline configuration.

3.2.1 Aerodynamics Baselines for Tractors

To establish GHG standards, the aerodynamic assessment methods and baselines needed to be evaluated. A combination of coastdown, wind tunnel, CFD, and constant speed tests were used to determine the wind-averaged drag performance of several sleeper cab and day cab tractors. The coastdown was used as the reference method, due to its familiarity within the industry and the ability to test a real full-scale truck instead of relying on scale models or simulations, which would require simplifications to the vehicle geometry and other factors.

The agencies used a multistep process for determining baseline performance. First, we evaluated which Phase 1 aerodynamic bin our test tractors were in by doing a Phase 1-style analysis from coastdown tests in the Phase 1 trailer configuration. Then, we tested the same tractors with trailer skirts (the Phase 2 trailer configuration) and analyzed the data using the Phase 2 analysis procedure that is being finalized in this rulemaking. Finally, we translated this Phase 2 coastdown result to a wind-averaged drag area value.

For this final step, the agencies conducted or obtained test and simulation data using a variety of alternate aerodynamic methods: scale wind tunnels at Auto Research Center (ARC) and National Research Council Canada (NRC), CFD using Navier-Stokes and Lattice-Boltzmann codes, and constant speed on-road tests at Southwest Research Institute (SwRI) conducted with the same vehicles used in the coastdown tests.[5,6,7,8] Given that tunnels, simulations, and road load tests are all approximations of aerodynamic performance, the agencies made an effort to have multiple methods for a given tractor to the extent possible. The aerodynamic drag as a function of yaw angle determined from these alternate methods was used to adjust the coastdown results to a wind-averaged drag area value.

This analysis provided a basis to derive aerodynamic bins for Phase 2. By evaluating the aerodynamic performance of tractors in both the Phase 1 and Phase 2 domains, we were able to create numerical values for the Phase 2 aerodynamic bin boundaries by aligning the relative aerodynamic performance from both test procedures.

3.2.1.1 Coastdown Testing

During development and since the beginning of Phase 1 implementation, we received persuasive suggestions for improving the coastdown test procedure analysis methodology to reduce data post processing and improve data resolution. Accordingly, for Phase 2 aerodynamic assessment methods, we modified the coastdown test procedure analysis methodology, made changes to the specifications and protocols for conducting and analyzing the results of the constant speed test procedure, and updated the conditions for performing CFD analysis.

Based on feedback from the heavy-duty vehicle manufacturing industry and other entities, the agencies finalized a Modified SAE J1263 coastdown procedure in the Phase 1 rulemaking. During and since the finalization of those 1 regulations, stakeholders suggested increasing accuracy and precision by analyzing portions of the data generated during coastdown testing rather than the full data set. One OEM suggested the use of the high speed portion of the coastdown test procedure speed range to solely or predominantly isolate the aerodynamic forces. Another OEM suggested using the high speed and low speed portions of the coastdown test procedure speed range in an iterative fashion to isolate the mechanical/frictional losses and rolling resistance predominantly present at lower speeds and removing these forces from the higher speed forces to capture predominantly aerodynamic forces. Comments to the Phase 2 NPRM indicated a preference to include a tire rolling resistance dependence on speed, which was assumed to be zero in the proposal.

To develop baseline aerodynamic performance and refine the aerodynamic test procedures, the agencies (via contractors ICF Corporation and SwRI) coasted down combination tractors on Farm-to-Market Highway 70, a rural highway between Bishop, Texas and Chapman Ranch, Texas. Testing was performed by SwRI. Filtered USGS elevation data were obtained for the same stretch of roadway.[9] The grade information was incorporated into our analysis. The testing was conducted overnight, usually between 12 am and 4 am, to minimize traffic and wind. To get a comprehensive data set to conduct various analysis techniques, the vehicles were coasted down from 70 mph to 0 mph, where 14 to 20 runs were conducted for each test. Some tests were conducted with only high-speed and low-speed coastdowns, where up to 32 runs were conducted. An ultrasonic anemometer was mounted 0.85 m above the leading edge of the trailer at the midpoint of the trailer width. This anemometer recorded air speed and direction onboard the vehicle at 10 Hz. A weather station, which measured wind speed, wind direction, temperature, and air pressure at 1 Hz, was placed alongside the road at the approximate midpoint of the stretch of road being used for the tests. Details of the test setup and vehicle information can be found in the on-road testing summary report from SwRI. The tractors that were used in this analysis are represented in this chapter using the following numbers: Sleeper Cab tractors 1 through 5 and Day Cab tractors 20, 30, and 31.

The average and maximum wind speeds were calculated for each run to determine validity of the run with respect the wind restrictions. Some tests were performed outside of these specifications to assess the impact of wind variation. Table 3-1 below shows the ambient conditions desired for each coastdown run within a coastdown test, which resembles the SAE J1263 recommended practice.

Table 3-1 Desired Ambient Conditions for Coastdown Tests

PARAMETER	LIMIT
Maximum average wind speed	10 mph
Maximum wind speed	12.3 mph
Maximum average cross wind component	5 mph

3.2.1.1.1 Phase 1 analysis

To first understand how our test vehicles performed, we conducted coastdown tests using the Phase 1 trailer configuration and Phase 1 test and analysis procedure. Force was calculated for every 10-Hz measurement. Grade force was calculated at every 10-Hz measurement and incorporated into the force value. The data was not filtered. The regression was applied between force and vehicle speed for the entire test (not run by run). The results are plotted against the Phase 1 aerodynamic bin structure below. An additional tractor not included in the SwRI report, Sleeper Cab 11, was included for reference. It was an identical model ("sister tractor") to Sleeper Cab 1 and produced a similar drag area result. The Phase 1 C_dA bins are superimposed on the plots to show the aerodynamic levels of the various tractors. Every tractor tested in this program (both sleeper cabs and day cabs) were in Bin III or Bin IV.

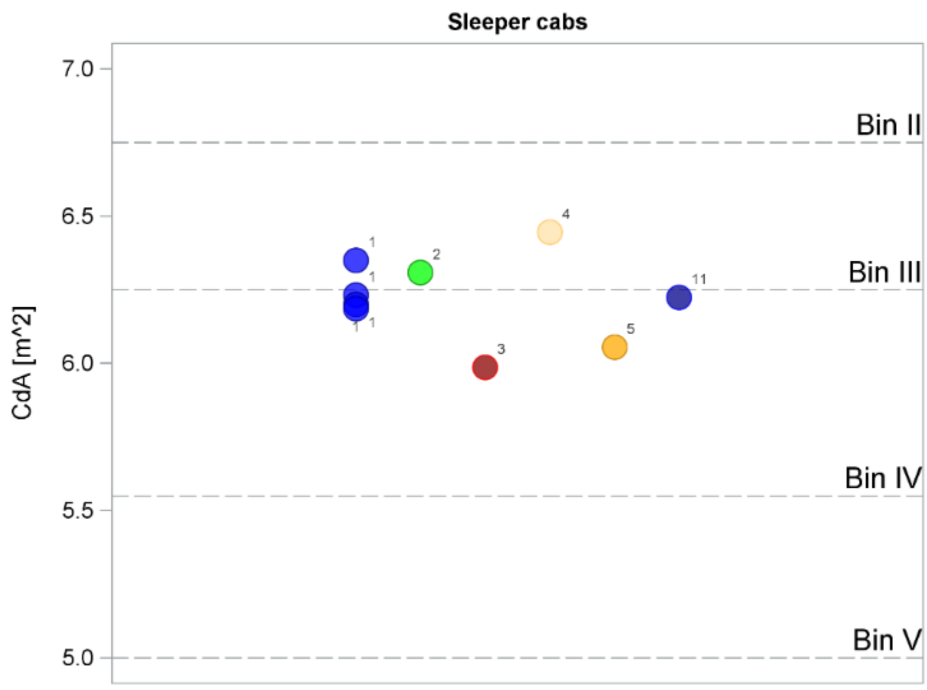


Figure 3-1 Drag Area Values by Truck Number from Sleeper Cab Tractors Using Phase 1 Analysis; With Phase 1 Bin Boundaries

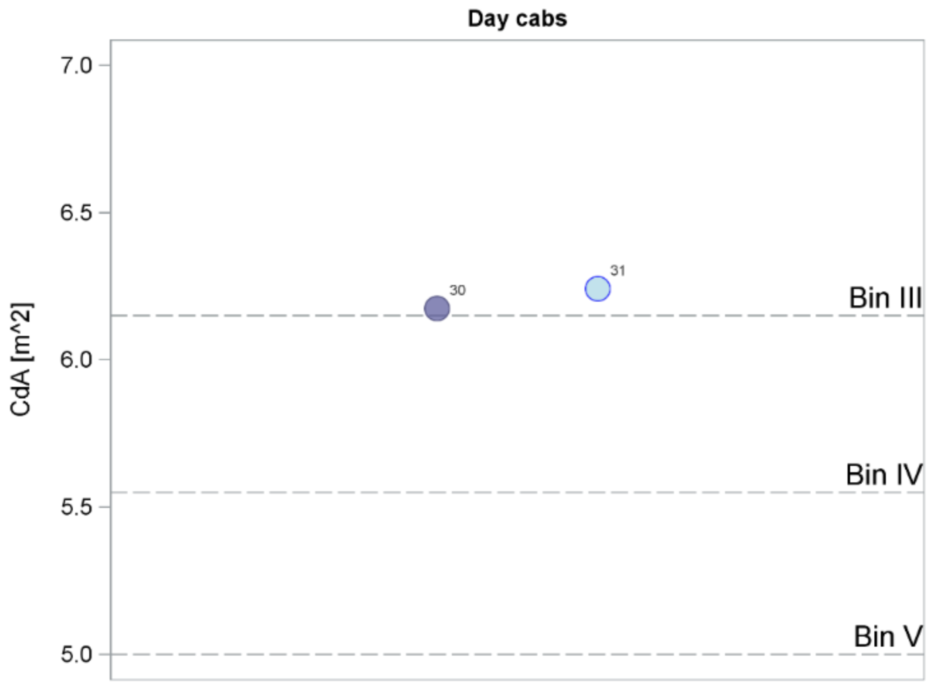


Figure 3-2 Drag Area Values by Truck Number from Day Cab Tractors Using Phase 1 Analysis; With Phase 1 Bin Boundaries.

3.2.1.1.2 Phase 2 Analysis

3.2.1.1.2.1 Data filtering

In the analysis for the NPRM, air speed and vehicle speed data, collected at 10 Hz, were filtered using a 1-second weighted centered moving average. Given that the coastdown analysis procedure already involves averaging over certain vehicle speed intervals, instead of the moving average filter, a different filtering scheme was used in this analysis only to remove outliers. Based on feedback from the heavy-duty vehicle manufacturers, a moving median filter was used to remove the outliers, which were defined as points differing by more than three standard deviations from the three-second centered moving median. The standard deviation was calculated as the 1.4826 times the median absolute deviation of the three-second window. The outlier was then replaced by the median of the three-second window. This technique is equivalent to the Hampel filter in Matlab.

This filter was not applied to the weather station measurements (wind speed and wind direction), as these measurements were collected only at 1 Hz. However, we finalizing that the wind speed and wind direction must be collected at 10 Hz to be consistent with the air speed and vehicle speed measurement frequencies. We are finalizing that the Hampel filter described above must be applied to vehicle speed, air speed, yaw angle, wind speed, and wind direction measurements.

3.2.1.1.2.2 Air Speed Measurements

The position of the onboard anemometer is such that the air speed readings need to be corrected. Located above the trailer, the anemometer's air velocity measurements will typically be greater than the free stream air speed. The roadside weather station was used to correct the onboard air speed measurements, using the trigonometric calculations below. Yaw angles counter-clockwise to the direction of travel were considered as positive. Yaw angles clockwise to the direction of travel were considered as negative.

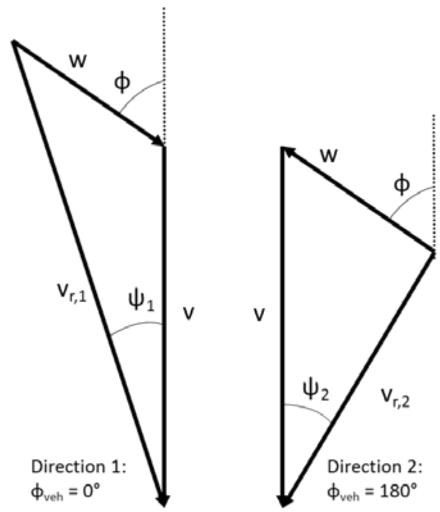


Figure 3-3 Diagram Of Vehicle Speed and Air Speed Vectors during Coastdowns in Opposite Directions for a Given Vehicle Speed, Wind Speed and Wind Direction

Basic trigonometric relationships were used to calculate the theoretical air speed $v_{r,th}$ from the vehicle speed and weather station measurements, as described in the equation below. The vehicle travel direction affects the resultant vector, and is included as a ϕ_{veh} value of either 0° or 180°.

$$v_{r,th} = \sqrt{w^2 + v^2 + 2v \cdot w \cdot \cos(\phi + \phi_{veh})}$$

Equation 3-1

The resulting theoretical air speed values were regressed against the measured air speed values for every high-speed and for every low-speed segment for every run. Unlike the proposal, this analysis did not average these values for 5-mph increments. The resulting linear relationship was used to correct the air speed measurements in the real-time data.

3.2.1.1.2.3 Yaw Angle Measurements

The agencies also received comments on the inclusion of yaw angle in the coastdown procedure. The proposal assumed that the coastdown occurs at zero yaw, however this condition can only occur in perfect headwind, perfect tailwind, or no wind; which are all extremely unlikely. Though it is difficult to obtain the yaw curve (drag polar) from coastdown tests, we can characterize a certain coastdown test at an average yaw angle. First, the yaw angle for every run was calculated assigned to each C_dA value. The air direction was measured onboard with an anemometer that is accurate to ±2°, according the product specifications.[10] Thus, the average yaw angle for each run was calculated using trigonometric relations from the average parameters from the high-speed segment. See Figure 3-3 above for variable references.

$$\overline{\psi_{\text{run}}} = \arctan\left[\frac{w \cdot \sin(\phi + \phi_{\text{veh}})}{v + w \cdot \cos(\phi + \phi_{\text{veh}})}\right]$$

Equation 3-2

The effective yaw angle for the coastdown test, ψ_{eff}, was then calculated by averaging the yaw angles from all the runs from that test. Because the opposite direction runs yield positive and negative angles, the absolute value of the yaw angle from every run was used.

$$\psi_{\text{eff}} = \frac{1}{n_{\text{runs}}} \sum \left|\overline{\psi_{\text{run}}}\right|$$

Equation 3-3

3.2.1.1.2.4 Tire rolling Resistance Impacts

The agencies also commissioned a study on tire rolling resistance as a function of speed on the tire models that were being used on the tractors and trailers tested in the coastdown program. The agencies conducted a tire coastdown test using SAE J2452 at Smithers Rapra to measure tire rolling resistance force at various speeds. The load and inflation test points were modified slightly to accommodate operating conditions of tires on an empty tractor-trailer configuration, as listed in Table 3-2.

Table 3-2 Test Points for Tire Rolling Resistance Stepwise Coastdowns

SAE J2452 (light truck)		EPA test	
Load (% of max)	Inflation pressure (% of max)	Load (% of max)	Inflation pressure (% of max)
20	110	20	100
40	50	55	70
40	100	85	120
70	60	85	100
100	100	100	95

The result of each test was a regression equation relating the rolling resistance force to load, inflation pressure, and speed, as described in Eq. 3 of SAE J2452.

$$P^{\alpha} \cdot L^{\beta}(a + b \cdot v + c \cdot v^2)$$

Equation 3-4

This equation was used for each tire to develop the tire rolling resistance characteristics with speed for each vehicle. Since the same tire model was installed on a given axle, the calculation was done one axle at a time, assuming uniform load distribution over all the tires on a given axle.

$$F_{\mathrm{TRR,axle}}(v) = n_{\mathrm{axle}} \cdot P_{\mathrm{axle}}^{\alpha_{\mathrm{axle}}} \cdot \left(\frac{L_{\mathrm{axle}}}{n_{\mathrm{axle}}}\right)^{\beta_{\mathrm{axle}}} \cdot (a_{\mathrm{axle}} + b_{\mathrm{axle}} \cdot v + c_{\mathrm{axle}} \cdot v^2)$$

Equation 3-5

The tire rolling speed characteristic for the full vehicle is the sum of the three axles.

$$F_{\mathrm{TRR,veh}}(v) = F_{\mathrm{TRR,drive}}(v) + F_{\mathrm{TRR,steer}}(v) + F_{\mathrm{TRR,trailer}}(v)$$

Equation 3-6

The change in tire rolling resistance between two speeds, ΔF_{TRR}, can be calculated by calculating the difference in $F_{\mathrm{TRR,veh}}$ values at those two speeds.

3.2.1.1.2.5 Drive Axle Spin Loss Impacts

The proposed coastdown procedure included an assumption for drive axle spin loss as a function of vehicle speed. It included fixed values at an average speeds of 20 mph and 65 mph. However, the agencies obtained additional spin loss data, which indicated that spin losses can vary significantly between axle models. This means that two identical tractors with differing axle models could produce different drag area results even if tested in the same wind conditions. The data we obtained showed a spin loss impact on the calculated drag area of up to 0.15 m^2.

As a result, the agencies used spin loss data specific to the axle model in the vehicle being tested, where the data were available. Data were obtained as power loss as a function of wheel speed and converted to force loss using estimates for wheel size. Consultation with one axle manufacturer indicated that similarly sized axles from a given manufacturer could be assumed to have similar spin losses as a function of speed. We did not have spin loss data for 4x2 configurations, so we estimated the spin loss for these vehicles to be half of a similar axle model in the 6x4 configuration. The axle efficiency test discussed in Chapter 3.8 is the source for such data, the zero-torque subset of which is applicable to the coastdown analysis.

3.2.1.1.2.6 Drag Area Calculation

The agencies proposed an iterative analysis method to determine drag area from a coastdown test. While this analysis can be done for any pair of speed ranges, a low-speed range of 25 to 15 mph and a high-speed range of 70 to 60 mph were proposed. Table 3-3 below describes the analysis methodology in the NPRM step by step. This analysis involves analyzing the coastdown over two separate speed ranges. A low-speed range is used to estimate mechanical losses and subtract them out of a high-speed range to estimate aerodynamic drag. This process is iterated until mechanical and aerodynamic drag forces converge. The force is not calculated at each measurement, but instead the net force over each speed range is calculated by measuring the time taken to decelerate through each speed range. We assumed a linear decrease in speed (i.e. constant deceleration), because the speed ranges are small.

Table 3-3 Drag Area Calculation Steps for High-Low Iteration Analysis in the Phase 2 Proposal

STEP	VARIABLES AND EQUATIONS	*VARIABLE DEFINITIONS*
Step 0: Find the times bracketing the low-speed and high-speed ranges $v_{lo1}<v_i<v_{lo2}$ (low speed) $v_{hi1}<v_i<v_{hi2}$ (high speed)	$t_{lo1}, t_{lo2}, t_{hi1}, t_{hi2}$	*v = vehicle speed* lo1=*15mph*, lo2=*25mph* hi1=*60mph*, hi2=*70mph*
Step 1: Calculate acceleration for each speed range.	$a_{lo} = \frac{v_{lo2} - v_{lo1}}{t_{lo2} - t_{lo1}} = \frac{\Delta v_{lo}}{\Delta t_{lo}}$ $a_{hi} = \frac{v_{hi2} - v_{hi1}}{t_{hi2} - t_{hi1}} = \frac{\Delta v_{lo}}{\Delta t_{lo}}$	*a = vehicle acceleration* *t = time*
Step 2: Calculate average road grade force over each speed range.	$F_{grade,lo} = Mg\left(\frac{\Delta h}{\Delta s}\right)_{lo} = Mg\frac{h_{lo2} - h_{lo1}}{s_{lo2} - s_{lo1}}$ $F_{grade,hi} = Mg\left(\frac{\Delta h}{\Delta s}\right)_{hi} = Mg\frac{h_{hi2} - h_{hi1}}{s_{hi2} - s_{hi1}}$	*M = vehicle mass* *h = elevation (relative)* *s = travel distance* *g = gravitational acceleration = 9.81 m/s²*
Step 3: Inertial and Effective Mass (Add 125 lbm per tire to account for rotational inertia).	$M_{inertial} = 125\frac{lbm}{tire}\cdot n_{tires} = 56.7\frac{kg}{tire}\cdot n_{tires}$ $M_e = M + M_{inertial}$	$M_{inertial}$ *= additional inertia from rotating components* M_e *= effective mass* n_{tires} *= total number of tires in test configuration*
Step 4: Road load force for each speed range, also accounting for rear axle loss estimate (F_{axle}).	$F_{lo} = -M_e a_{lo} + F_{grade,lo} - F_{axle,lo}$ $F_{hi} = -M_e a_{hi} + F_{grade,hi} - F_{axle,hi}$	$F_{axle,lo}$ *= 100 N* $F_{axle,hi}$ *= 200 N*
Step 5: Air density during each high speed section.	$\rho = \frac{1000 \times P}{R(T + 273.15)}$	*ρ = density of air* *P= average ambient pressure during high speed run in kPa* *T = average ambient temperature during high speed run in °C* *R = gas constant for air =287.058 J/(kg-K)*
Step 6: Average relative air speed over each speed range.	$\bar{v}_{r,lo} = \sum_{v_{lo1}}^{v_{lo2}} \frac{v_r}{n_{lo}}$ $\bar{v}_{r,hi} = \sum_{v_{hi1}}^{v_{hi2}} \frac{v_r}{n_{hi}}$	v_r *= relative air speed*
Step 7: Initial conditions (i=0). Start with no aerodynamic forces in the low speed range.	$F_{aero,lo,0} = 0$	

Step 8: Subtract low-speed aerodynamic forces from low speed forces to estimate mechanical forces.	$F_{\text{mech,i}} = F_{\text{lo}} - F_{\text{aero,lo,i}}$	
Step 9: Subtract mechanical forces from high speed forces to estimate aerodynamic forces.	$F_{\text{aero,hi,i}} = F_{\text{hi}} - F_{\text{mech,i}}$	
Step 10: Adjust aerodynamic forces by speed to estimate low-speed aerodynamic forces.	$F_{\text{aero,lo,i+1}} = F_{\text{aero,hi,i+1}} \left(\frac{\bar{v}_{\text{r,lo}}^2}{\bar{v}_{\text{r,hi}}^2} \right)$	
Step 11: Repeat steps 8-10 until both high-speed aerodynamic and low-speed mechanical forces both converge less than 1%.	Repeat steps 8-10 until: $\left\| 1 - \frac{F_{\text{aero,hi,i+1}}}{F_{\text{aero,hi,i}}} \right\| < 0.01$ and $\left\| 1 - \frac{F_{\text{mech,lo,i+1}}}{F_{\text{mech,lo,i}}} \right\| < 0.01$	
Step 12: Calculate drag area.	$C_{\text{d}}A = \frac{2F_{\text{aero,hi,i+1}}}{\rho \bar{v}_{\text{r,hi}}^2}$	

There are some advantages to using this method over the Phase 1 method. Focusing on segmented speed ranges may open up more test locations, as less road or track space would be required to collect a full data set. The middle range of speeds that would be eliminated contains a higher proportion of rolling resistance forces and also sweeps through greater yaw angles, even at modest crosswind conditions, which can increase the aerodynamic drag of certain runs and subsequently increase the variability of a test.

Essentially, the proposed iteration method is attempting to solve two force equations, one at the low speed and one at the high speed, were the drag area and mechanical forces (except spin loss) are the same in the high speed and low speed.

$$F_{\text{hi}} = F_{\text{mech}} + \frac{1}{2}\rho C_{\text{d}} A v_{\text{air,hi}}^2$$
$$F_{\text{lo}} = F_{\text{mech}} + \frac{1}{2}\rho C_{\text{d}} A v_{\text{air,lo}}^2$$

Equation 3-7

This system of equations that the iteration method represents can be simplified into an analytic equation that produces the same result and avoids the iteration process altogether.

$$C_{\mathrm{d}}A = \frac{F_{\mathrm{hi}} - F_{\mathrm{lo}}}{\frac{1}{2} \cdot \rho \cdot (\bar{v}_{\mathrm{r,hi}}^2 - \bar{v}_{\mathrm{r,lo}}^2)}$$

Equation 3-8

The iteration-based and analytical solutions were compared and shown to be identical (within very small rounding errors), as shown in Figure 3-4.

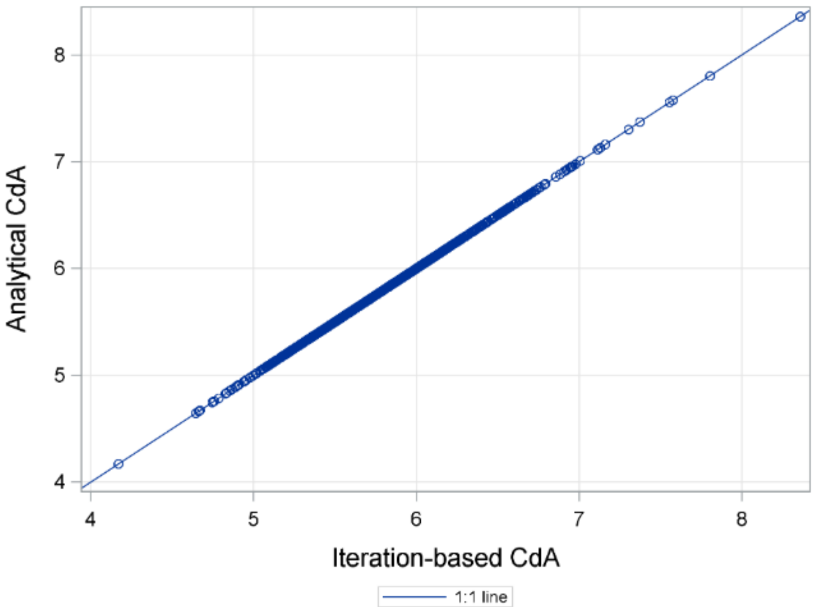


Figure 3-4 Analytical Solutions from All Coastdown Runs are Identical to the Iteration Method.

Similarly, the inclusion of tire rolling resistance and drive axle spin loss as a function of speed could also be incorporated into the analytical equation.

$$C_{\mathrm{d}}A = \frac{F_{\mathrm{hi}} - F_{\mathrm{lo}} - \Delta F_{\mathrm{spin}} - \Delta F_{\mathrm{TRR}}}{\frac{1}{2} \cdot \rho \cdot \left(\bar{v}_{\mathrm{r,hi}}^2 - \bar{v}_{\mathrm{r,lo}}^2\right)}$$

Equation 3-9

In this new equation, F_{hi} and F_{lo} include the drive axle spin loss (i.e. they are not subtracted out), unlike the proposal. The ΔF_{spin} and ΔF_{TRR} values are determined from the average vehicle speeds in the low-speed and high-speed ranges, using the tire rolling resistance and axle spin loss test procedures in the manner described above and in 40 CFR 1037.528.

As mentioned, the agencies proposed a low-speed range of 25-15 mph. With the inclusion of yaw angle in the final rule, the agencies reviewed the appropriateness of this speed range with respect to yaw characterization and the coastdown procedure generally. The agencies partnered with National Research Council Canada (NRC) to investigate coastdown and constant speed testing. The ProStar sleeper cab tractor borrowed by the agencies from Environment Canada and tested by SwRI, was tested by NRC at Transport Canada's Test and Research Centre in Blainville, Quebec. One of NRC's conclusions from their study was to reduce the low-speed range from 25-15 mph to 15-5 mph to reduce the contribution of aerodynamic forces to the road load at low speeds, thus leading to drag area measurements with higher precision.[11]

The agencies analyzed the yaw characterization as a function of low-speed range. Sleeper Cab 3 contained the greatest number of coastdown tests and was used for this purpose. The drag area and yaw angle of every run that was conducted within the wind specifications was calculated and plotted to evaluate the effect of yaw angle on the calculated drag area for the various low-speed ranges.

Figure 3-5 shows that lowering the speed range shows a flatter yaw characterization. Since we expect drag to increase with yaw angle, the lower speed ranges, particularly 15-5 mph, better represent a realistic yaw curve. This aligns with the recommendation from NRC. However, with average wind conditions allowed up to 10 mph, it would be possible to have a tail wind "pushing" the vehicle at the low end of the 15-5 mph range. Testing at this low-speed range without this tail wind effect would require that the tail wind not exceed 3 mph. The agencies considered this constraint to be too restrictive to allow for enough available days to test. As a result, the agencies are finalizing that the low-speed range be 20-10 mph with an added constraint that the component of wind parallel to the direction of travel must not exceed 6 mph. This value was chosen to be fully out of the low-speed coastdown speed range, which requires coasting down to 8 mph for determining the coastdown ending time and ending speed points.

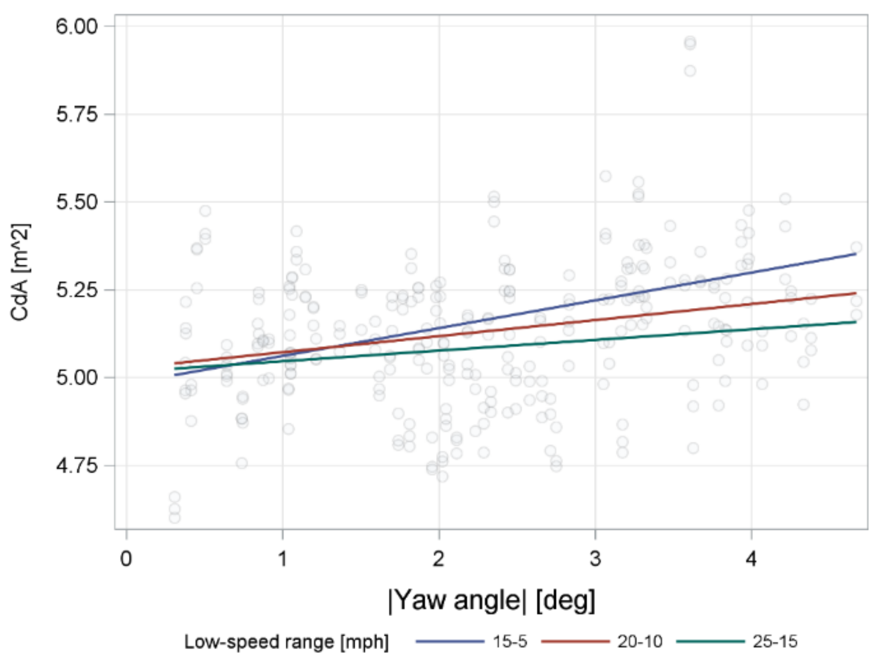


Figure 3-5 Drag Area as a Function of Yaw Angle Calculated for Different Low-Speed Ranges.

Further analysis using the method described above showed an unexpected difference in the C_dA results with respect to run direction. For example, Figure 3-6 shows that the average C_dA for the westbound runs is consistently higher than the eastbound runs despite different yaw conditions.

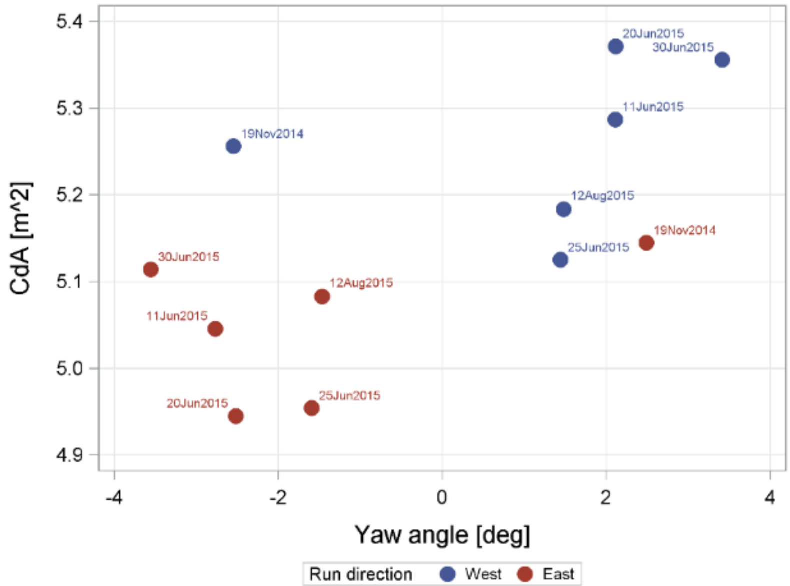


Figure 3-6 Average C_dA by Direction from Sleeper Cab 3 Shows Direction Bias for 5 Different Tests.

The vehicle experiences different air speeds and yaw angles depending on the direction during testing, even if wind conditions remain stable. The equations described so far have used a "matched pair" approach, where a high-speed segment is matched with its corresponding low-speed segment, both of which are in the same direction. This approach assumes that aerodynamic forces are constant in the low-speed range. In reality, these forces will vary given the varying magnitude and orientation of the air speed between the two travel directions in the low-speed range. Conditions associated with the test site may also cause some differences between the directions that may not be related to aerodynamics. To account for these effects, the low-speed air speed and force values were averaged by opposite direction pairs before applying them to the analytical solution for each high-speed segment. The resulting equation is below. For tests conducted with two consecutive high-speed segments and two consecutive low-speed segments in the same direction, the averaging was done for every four low-speed segments.

$$C_dA = \frac{F_{hi} - F_{lo,pair} - \Delta F_{spin} - \Delta F_{TRR}}{\frac{1}{2} \cdot \rho \cdot \left(\bar{v}_{r,hi}^2 - \bar{v}_{r,lo,pair}^2\right)}$$

Equation 3-10

The results from this calculation, shown in Figure 3-7, shows mitigation of the bias, with a more even distribution of results by direction.

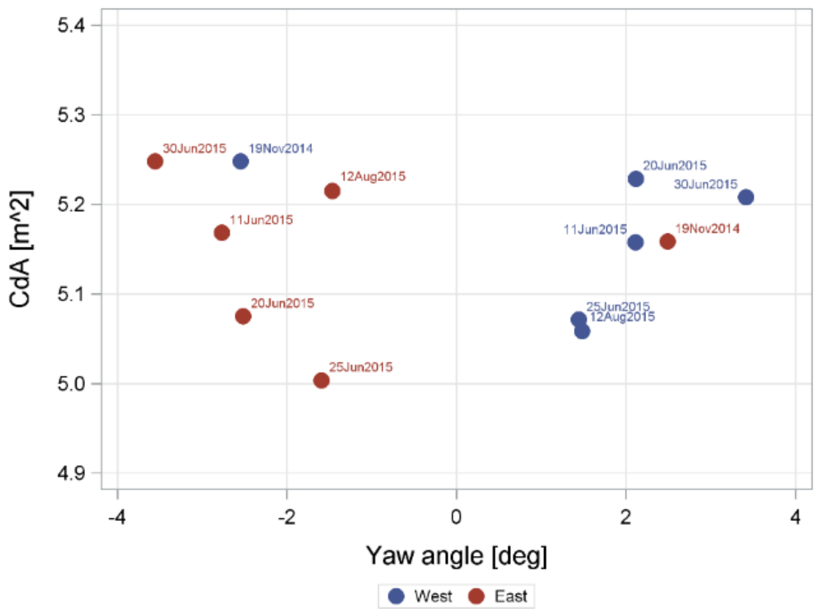


Figure 3-7 Average C_dA, Using Low-Speed Paired Means, by Direction from Sleeper Cab 3 for 5 Different Tests

While the low-speed paired results for individual runs and directions are different from the matched pair results, the overall mean C_dA result is not significantly affected, as shown in Figure 3-8 for the five tests on Sleeper Cab 3. Though the results are similar, the benefit in this method is the reduced scatter in the results from individual runs, which helps to prevent the presence of outliers and include more data when determining results for the reference tractors. This process is discussed in greater detail in Chapter 3.2.2.2.1. The agencies are finalizing the low-speed paired method for calculating C_dA.

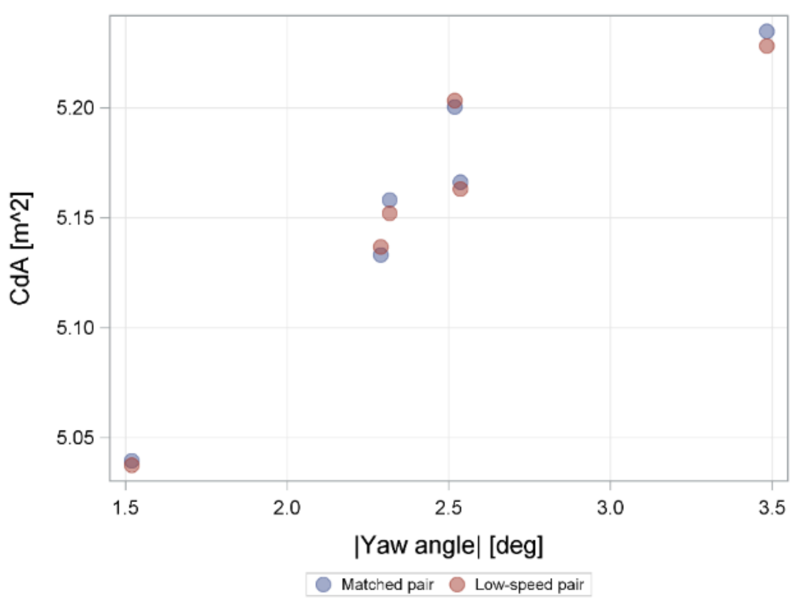


Figure 3-8 C_dA Result vs Effective Yaw Angle (ψ_{eff}) by Calculation Method for Sleeper Cab 3 Tests

The uncertainty of the coastdown result was characterized through the standard error. In the test program, most tests were conducted with 14 to 16 runs. Several other tests were conducted up to 32 runs. As shown in Figure 3-9, on average, the standard error of the tests decreased as the number of valid runs increased, with the standard error trending below 1 percent beyond 20 runs.

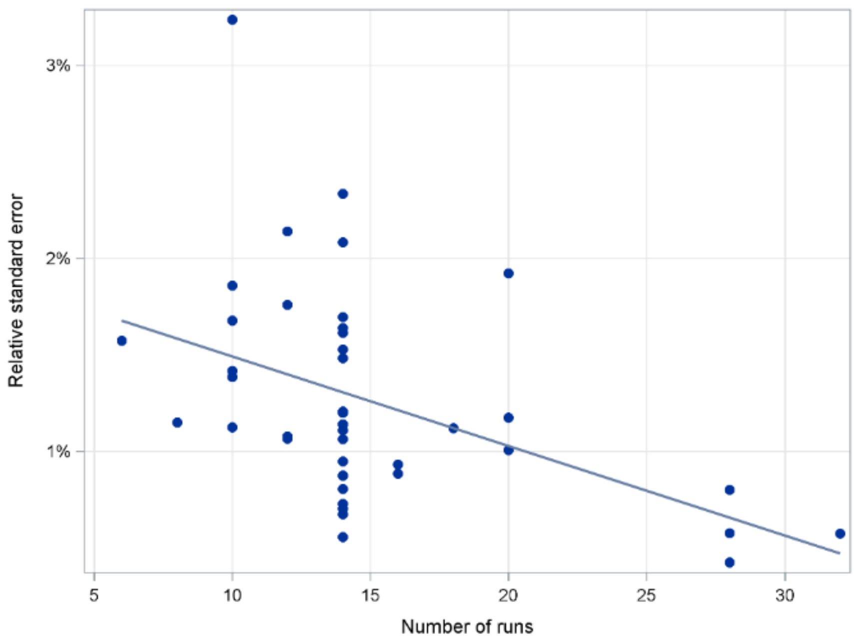


Figure 3-9 Standard Error of Coastdown Test Decreases with Increasing Number of Runs.

After conducting the analysis above, the agencies are finalizing the high-low analysis method using 70-60 mph and 20-10 mph along with requirements to quantify the speed dependence of tire rolling resistance and drive axle spin loss to determine the drag area from the coastdown test. Determining the effective yaw angle of the coastdown test is also being finalized. Additional requirements on the statistical validity of data points, which were not applied for the data set discussed here, are being finalized for reference tractors tested to determine $F_{\text{alt-aero}}$. They are discussed later in Chapter 3.2.2.2.

3.2.1.1.3 Wind-averaged Drag Adjustment

We received comments in Phase 1 regarding the use of the wind-averaged drag since it accounts for aerodynamic performance across a broader spectrum of wind conditions rather than a pure headwind or tailwind. Consequently, the use of wind-averaged drag for aerodynamic assessment may better reflect real-world aerodynamic performance and fuel consumption. We assessed the use of wind-averaged drag for Phase 2 and the results are discussed below in this section.

EPA and NHTSA recognize that wind conditions have a greater impact on real world CO_2 emissions and fuel consumption of heavy-duty tractor-trailers than light-duty vehicles. As stated in the NAS report[12], the wind averaged drag coefficient is about 15 percent higher than the zero degree coefficient of drag (C_d). The large ratio of the side area of a combination tractor and trailer to the frontal area suggests that winds will have a significant impact on drag. One disadvantage of the agencies' approach to aerodynamic assessment in Phase 1 is that the test methods have varying but limited degrees of ability to assess wind conditions. Wind tunnels and CFD are existing tools to determine wind-averaged drag. The coastdown test has limited ability to assess yaw conditions. The constant speed test has the potential to determine wind-average drag, but an industry standard for this does not exist. It is very possible that different tools produce different drag results for the same vehicle.

In Phase 1, the agencies finalized the use of coefficient of drag values that represented zero yaw (i.e., representing wind from directly in front of the vehicle, not from the side). The agencies recognized that the results of using the zero-yaw approach will produce fuel consumption results in the regulatory program which are slightly lower (i.e. predict better fuel consumption results) than in-use, but we believed this approach was appropriate since not all manufacturers were using wind tunnels for the aerodynamic assessment to the extent needed for wind-averaged drag quantification purposes.

While the coastdown test yields a drag area and an effective yaw angle, the aerodynamic input into GEM for GHG compliance is a wind-averaged drag area. This was chosen for its representation of more real-world wind conditions. Therefore, the agencies needed to adjust the coastdown drag area to a wind-averaged drag area using data other than a coastdown test. For Phase 2, the agencies are continuing to require the use of an alternate method adjustment factor, or $F_{\text{alt-aero}}$, to relate alternate aerodynamic methods to coastdown results. However, for Phase 2, $F_{\text{alt-aero}}$ will be based on the effective yaw angle of the coastdown instead of zero degrees, which was the basis for Phase 1.

The agencies are finalizing a wind-average drag input based on a 65-mph vehicle speed, instead of 55 mph, which was originally proposed. We had received comment that 65 mph was more representative of tractor driving behavior. Also, the GEM result for tractors more heavily weights the 65-mph cycle over the 55-mph and ARB Transient cycles. Requiring a drag input based on 65 mph makes this more consistent with the overall GHG evaluation of the tractor.

We also received comments that a surrogate angle can be used to accurately determine wind-averaged drag, as opposed to the full yaw sweep using SAE J1252 that the agencies had proposed. A surrogate angle of 4.5° was suggested by industry commenters. The agencies compared results between the full yaw sweep and the suggested surrogate angle and found that 4.5° could be an accurate representation of wind-average drag at 65 mph vehicle speed and 7 mph wind speed. This analysis is described in further detail in the scale wind tunnel and CFD sections below.

The analysis in this section shows how alternate aerodynamic test methods were used to develop wind-averaged drag area baselines and the acceptability of 4.5° as a surrogate yaw angle for determining wind-averaged drag at 7 mph wind speed and 65 mph vehicle speed. A fourth-order polynomial curve was used to estimate C_dA at $\pm\psi_{\text{eff}}$ and ±4.5° with the alternate methods.

$$(\boldsymbol{C_d A})_{\textbf{alt}} = \boldsymbol{a_0} + \boldsymbol{a_1} \cdot \boldsymbol{\psi} + \boldsymbol{a_2} \cdot \boldsymbol{\psi^2} + \boldsymbol{a_3} \cdot \boldsymbol{\psi^3} + \boldsymbol{a_4} \cdot \boldsymbol{\psi^4}$$

Equation 3-11

The following equation was used to adjust coastdown results from the coastdown effective yaw angle to the wind-averaged surrogate angle of 4.5° using the yaw data generated from the alternate aerodynamic methods. Average results from positive and negative angles were used at both the coastdown effective yaw angle and 4.5° where data were available.

$$(C_\mathrm{d}A)_\mathrm{wa} = (C_\mathrm{d}A)_\mathrm{coast} \cdot \frac{(C_\mathrm{d}A)_{\mathrm{alt},\pm 4.5°}}{(C_\mathrm{d}A)_{\mathrm{alt},\pm\psi_\mathrm{eff}}} = (C_\mathrm{d}A)_\mathrm{coast} \cdot \frac{\left[(C_\mathrm{d}A)_{\mathrm{alt},4.5°} + (C_\mathrm{d}A)_{\mathrm{alt},-4.5°}\right]}{\left[(C_\mathrm{d}A)_{\mathrm{alt},\psi_\mathrm{eff}} + (C_\mathrm{d}A)_{\mathrm{alt},-\psi_\mathrm{eff}}\right]}$$

Equation 3-12

For most tests, results from positive and negative angles were averaged to calculate this value. This equation was used with three alternate methods – wind tunnel, CFD, and constant speed testing – to develop a broad set of wind-averaged drag area values for a given tractor. These values then informed the aerodynamic bin structure for Phase 2.

3.2.1.1.3.1 Scale Wind Tunnel

Two scale wind tunnels were used in the aerodynamics baseline determination. The agencies conducted 1/8-scale wind tunnel tests at Auto Research Center (ARC) in Indianapolis. The ARC wind tunnel is a closed single return tunnel with 3/4 open-jet working section and moving ground plane (2.3 m wide x 2.1 m high x 5.5 m long). It is powered by an air-cooled 373kW variable speed DC motor that drives a 9-bladed fan with carbon fiber blades. Its speed may be varied and set at any value from 0 to 610 rpm. The maximum wind speed is about 50 m/s. The wind tunnel can accommodate a model up to 50 percent scale (1/2 scale) for race car applications down to 12.5 percent scale (1/8th scale) for Class 8 tractor and trailer combinations. The wind tunnel is equipped with a moving ground plane (*i.e.*, rolling road), four-stage boundary layer suction system, and a top-mounting "Sting" system that allows for yawing of the model. For model development, ARC has in-house model developers and can create highly detailed scale models using original computer aided design and engineering (CAD/CAE) drawings or using in-house scanning equipment to perform scanning and digitizing to create CAD/CAE drawings (see Figure 3-10 below).

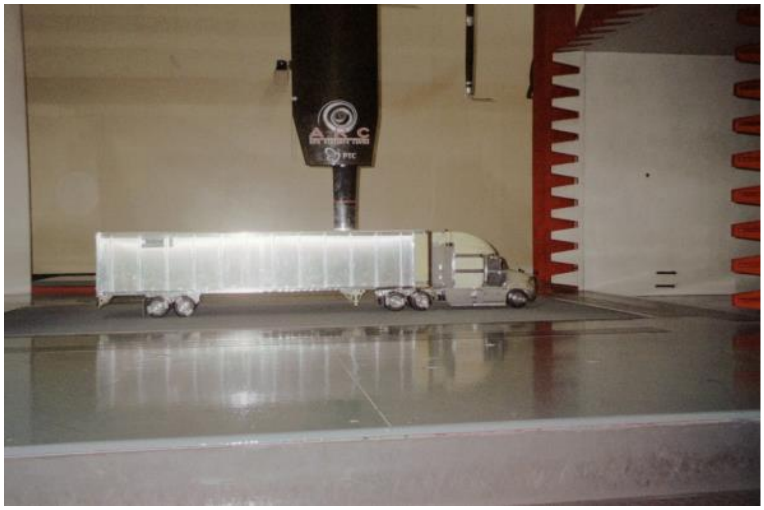


Figure 3-10 1/8th Scale Tractor-Trailer Model in ARC Reduced Scale Wind Tunnel.

The testing was conducted with a tunnel speed of 50 m/s, equivalent to a Reynolds number (*Re*) of 1.1 million, with Class 8 sleeper and day cab tractors equipped with aerodynamics components sold on the full size version of the tractors. For our test program, we assumed a base tractor-trailer gap of 45 inches and a bogey position of 40 feet (California position) from the leading edge of the trailer.

To support Phase 2, we tested model year 2011 or later sleeper cab and day cab tractors. The tractor models used in the reduced scale wind tunnel (RSWT) test matched the tractor models used for the on-road testing to the extent feasible. Not every wind tunnel tractor was a close match to the tractors tested on-road at SwRI. The wind tunnel tractors that were close matches, based on model year, make/model, and general aerodynamic features, were used to determine the yaw curve adjustment of the coastdown to 4.5°. The RunID numbers from the ARC study that were used in this analysis are listed in Table 3-4.[5]

Table 3-4 ARC Wind Tunnel Runs Representing Tractor Configurations Tested at SwRI

Tractor	Run ID
Sleeper Cab 1	2013091224
Sleeper Cab 3	2015082651
Sleeper Cab 4	2014102906
Day Cab 30	2015082531
Day Cab 31	2015082413

The ARC tunnel data also confirmed that the use of 4.5° was an appropriate approximation of wind-averaged drag. The yaw sweep data from each test was fitted to a fourth-order polynomial. Wind-averaged drag area was then calculated using SAE J1252, and the surrogate angle drag area was calculated from the average of the 4.5° and -4.5° predictions from the polynomial fit. For the 373 tests analyzed, the error from the surrogate-angle drag area to the J1252 drag area ranged from -1.0 percent to 3.0 percent, with a mean of 0.2 percent and a median of 0.3 percent. Only ten tests from a single tractor-trailer configuration had an error greater than 1.0 percent.

National Research Council Canada (NRC) also performed a scale wind tunnel study to support Transport Canada's ecoTECHNOLOGY for Vehicles program. The testing was done at their 9-meter wind tunnel at 30 percent scale to measure the aerodynamic performance of various drag reduction technologies. While the tractor model used in this study was not identical to a particular OEM tractor model available on the market, NRC did advise us that it was originally based on a design similar to Sleeper Cab 3 from the coastdown test program. The data from this study was used to inform the adjustment of the coastdown result for this tractor model.

Figure 3-11 1/8th Scale Tractor-Trailer Model in Canada Reduced Scale Wind Tunnel.

A few adjustments were made to the NRC data. NRC ran tests at tractor-trailer gaps of 36, 42, and 48 inches without any trailer aerodynamic devices (baseline). They also ran a test at a tractor-trailer gap of 36 inches with "standard side-skirts," the skirt type in the study that most closely matched the skirt tested by SwRI. SwRI conducted coastdown testing with Sleeper Cab 3 with a 47-inch gap. Interpolations were made to the NRC tunnel to estimate the yaw curve for a configuration with 47-inch gap and standard side-skirts. NRC collected a full-sweep of yaw angles (-12° to 12°, inclusive) for a tractor-trailer gap of 36 inches, but only collected data for seven angles between -12° to 1°, inclusive, for the 42-inch and 48-inch configurations. As a result, final curve was only calculated over the -12° to 1° range of yaw angles.

First, the drag area results for each of these seven angles from the 42-inch and 48-inch baseline tests were linearly interpolated to estimate results for a 47-inch gap. Then, the ratios of these 47-inch-gap results to the 36-inch-gap baseline results was applied to the 36-inch-gap standard side-skirts results to estimate the yaw curve for the configuration tested by SwRI.

The results from each coastdown test were adjusted to a wind-averaged value from the coastdown effective yaw angle, ψ_{eff}, with the wind tunnel results, using Equation 3-12. A fourth-order polynomial fit, described by Equation 3-11, was used to estimate C_dA at $\pm\psi_{eff}$ and ±4.5°.The numbers determined from both wind tunnels for the baseline calculations are presented in Table 3-5 below. The number is an average where multiple coastdowns were conducted.

Table 3-5 Wind Tunnel Results and Baseline Calculations from ARC and NRC Studies; C_dA in m²

Site	Tractor	$(C_dA)_{coast}$	ψ_{eff} [°]	$(C_dA)_{alt,\pm\psi_{eff}}$	$(C_dA)_{alt,\pm 4.5°}$	$F_{alt-aero}$	$(C_dA)_{wa}$
ARC	Sleeper 1	5.32	0.60	5.23	5.81	1.02	5.91
	Sleeper 3	5.15	2.44	5.15	5.44	1.00	5.44
	Sleeper 4	5.63	1.88	5.15	5.64	1.09	6.16
	Day Cab 30	5.80	0.81	5.46	5.94	1.06	6.32
	Day Cab 31	5.37	1.65	5.61	6.05	0.96	5.79
NRC*	Sleeper 3	5.15	2.44	5.38	5.65	0.96	5.41

*Only negative angles were evaluated from the NRC tunnel, due to available data.

3.2.1.1.3.2 Computational Fluid Dynamics (CFD)

Computational Fluid Dynamics (CFD) capitalizes on today's computing power by modeling a full size vehicle and simulating the flows around this model to examine the fluid dynamic properties, in a virtual environment. CFD tools are used to solve either the Navier-Stokes equations that relate the physical law of conservation of momentum to the flow relationship around a body in motion or a static body with fluid in motion around it, or the Boltzmann equation that examines fluid mechanics and determines the characteristics of discrete, individual particles within a fluid and relates this behavior to the overall dynamics and behavior of the fluid. CFD analysis involves several steps: defining the basic model structure or geometry based on provided specifications; applying a closed surface around the structure to define the external model shape (wrapping or surface meshing); dividing the model and the surrounding environment control volume into smaller, discreet shapes (gridding); defining the flow conditions in and out of the control volume and the flow relationships within the grid (including eddies and turbulence); and solving the flow equations based on the prescribed flow conditions and relationships.

The agencies commissioned a CFD a study through contractor ICF to study a number of issues related to the Phase 2 rulemaking. Two CFD providers, ARC and Exa, were chosen to perform a CFD evaluation of one of the tractors used in SwRI's on-road testing. ARC used Elements, a Reynolds Averaged Navier-Stokes (RANS)-based model. Exa used PowerFLOW, a Lattice Boltzmann-based model. Three trailer configurations were simulated with this tractor: Phase 1 (no-control) trailer, trailer with skirts, and trailer with skirts and a tail. Attempts were made through photographs and measurements to create a vehicle geometry as close as possible to the on-road vehicle. Multiple Reynolds numbers and turbulence intensities were evaluated. Details of the simulations can be found in the CFD report prepared by ICF. [7]

Full yaw sweeps were run for the 5.1 million Reynolds number (65-mph), zero turbulence simulations. These simulations showed that 4.5° is a viable surrogate for wind averaged drag at 7/65 mph, with variations of under 1.6 percent between the surrogate angle average and wind-averaged drag calculated per SAE J1252.

Table 3-6 Surrogate Angle C_dA Comparison with SAE J1252 Wind-Averaged Drag Calculation; C_dA in m^2

CFD source	Configuration	Wind-averaged C_dA (SAE J1252, 7/65 mph)	C_dA average at ±4.5°	% error
Exa	Phase 1	5.58	5.60	0.4%
	Skirts	5.01	5.04	0.6%
	Skirts + Tail	4.38	4.36	−0.5%
ARC-ELEMENTS	Phase 1	6.25	6.35	1.6%
	Skirts	5.57	5.63	1.1%
	Skirts + Tail	5.07	5.11	0.8%

The CFD results also show that a multiplicative adjustment is likely more appropriate to adjust based on yaw angle. Multiple turbulence intensities were evaluated to understand the effect of real-world air flow that exists during coastdowns compared to a controlled zero-turbulence result. Two non-zero turbulence intensities, 3 percent and 6 percent, were evaluated in the skirt configuration in both CFD environments. Turbulence intensity over the road can be higher, but this is often due to traffic, which is minimized during coastdown testing. The ARC results showed less than 1 percent effect from increased turbulence intensity. The Exa results, however, showed the wind-averaged drag area increased with turbulence intensity by 4.4 percent and 6.5 percent, respectively. Importantly, the increase in drag from 0° to 4.5° within each turbulence intensity simulation is more consistent as a ratio than as a difference. This is also true across the two CFD codes. The simulation results are shown in Table 3-7.

Table 3-7 Comparison of Scalar Difference (Increase) to Ratio across CFD Codes and Turbulence Conditions

CFD Source	TI [%]	C_dA at 0° [m^2]	C_dA at 4.5° [m^2]	C_dA increase (0° to 4.5°) [m^2]	C_dA ratio (4.5° to 0°)
Exa	0	4.501	5.017	0.516	1.115
	3	4.677	5.237	0.560	1.120
	7	4.777	5.342	0.565	1.118
ARC-ELEMENTS	0	5.031	5.636	0.605	1.120
	3	4.989	5.615	0.626	1.125
	7	4.999	5.615	0.616	1.123

The scalar increase of drag area from 0° to 4.5° varies from 0.516 to 0.626 m^2. The multiplicative increase (ratio) varies from 1.115 to 1.125. For a hypothetical coastdown result of 5.000 m^2, this results in a range of coastdown yaw-adjusted drag values of 5.516 to 5.626 m^2 using the scalar approach and 5.575 to 5.625 m^2 using the multiplicative approach. This shows that the multiplicative approach has less variability when applied to the coastdown tests and is the reason why the multiplicative approach is being used in this analysis and the test procedure the agencies are finalizing.

In addition to the CFD study commissioned by the agencies, certain manufacturers provided CFD data for models represented by Sleeper Cab 4, Sleeper Cab 5, and Day Cab 20.

The results from each coastdown test were adjusted to a wind-averaged value from the coastdown effective yaw angle, ψ_{eff}, with the CFD results, using Equation 3-12. A fourth-order polynomial fit, described by Equation 3-11, was used to estimate C_dA at $\pm\psi_{eff}$ and ±4.5°. The numbers determined from both wind tunnels for the baseline calculations are presented in Table 3-8 below. The number is an average where multiple coastdowns were conducted.

Table 3-8 CFD Results and Baseline Calculations; C_dA in m^2

CFD Source	Tractor	$(C_dA)_{coast}$	ψ_{eff} [°]	$(C_dA)_{alt,\pm\psi_{eff}}$	$(C_dA)_{alt,\pm 4.5°}$	$F_{alt\text{-}aero}$	$(C_dA)_{wa}$
ARC-ELEMENTS	Sleeper 1	5.32	0.6	5.00	5.62	1.06	5.98
Exa	Sleeper 1	5.32	0.6	4.51	5.06	1.18	5.96
	Sleeper 4	5.63	1.88	**	**	1.20	6.12
	Sleeper 5	5.16	2.06	**	**	1.16	5.44
	Day Cab 20*	5.38	2.31	**	**	1.13	5.81

Note:
*Only positive angles were evaluated with CFD for Day Cab 20, due to available data.
**CFD results provided confidentially by manufacturers. Only final $(C_dA)_{wa}$ result shown.

3.2.1.1.3.3 Constant Speed Testing

Similar to the coastdown testing, constant speed testing is conducted on road and measures road load forces acting on the tractor. In contrast to the coastdown test where the vehicle is accelerated to a set speed and then allowed to coast to a lower speed in neutral, the constant speed test is conducted by measuring torque along the driveline while the vehicle is driven at various constant speeds. This helps to reduce measurement uncertainty due to potential driveline vibration experienced during coastdown and better isolate the force contributions between speed transitions over the speed range (e.g., aerodynamic drag dominance at high speed; a mix of aero drag and mechanical/frictional forces in middle speeds; and mechanical/frictional force dominance at low speeds). In addition, whereas the total force, and consequently the total drag force, is derived based on the speed and time for the coastdown test, the constant speed test measures the total force at the wheels using wheel hub torque meters and/or a driveshaft torque meter. The constant speed test has the potential to reduce uncertainty compared to a coastdown because it can collect data at a single speed for a sustained amount of time. For Phase 1, we allowed the use of Constant Speed testing as an alternate aerodynamic method but did not promulgate specific test procedure requirements. In lieu of this, a manufacturer would have been required to develop its own test procedure for constant speed testing and submit it to the agencies for approval.

Currently, there is no industry standard for conducting constant speed tests with heavy-duty vehicles and no manufacturers have submitted alternative compliance test plans for approval from EPA. The European Union did include constant speed testing in the aerodynamic component of their greenhouse gas emissions monitoring and certification program, but it did not include a calculation of wind-averaged drag.[13] For Phase 2, we proposed specific requirements for the constant speed test procedure to be used by manufacturers to certify their tractors. Accordingly, we evaluated the constant speed testing using the same vehicles tested with the coastdown test procedure. For our evaluations, we used several speeds to determine the optimal speeds for constant speed testing. In addition, we performed the testing with both wheel hub torque meters and a driveshaft torque meter to quantify the benefits and detriments of both methods.

The agencies conducted constant speed testing through SwRI along the same stretch of roadway as the coastdown testing. Torque was measured at the driveshaft for all the tests and also at each of the four wheel hubs for most of the tests. More details of the test setup and procedure can be found in SwRI's coastdown and constant speed testing report.[8] Each vehicle configuration of interest was tested at least twice, once in winds within the SAE J1263 specifications, and once outside of the specifications.

Testing was performed at the following speeds and durations while recording torque and engine data.

- 10 mph – 7.5 minutes in each direction
- 20 mph – 7.5 minutes in each direction
- 30 mph – 7.5-10 minutes in each direction
- 50 mph – 8-13 minutes in each direction
- 70 mph – 8-10 minutes in each direction.

If necessary, multiple passes were conducted to meet the time requirements. The 20-mph run was eliminated partially through the test program in favor of the higher speeds. Cruise control was used to maintain speeds, except for the lower one or two speeds for certain tests, where the driver controlled the speed through pedal position and close monitoring of instantaneous vehicle speed. The combination of multiple wind conditions and multiple high speeds created enough of a yaw angle distribution to construct a yaw curve for a given configuration. This yaw curve construction would then help adjust the coastdown result to 4.5°.

For analysis of the constant speed test procedure data, the 10-Hz data were split into 10-second segments over which the torques, air speed, and air direction were averaged. For tractors equipped with the driveshaft torque meter, the road load force was calculated for each 10-second segment as follows:

$$F_{\mathrm{RL,shaft}} = \frac{\tau_{\mathrm{shaft}} \cdot \omega_{\mathrm{eng}}}{GR \cdot v} + F_{\mathrm{grade}}$$

Equation 3-13

For tractors also equipped with the wheel torque meters, the road load force was calculated as follows:

$$F_{\mathrm{RL,wheel}} = \frac{\tau_{\mathrm{wheel}} \cdot \omega_{\mathrm{wheel}}}{v} + F_{\mathrm{grade}}$$

Equation 3-14

Where:

τ_{shaft} = driveshaft torque
ω_{eng} = engine speed
GR = transmission gear ratio
$F_{\mathrm{RL,shaft}}$ = road load force calculated from the driveshaft torque
τ_{wheel} = wheel torque, sum of all four wheel torque measurements

ω_{wheel} = wheel speed, average of all four wheel speed measurements
$F_{RL,wheel}$ = road load force calculated from the wheel torque
F_{grade} = grade force

Since we received comments that the speed dependence of tire rolling resistance should be incorporated into coastdowns, we applied a similar process for the constant speed data analysis. Under the same tire test program that was done for coastdown analysis, the agencies tested the same tires at Smithers Rapra using the SAE J1269 constant speed tire rolling resistance test. SAE J1269 requires testing only at 80 km/h (50 mph), so the agencies also tested 16 km/h (10 mph) and 113 km/h (70 mph) to align with three of the speeds tested in the constant speed test program.[19] The change in rolling resistance with speed, $\Delta F_{TRR,veh}$, was calculated from these tests using the regression-based method described for the stepwise coastdown tests in Chapter 3.2.1.1.2.4 (Equation 3-4 through Equation 3-6).

Drag area C_dA was calculated using a subtraction of the low-speed force from the high-speed force. However, the low speed force that was used was the average 10-mph force and air speed from the calmer wind day. This was to avoid low-speed points where unusually high aerodynamic loads would be present. The high-speed values were individual 10-sec segment wheel force and air speed averages from the 50-mph and 70-mph runs.

$$C_dA = \frac{F_{RL,hi} - \overline{F_{RL,lo}} - \Delta F_{TRR,veh}}{\frac{1}{2} \cdot \rho \cdot v_{r,hi,avg}^2}$$

Equation 3-15

For each high-speed point, the yaw angle was also calculated from the measured vehicle speed and from the wind direction and wind speed measured by the roadside weather station, using Equation 3-2. A fourth-order polynomial fit of C_dA and yaw angle, described by Equation 3-11, was used to estimate the mean C_dA values from constant speed at $\pm\psi_{eff}$ and ±4.5°. Figure 3-12 below shows the resulting yaw curve for one of the tractors.

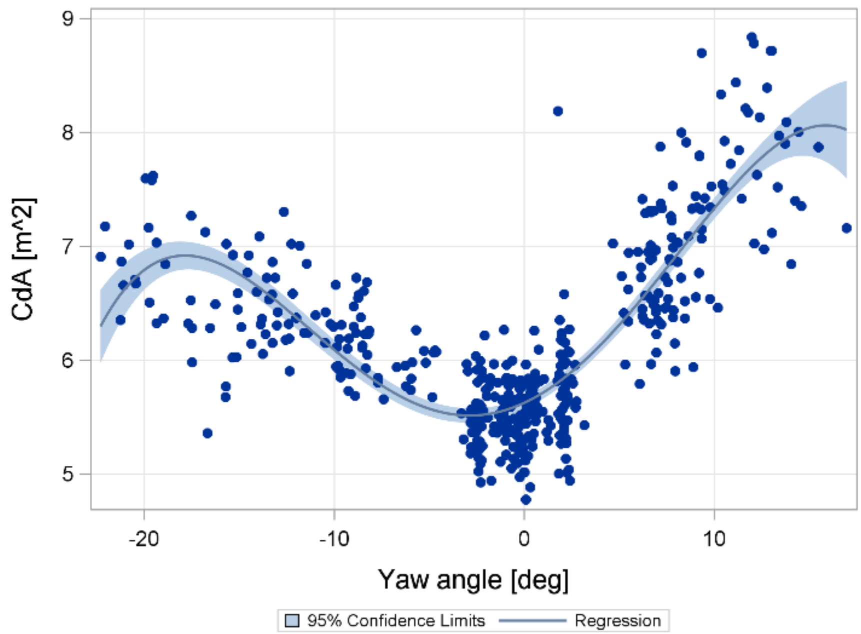


Figure 3-12 Yaw Curve Results from Sleeper Cab 4.

While the graph may appear to show a high level of scatter, the large number of data points shows a relatively low level of uncertainty. Uncertainties were determined using the statistics produced by the regression. The standard error was used because the objective of the regression was to identify the yaw characteristic for the vehicle and not to predict an individual test point. Standard errors ranged from 0.5 to 0.8 percent for C_dA values at 4.5° and −4.5° for the five configurations analyzed. It is possible that there are bias errors associated with constant speed testing, but determining the relative yaw characteristic within a given test was the objective of this analysis.

The results from each coastdown test were adjusted to a wind-averaged value from the coastdown effective yaw angle, ψ_{eff}, with the constant speed test results, using Equation 3-12. The numbers determined from both wind tunnels for the baseline calculations are presented in Table 3-9 below. The number is an average where multiple coastdowns were conducted.

Table 3-9 Constant Speed Results and Baseline Calculations; C_dA in m^2

Tractor	$(C_dA)_{coast}$	ψ_{eff} [°]	$(C_dA)_{alt,\pm\psi_{eff}}$	$(C_dA)_{alt,\pm4.5°}$	$F_{alt\text{-}aero}$	$(C_dA)_{wa}$
Sleeper 1	5.32	0.60	5.38	5.81	0.99	5.75
Sleeper 2	5.27	1.31	5.56	5.78	0.96	5.49
Sleeper 3	5.15	2.44	5.06	5.23	1.02	5.34
Sleeper 4	5.63	1.88	5.67	5.88	0.99	5.84
Sleeper 5	5.16	2.06	5.42	5.72	0.95	5.45

3.2.1.2 Phase 2 Aerodynamic Baseline and Bins

Bringing together the results from the baseline analysis of coastdowns, wind tunnel tests, CFD simulations, and constant speed tests, the agencies developed numeric values for the drag area bins to be used in GEM for certification of Phase 2 tractors. Figure 3-13 through Figure 3-16 below show the various coastdown test results at their effective yaw angles, along with each coastdown result adjusted to 4.5° based on the analysis from the alternate methods available for each tractor, as described in Chapter 3.2.1.1.3. These adjusted values at 4.5° for each tractor were then averaged to determine the mean wind-averaged drag area value for each tractor.

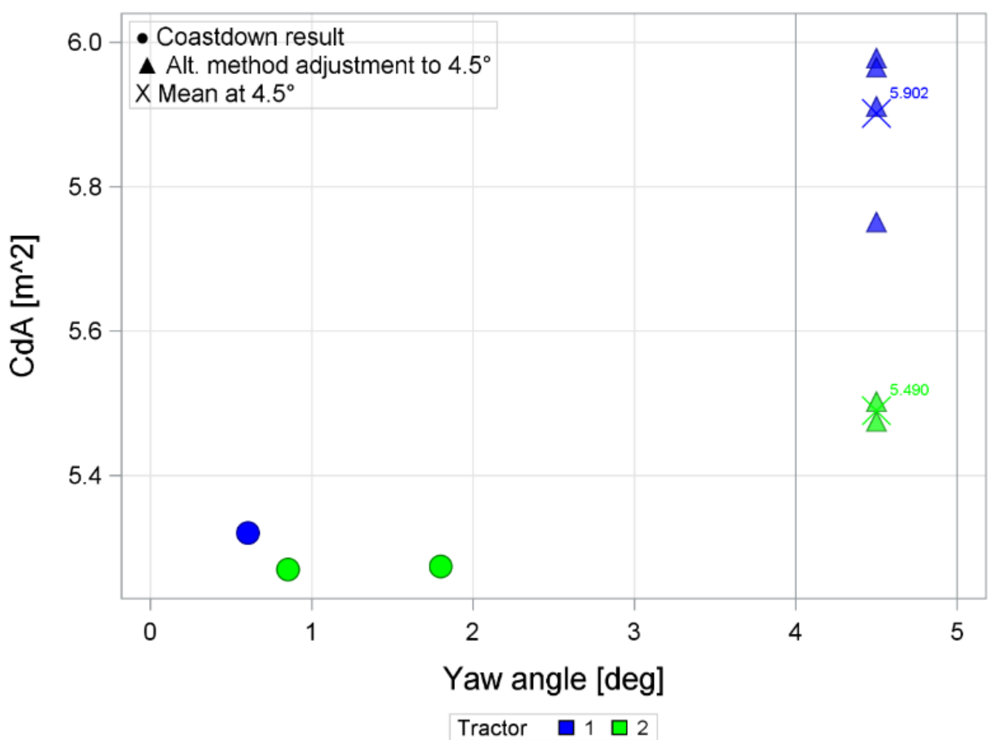


Figure 3-13 Coastdown Results with Alternate Method Adjustments to 4.5° Yaw – Sleeper Cabs 1 and 2

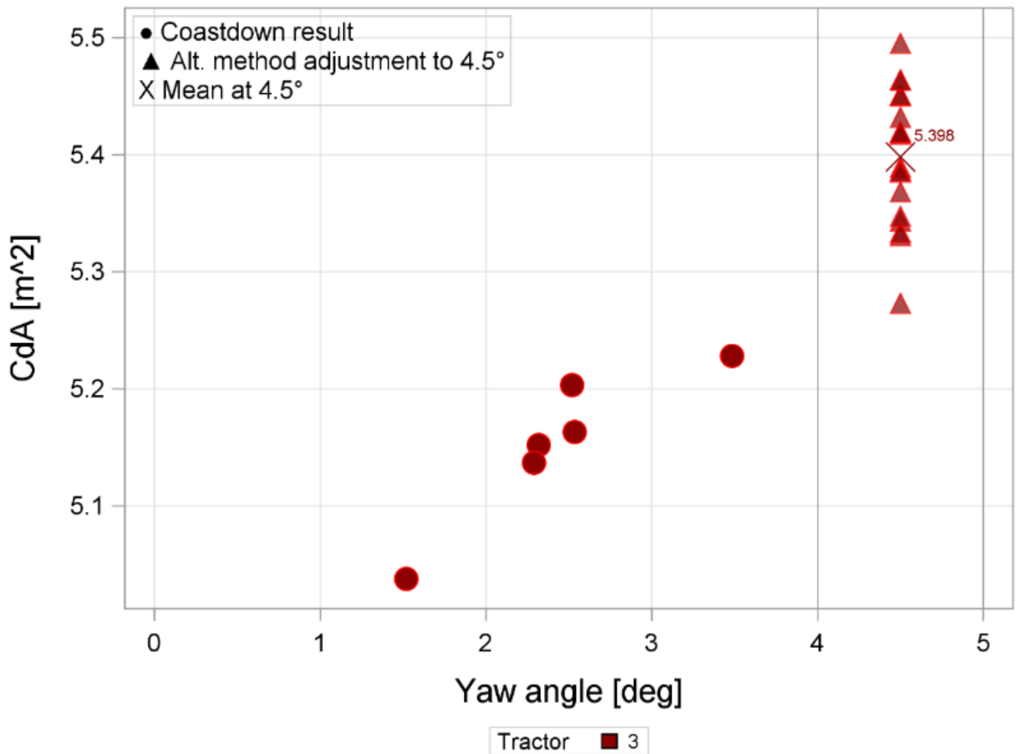


Figure 3-14 Coastdown Results with Alternate Method Adjustments to 4.5° Yaw – Sleeper Cab 3

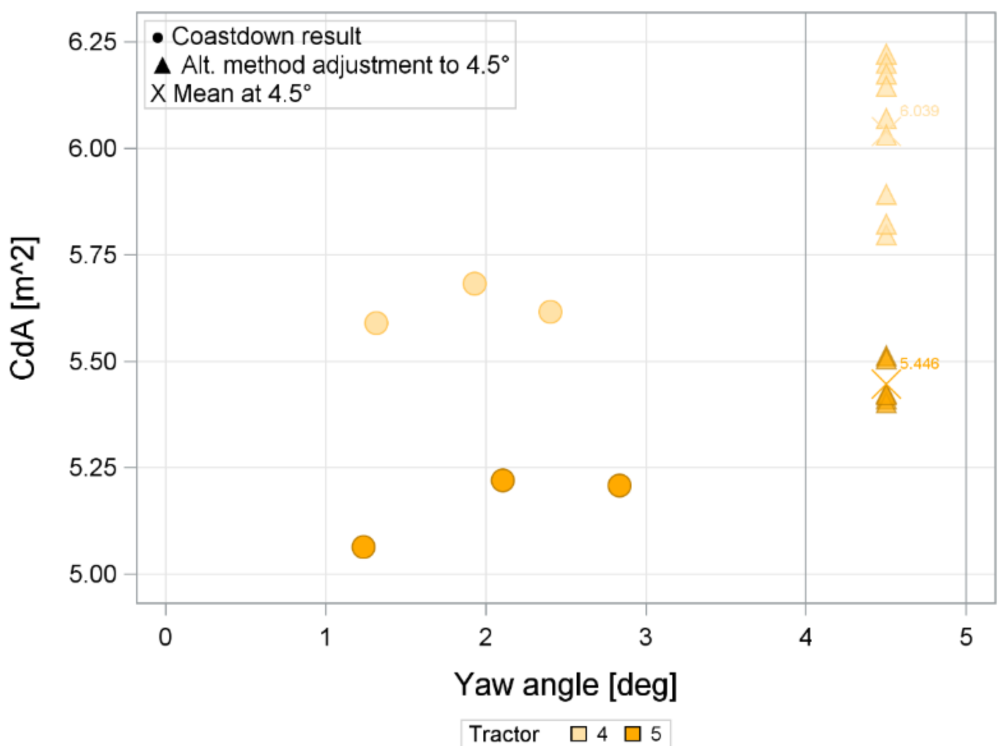


Figure 3-15 Coastdown Results with Alternate Method Adjustments to 4.5° Yaw – Sleeper Cabs 4 and 5

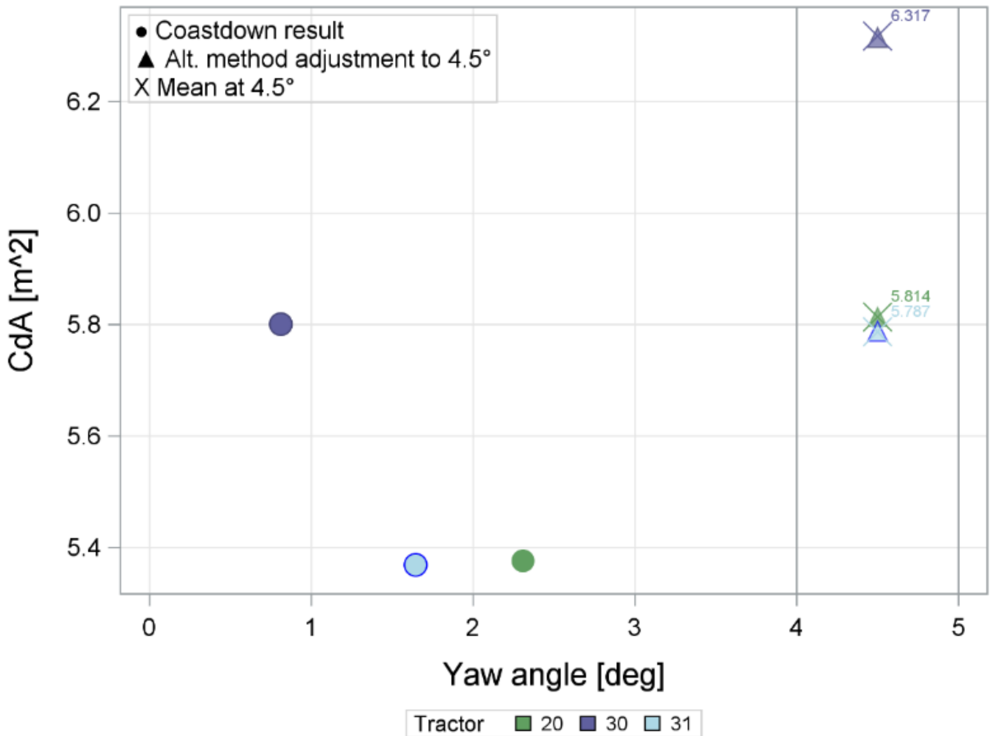


Figure 3-16 Coastdown Results with Alternate Method Adjustments to 4.5° Yaw – Day Cabs

The mean wind-average drag results for all the tractors for each cab type were combined to develop the C_dA bin boundaries for Phase 2. To keep the bin levels consistent between Phase 1 drag results and Phase 2 wind-averaged drag area results, the agencies developed the bin boundaries shown in Figure 3-17 for high-roof sleeper cab tractors and Figure 3-18 for high-roof day cab tractors. As these tractors were in Bin III and Bin IV for Phase 1, their Phase 2 results led to the numerical values for the Phase 2 bin boundaries for Bin III and Bin IV.

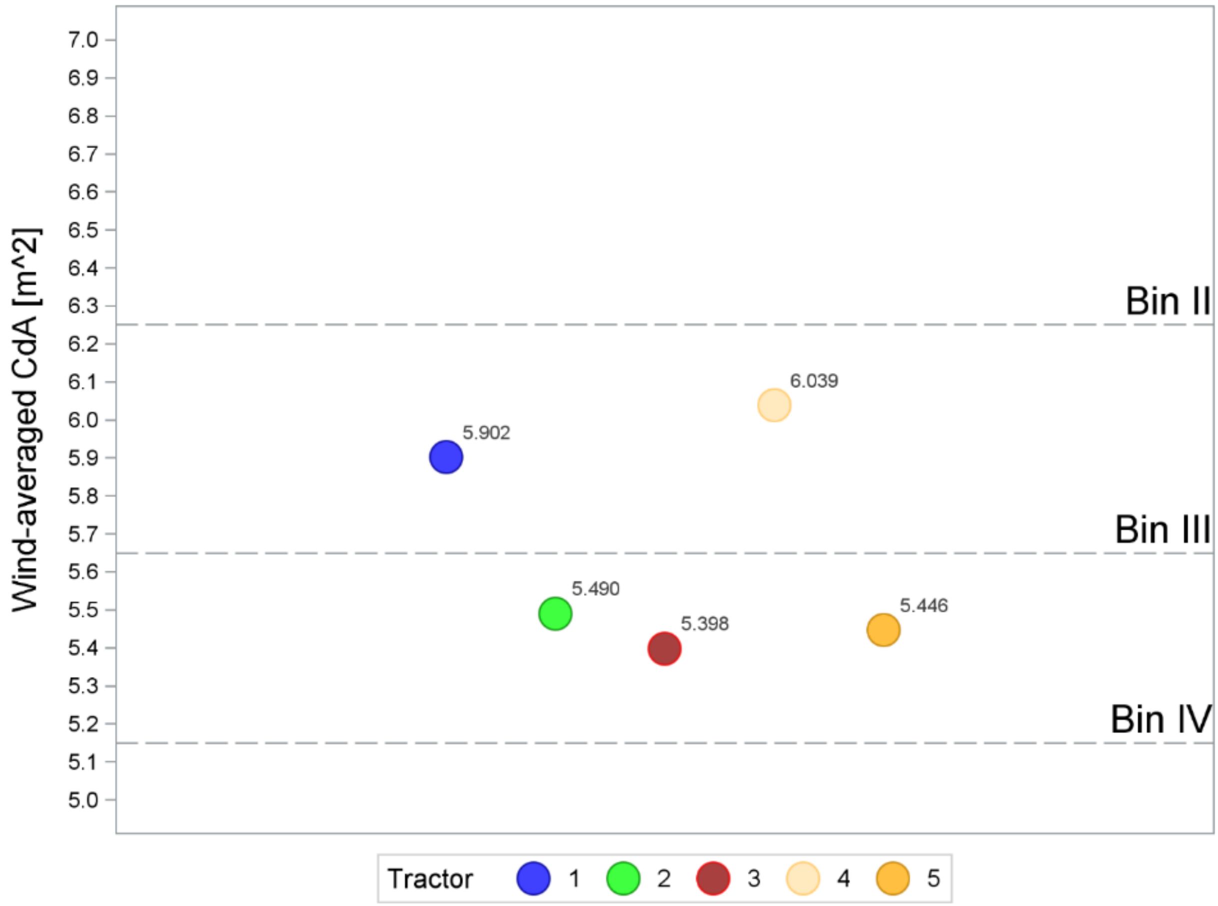


Figure 3-17 High Roof Sleeper Cab Phase 2 Results and Bin Boundaries

In general, the tractors' Phase 2 wind-averaged results with respect to one another are similar to their relative Phase 1 results (Figure 3-2). As a result, the agencies drew Phase 2 Bin IV such that Sleeper Cabs 3 and 5 were near the center of that bin. Sleeper Cab 1 moved further into Bin III, whereas it was near the Bin III/IV boundary for Phase 1. Sleeper Cab 2 moved just within Bin IV, whereas it was also near the Bin III/IV boundary for Phase 1. It is not unusual to see modest shifts like this because the addition of trailer skirts may have a varying influence for different tractors designs, but the tractors' overall order of results relative to one another were similar between Phase 1 and Phase 2.

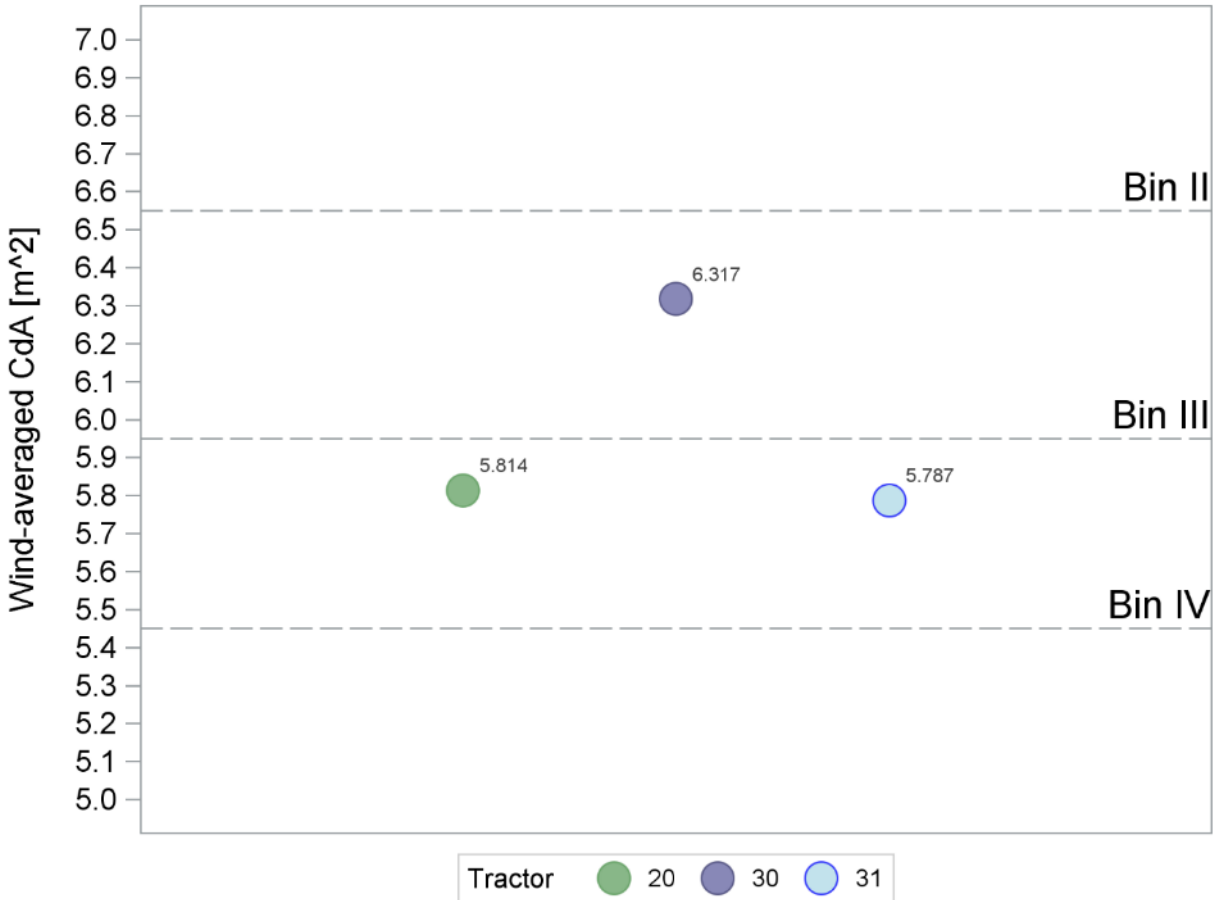


Figure 3-18 High Roof Day Cab Phase 2 Results and Bin Boundaries

The two day cabs that were tested using the Phase 1 procedure landed close to the Phase 1 Bin III/IV boundary (Figure 3-2). For Phase 2, these two tractors (30 and 31) diverged in their results and the Phase 2 Bin III/IV boundary was drawn in between them (6.0 m^2). A third day cab, only tested using the Phase 2 procedures, is included here for reference.

For bin boundaries beyond the Bin III/IV boundary, the bin widths were drawn similar to Phase 1 or slightly narrower, approximately 0.4 to 0.5 m^2 wide, for both the sleeper cabs and day cabs.

The analysis described in this section led to the creation of aerodynamic bins for high-roof sleeper cab and high-roof day cab tractors described in Table 3-10. This table can also be found in Section III.E(2)(a)(viii) of the Preamble along with the bin definitions for low and mid roof tractors, which were not tested in this program.

Table 3-10 Phase 2 Aerodynamic Input Definitions to GEM for High Roof Tractors

	CLASS 7	CLASS 8	
	Day Cab	Day Cab	Sleeper Cab
	High Roof	High Roof	High Roof
Aerodynamic Test Results (C_dA_{wad} in m^2)			
Bin I	≥7.2	≥7.2	≥6.9
Bin II	6.6-7.1	6.6-7.1	6.3-6.8
Bin III	6.0-6.5	6.0-6.5	5.7-6.2
Bin IV	5.5-5.9	5.5-5.9	5.2-5.6
Bin V	5.0-5.4	5.0-5.4	4.7-5.1
Bin VI	4.5-4.9	4.5-4.9	4.2-4.6
Bin VII	≤4.4	≤4.4	≤4.1
Aerodynamic Input to GEM (C_dA_{wad} in m^2)			
Bin I	7.45	7.45	7.15
Bin II	6.85	6.85	6.55
Bin III	6.25	6.25	5.95
Bin IV	5.70	5.70	5.40
Bin V	5.20	5.20	4.90
Bin VI	4.70	4.70	4.40
Bin VII	4.20	4.20	3.90

3.2.2 Final Aerodynamic Test Procedures for Phase 2 Tractors

3.2.2.1 Standard Trailer

The most widely implemented trailer aerodynamic devices in the market today are trailer side skirts that extend in the gap between the fifth wheel and the trailer bogey, and trailer treatments that extend from the rear of the trailer (e.g., boat tails). As discussed in Section III.E(2)(a)(iii) and Section IV.D(2) of the Preamble, we estimate that even without the Phase 2 rulemaking, approximately 50 percent of the new trailers sold in 2018 will have trailer side skirts.[14,15] As the agencies are finalizing GHG rules for tractors for model year 2021 and beyond, we believe that it is appropriate to update the standard box trailer definition to reflect the technologies we project will be used on the majority of the trailers in the fleet during that timeframe. Therefore, the agencies are finalizing a new standard trailer for Phase 2 tractor certification by requiring the use of trailer skirts with dimensions specified in 40 CFR 1037.501(g)(1)(v). As there may not be a commercially available skirt that meets these exact dimensions, the agencies were able to verify similar aerodynamic performance of two different skirts, one purchased and one fabricated by SwRI to the same dimensions. In order to help simplify any fabrication processes, the skirt mounting requirement is flush with the side of the trailer and does not contain curves.

With the addition of the skirt in our coastdown testing came a need for SwRI to move the trailer bogey rearward one notch, approximately 4 inches, as the edge of the skirt came very close to the leading outside trailer tires. This made the bogey position one inch out of the Phase

1 specifications. To avoid potential problems during certification, we are finalizing a minor change to the bogey position requirement to allow for more clearance of the skirt with the trailer tires. The Phase 1 bogey position was at 146 ± 4 inches from the rear of the trailer. We are finalizing 144 ± 4 inches. This still allows for the nominal 146-inch position but also allows for clearance if needed.

3.2.2.2 Coastdown

The agencies are requiring the use of coastdowns as the reference method with the high-low analysis method with the analytical solution discussed above. The coastdown test procedure for tractors is described in 40 CFR 1037.528. This section describes various changes to the procedure compared to the proposal.

As described in Chapter 3.2.1.1.2.6, the agencies are finalizing changes to the low-speed range required for the coastdown test as well as the wind constraints. The agencies are finalizing a low-speed range of 20-10 mph to better account for the drag behavior as a function of yaw angle. Also, the agencies are adding an additional wind constraint, that the average component of the wind speed parallel to the coastdown road or track must not exceed 6 mph. This additional constraint was finalized to be fully outside the new low-speed range, which requires coasting the vehicle down to 8 mph. Variability will also be reduced by limiting wind speeds, and the agencies believe that this can be done without sacrificing a significant number of available days for testing. The data from SwRI showed that 97 percent of the runs that were within the proposed wind constraints also had an average parallel wind component that was less than 6 mph. This percentage may be different for other test locations, depending on the direction of prevailing winds in those areas.

The agencies are requiring filtering of the wind speed, wind direction, air speed, yaw angle, and vehicle speed using the procedure described in Chapter 3.2.1.1.2.1. This method was developed with input from the manufacturers for the purposes of standardizing the condition of coastdown data to be analyzed.

In addition to the tire models tested to support the coastdown testing, the agencies tested more tire models to understand the variation of the speed dependence of tire rolling resistance. In total, four steer tire models, four drive tire models, and two trailer tire models, all SmartWay-verified, were tested, leading to 32 different combinations. The test procedure and calculations described in Chapter 3.2.1.1.2.4 were applied to each combination to determine its speed dependence. The rolling resistance increase, ΔF_{TRR}, was determined for a vehicle weight of 36,000 lbs, distributed at 34 percent, 36 percent, and 30 percent over the steer, drive, and trailer axles, respectively, and at 65 mph and 15 mph, the midpoints of the high-speed and low-speed coastdown segments being finalized. Values for ΔF_{TRR} ranged from 200 to 219 N over all the various combinations, a spread of about 10 percent. Because of this variation and because tire rolling resistance characteristics may change in the future when manufacturers will be performing coastdown tests for the Phase 2 rule, the agencies are requiring measuring tire rolling resistance as a function of speed according to 40 CFR 1037.528, similar to the method used by the agencies for this rulemaking.

As described earlier, the agencies are also requiring testing drive axle spin loss tests on the axle model and configuration to determine spin losses as a function of speed.

The requirements to perform tire rolling resistance and drive axle spin loss tests are a change from the proposal, where a default spin loss was assumed and no speed dependence for tire rolling resistance was included.

3.2.2.2.1 Reference Tractors ($F_{alt\text{-}aero}$ Testing)

The provisions in this section are particular to the tests to be performed on the reference tractors to determine $F_{alt\text{-}aero}$. Given the usefulness in collecting as many coastdown data points as possible, the agencies are requiring that at least 24 valid runs be conducted to determine a mean drag area and yaw angle for a given test. Validity is determined by the following:

1) Runs have no known technical or instrumentation errors,
2) The yaw angles of the runs lie in a range within ±1° of the median yaw angle of all the runs collected in one testing period no greater than 12 hours, and
3) The drag area values within this yaw range are within 2 standard deviations of the mean drag area of the drag area values within the yaw range.

These criteria establish the important objectives of defining yaw angle limits over which a mean drag area and yaw angle result can be characterized and eliminating statistical outliers. These validity criteria were not applied to our coastdown data because the vast majority of the tests had less than 20 runs. This was due to testing through a broader speed range to evaluate other aspects of the test procedure, such as speed range segmentation and analysis methods. This meant that each run took more time to conduct. However, a few tests were conducted with up to 28 runs, and this validity determination is demonstrated below for one of the tests. The C_dA and (absolute value of) yaw angle for every run from one of the tests is shown in Figure 3-19. None of the runs had any known technical of instrumentation errors.

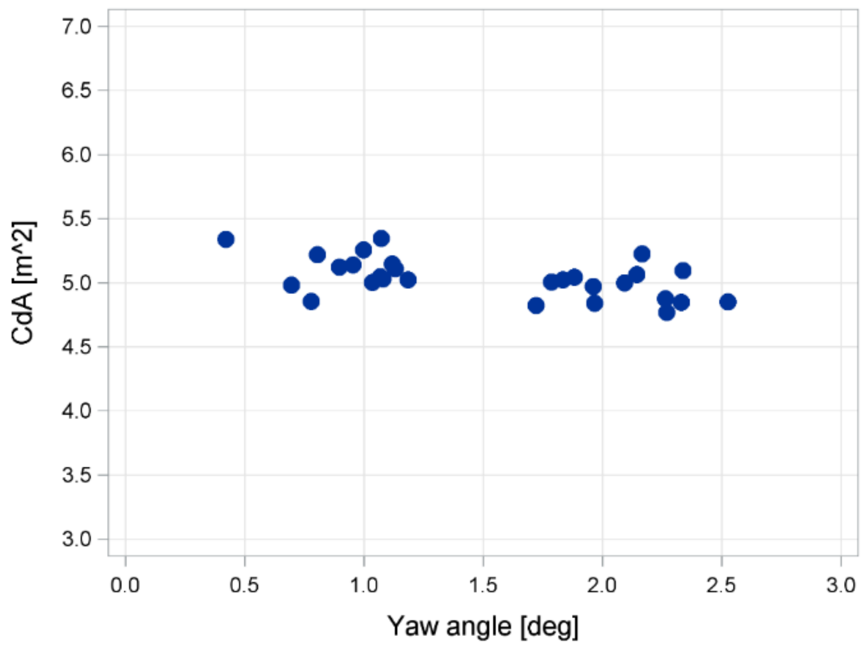


Figure 3-19 CdA vs Yaw Angle from One Test of Sleeper Cab 3 Consisting of 28 Runs.

The median of all the yaw angles, ψ_{med}, is 1.45°, which makes the yaw angle range 0.45° to 2.45°. Points outside of this range were eliminated, as shown in Figure 3-20.

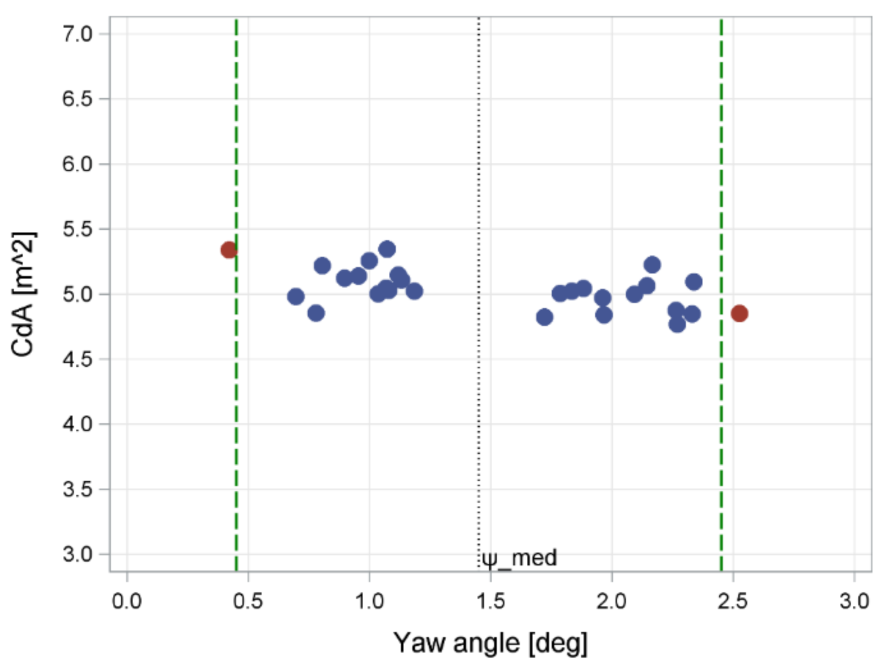


Figure 3-20 Yaw Angle Limits, Shown By the Dashed Lines - Eliminate the Points in Red From the Final C_dA Result.

Out of the remaining points (blue) the mean and the standard deviation of the C_dA values were calculated to determine the C_dA outlier boundaries. With a mean of 5.033 m^2 and standard deviation of 0.143 m^2, the boundaries were drawn at 4.747 m^2 and 5.319 m^2, as shown in Figure 3-21.

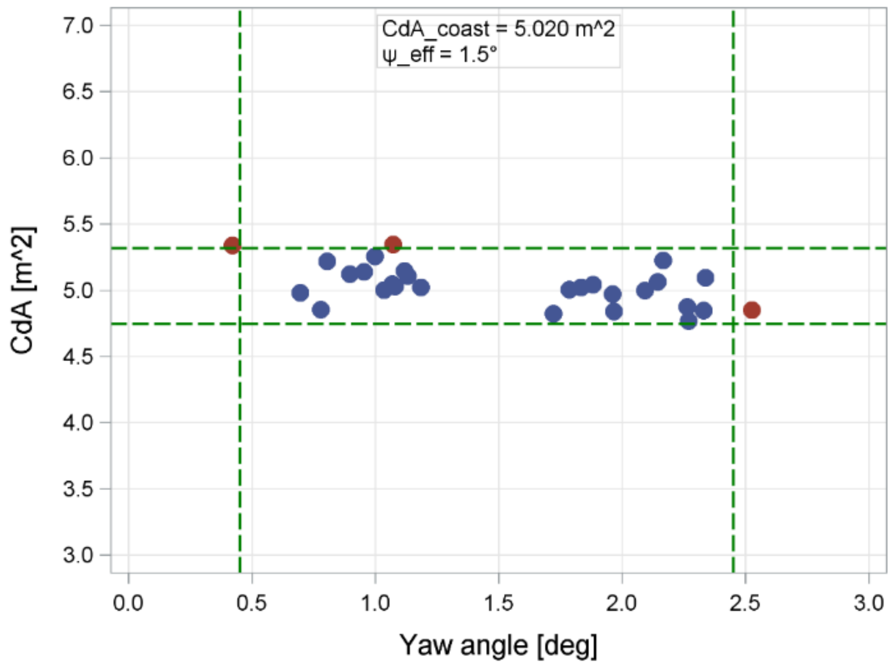


Figure 3-21 The Points In Blue Within The Middle Rectangle Are The Remaining Valid Points To Determine C_dA For The Test.

After eliminating the outliers using the process described above, the mean C_dA and mean yaw angle were calculated from the remaining points to determine the result of the test. In this case, the final result is $(C_dA)_{coast}$ = 5.020 m^2 at ψ_{eff} = 1.5°.

3.2.2.2.2 Selective Enforcement Audits

The agencies will require manufacturers to perform selective enforcement audits (SEA) on production tractors selected by the agencies. In general, the procedures will follow those for the reference tractors. Compliance will be determined by comparing the certification C_dA bin with the bin determined from the SEA. Variability in the coastdown tests are addressed partially through the implementation of a bin structure, as opposed to using the test result directly. However, there may be tractors whose results are near the edge of a bin for which the SEA result could be in the neighboring less aerodynamic bin.

To address this issue, the agencies are finalizing a confidence interval to apply to the top of the C_dA bin, within which an SEA result would be considered to be in compliance. The basis for this confidence interval, z, is $a \cdot \sigma_{\bar{x}} + b$, where $\sigma_{\bar{x}}$ is the standard error of the SEA result, a is a t-value, and b is an offset to account for testing variability. Details of this approach and the SEA process for aerodynamic performance are discussed in Section III.E(2)(a)(ix) of the Preamble.

The agencies determined that a value of 1.5 was appropriate for *a*. This critical t-value for a failure of 1.5 means that, from the precision error alone, the agencies must have a confidence level of 93 percent that the test results is above the boundary of the bin declared for that tractor configuration. This comes from the (one-tailed) probability of approximately 7 percent that a result falls in the tail of a normal distribution for a t-value of 1.5.

In addition to the precision component, the agencies are allowing an offset, *b*, to be applied to account for test-to-test variability. The variability of multiple tests of the same tractor was used to consider value *b*. As mentioned earlier, Sleeper Cab 3 was tested on multiple days. Wind conditions varied between each of these tests, causing different effective yaw angles. To compare the tests with each other, the wind-averaged C_dA values were used, after adjustment to 4.5° as described in Section 3.2.1.1.3. For a given alternate method used for the yaw adjustment, the wind-averaged C_dA values varied by a range of 0.11 m^2.

The coastdown testing at NRC was used to investigate site-to-site variability to inform the *b* value. While the agencies anticipate that the manufacturers would use the same test facilities that they used for their reference tractor tests, they could choose a different site based on availability or other factors. The coastdown analysis process the agencies are finalizing could not exactly be used on the NRC data because wind conditions were not always favorable, and an unequal numbers of runs were conducted in each direction. A matched pair analysis (instead of a low-pair mean) was used along with the alternate method adjustments that were performed for the SwRI data in order to compare all results in the wind-averaged drag domain. The wind-average C_dA estimated using the NRC data differed by 0.15 m^2 from that using the SwRI data.

As shown in Figure 3-9, the standard error of test decreases as the number of runs in a test increases. At 24 runs, the standard error is on average, approximately 0.84 percent. For a given distribution, increasing the number of runs to 100 would roughly halve the standard error to 0.42 percent, as the standard error decreases with the square root of the number of runs. With an *a* value of 1.5, the contribution to the confidence interval, *z*, of the precision error at the Bin III/IV boundary of 5.6 m^2 is approximately 0.04 m^2.

Since the bin boundaries are expressed to one decimal place, the SEA provision also allows for rounding, which provides an additional 0.049 m^2. Finally, the agencies selected a *b* value of 0.03 m^2. Combining the selected *a* and *b* values, the estimated standard error after 100 tests, and the rounding margin; the estimated confidence interval for a tractor at the Bin III/IV boundary is 0.12 m^2. This in the 0.11-0.15 m^2 range estimated by the repeat tests done on Sleeper Cab 3 at SwRI and NRC and is around 30 percent of the width of Bin IV. The agencies are finalizing a confidence interval of $z = 1.5 \cdot \sigma_{\bar{x}} + 0.03$, which would be applied to the SEA result when determining compliance as per SEA test procedures in 40 CFR 1037.305.

3.2.2.3 CFD

For Phase 1, we established CFD procedures based on our results and industry collaboration since there were no standardized practices at the time. In addition, to ensure data consistency, a minimum set of characteristics and criteria was included for CFD analysis to ensure that the boundary and surface conditions are not too coarse and thus not representative of the real tractor and environmental conditions.

For Phase 2, we are finalizing the requirement to use the Society of Automotive Engineering (SAE) standard for CFD, SAE J2966, as the basis for our CFD procedures.[16] We included a few exceptions and clarifications to SAE J2966 to align with various requirements in Phase 1 along with new provisions for Phase 2:

- SAE J2966 contains provisions for both open road and wind tunnel simulations. We are requiring that the CFD runs must simulate the open road condition.
- The Reynolds number must be 5.1 million and vehicle speed must be 65 mph in a full-scale environment. This is to harmonize with various other aspects of the rulemaking, such as coastdown testing being done at a speed range around 65 mph and GEM GHG results being heavily weighted toward the 65-mph drive cycle.
- The output of the CFD must be drag area, not drag coefficient. This is to harmonize with coastdown testing and GEM inputs, which are in the drag area domain. This also eliminates the need to determine frontal area for the vehicle.
- We are retaining Phase 1 grid size requirements for Phase 2, which may be finer than what is recommended in SAE J2966.
- Turbulence intensity must be 0.0 percent.

As discussed earlier, the agencies are requiring results from surrogate angle of ±4.5°. However, CFD simulations may be performed at either +4.5° or -4.5°, but the manufacturer is responsible for compliance with the average result, as would be determined from on-road confirmatory and selective enforcement audit (SEA) testing combined with the alternate aerodynamic methods.

3.2.2.4 Wind tunnel

The agencies are not making any major changes to the wind tunnel specifications from the proposal. However, as discussed earlier, the agencies are requiring results from surrogate angles of ±4.5°, instead of the SAE J1252 yaw sweep that was proposed. Also, the test for Reynolds effects described in Section 7.1 of SAE J1252 will not be required. The CFD simulations performed by Exa and ARC showed that Reynolds effects are very small in the range of the Reynolds numbers that are allowed, which is required to be at least 1.0 million. The use of $F_{\text{alt-aero}}$ to adjust back to a coastdown test also mitigates most of these effects; a change in Reynolds number would require a recalculation of $F_{\text{alt-aero}}$.

3.2.2.5 Aerodynamic Method Adjustment Factor ($F_{\text{alt-aero}}$)

As the agencies showed in Phase 1, and in the various results shown in this Phase 2 analysis, aerodynamic test methods differ in their predictions of drag coefficient.[17] On-road methods, such as coastdown and constant speed tests, are performed in uncontrolled real-world environments, whereas wind tunnel testing is performed in constrained, controlled conditions, and CFD is a simulation that attempts to replicate complex aerodynamic events. Different test methods have differences with regard to environmental conditions, assumptions for non-aerodynamic drag forces, tunnel geometry, boundary conditions, and simulation characteristics.

These differences can lead to different results, even though they are used to measure or calculate the same parameter. The agencies acknowledged that there will never be perfect alignment between the predicted drag area values from the aerodynamic methods even with full, appropriate correction for every factor, but wanted to allow the use of these methods, which are currently being used by the manufacturers, to limit test burden for certification.

As a result, for Phase 1, we employed the use of an aerodynamic method adjustment factor, or $F_{\text{alt-aero}}$ to relate the results from the reference method, a coastdown test, to the results from the alternative method as a ratio of the coastdown result to the alternate method result for selected Class 8 high roof sleeper cabs. The $F_{\text{alt-aero}}$ is then multiplied by the results generated using the alternative method for all other OEM configurations. This allowed manufacturers the convenience and lower test burden of using existing aerodynamic protocols rather than pursuing extensive data correction to produce equivalent results across the aerodynamic methods.

For Phase 2, we will require the use of data from alternate aerodynamic test methods, and subsequently the aerodynamic method adjustment factor. An important change is that we are requiring that this factor be determined at the average yaw angle from the coastdown, not at zero yaw. This is to recognize that coastdowns are not conducted in zero yaw conditions and assuming such conditions would add error to the drag area determination. Furthermore, using the average yaw angle provides manufacturers more flexibility to test in various wind conditions (within the limits required in the regulation) without the risk of a zero-yaw assumption causing an incorrect adjustment to the surrogate yaw angle.

3.2.2.6 Certification Calculation Steps

Table 3-11 describes, through a sample calculation, how to calculate the drag area for a certification tractor using a coastdown reference tractor and an alternate method. This is the most common way the agencies expect tractor manufacturers to certify their tractors.

Table 3-11 Sample Calculations of Drag Area for Certification Tractor

STEP	**VARIABLE**	**EXAMPLE VALUE OR CALCULATION**
Coastdown of reference tractor	$(C_dA)_{\text{coast}}$	5.208 m^2
	ψ_{eff}	1.6°
Drag area of reference tractor from alternate method at positive and negative effective yaw angle from coastdown	$(C_dA)_{\text{alt}}$ at ±1.6°	5.002 m^2
Alternate Method Factor	$F_{\text{alt-aero}}$	$F_{\text{alt-aero}} = (C_dA)_{\text{coast}} / (C_dA)_{\text{alt},\pm1.6°}$ = 5.208/5.002 = 1.041
Wind-averaged drag area of certification tractor from alternate method	$(C_dA)_{\text{alt}}$ at ±4.5°	5.614 m^2
Adjustment to wind-averaged drag; round final value to one decimal place	$(C_dA)_{\text{wa}}$	$(C_dA)_{\text{alt},\pm4.5°} \times F_{\text{alt-aero}}$ = 5.614 x 1.041 = 5.8 m^2

Using the value of 5.8 m^2, a manufacturer will then identify the appropriate bin for that value and use the associated aerodynamic GEM input for determining CO_2 emissions and fuel consumption. If this tractor were a high-roof sleeper cab tractor, it would fall into Bin III, as per Figure 3-17.

The example described above uses a $F_{alt\text{-}aero}$ value from a single reference tractor. However, the CFD results in Table 3-8 show modest variation of $F_{alt\text{-}aero}$, from 1.13 to 1.20, among the four tractors evaluated using the Exa software. As a result, the agencies are finalizing a requirement to test at least one high-roof sleeper cab and one high-roof day cab from each of model years 2021, 2024, and 2027. The $F_{alt\text{-}aero}$ value will be determined using data from these tractors and any data from selective enforcement audits, as described in 40 CFR 1037.525.

3.2.3 Aerodynamic Test Procedures for Trailers

For Phase 2, the agencies are finalizing CO_2 standards reflecting CO_2 and fuel consumption reductions from trailers. Aerodynamic improvements are among the technologies on which those standards are predicated. New aerodynamic technologies have been implemented on box vans to improve their aerodynamic efficiency and lower overall tractor-trailer fuel consumption. In addition, as discussed in Chapter 3.2.2.1, the agencies have assessed the extent that some of these technologies may migrate to the trailer sector without regulation, and the extent these improvements should be reflected in the standard trailer used in tractor certification testing.

Consistent with the tractor regulations, our aerodynamic assessment of different trailer configurations (applicable to coastdown, constant speed and reduced-scale wind tunnel testing) and trailer types (applicable to reduced scale wind tunnel testing only) was limited to dry box van type trailers of several lengths. Specifics on the applicable trailer types and certification protocols are discussed further in Section IV.D.2, of the Preamble.

The trailer program is also based on wind-averaged drag area. However, unlike the tractor program, trailer manufacturers will generate A to B test values where the “A” represents a baseline test and “B” represents the certification trailer; both tests performed using the same test method and same standard tractor. Subsequently, the trailer manufacturer will input their specific ΔC_dA value in the GEM-based equation, which will determine the appropriate C_dA value, based on the analysis discussed in Chapter 2.10 of the RIA. GEM subtracts the ΔC_dA value from the default C_dA value before running to determine the greenhouse gas emissions for this configuration.

While the aerodynamic test procedures for trailers are based on the same procedures outlined above for tractors, we have made several simplifications for the trailer program. As discussed in the following sections, this rulemaking includes default values for tire rolling resistance effects and axle spin losses in the coastdown test procedures, additional wind restrictions to ensure consistency between A and B coastdown tests, and interim provisions that allow manufacturers to use test results without correction to reference method (i.e., no $F_{alt\text{-}aero}$).

3.2.3.1 Standard Tractor Definition for Trailer Testing

Similar to the standard trailer definition for tractor aerodynamic assessment, the agencies finalized standard tractor definition for trailer aerodynamic assessment. The standard tractor definition is based on attributes of a high-roof tractor equipped with, at a minimum, a roof fairing, cab side extenders and fuel tank/chassis skirts. This tractor must meet a Bin III or better tractor aerodynamic level under either Phase 1 or Phase 2. We believe the majority of tractors in the U.S. trucking fleet will be Bin III or better in the timeframe of this rulemaking and trailer manufacturers have the option to choose higher-performing tractors in later years as tractor technology improves. As with the standard trailer's test article specification for the tractor program, the aerodynamic specification for the standard tractor here is strictly for the purpose of certifying trailers beginning in model year 2018. Because the trailer program begins in model year 2018, before the Phase 2 tractor program, a tractor meeting either the Phase 1 or Phase 2 aerodynamic Bin III or better can be used.

Accordingly, we are finalizing that trailer manufacturers will use this standard tractor definition with their trailers to conduct A to B testing to capture the $\Delta C_d A$ for their trailers that are either: equipped with aerodynamic devices to meet the trailer standards or are designed to be more aerodynamic than current, standard trailers.

For trailer OEMs that are certifying a trailer where devices are added to an existing OEM trailer design, the trailer used for both "A" and "B" tests uses a trailer meeting our standard trailer definition for 53' dry box vans shown above in Chapter 3.2.2.1, without any trailer devices installed (i.e., no skirts); with the same standard reference tractor used for both tests.

In contrast, for trailer OEMs that certify a completely new trailer design, the "A" test uses a trailer meeting our standard trailer definition for 53' dry box vans shown above in Chapter 3.2.2.1, without any trailer devices installed and the "B" test will be the new, OEM trailer design; with a standard reference tractor used for both tests. In summary, the standard reference tractor will be used for all trailer OEM "component" level testing; where the "component" in the B test can range from an add-on trailer device up to a completely different trailer design.

To assist in defining the standard tractor for different trailer types, Table 3-12 shows the trailers modeled in GEM. As mentioned in Section IV of the Preamble to this rulemaking, the trailer program will use a GEM-based equation for compliance with is equivalent to using GEM.

Table 3-12 Description of Baseline Tractor-Trailers Used In GEM from Section IV.D(2)(b)(ii), of the Preamble

TRAILER SUBCATEGORY	FEATURES
Dry van 50 feet and shorter	Class 7 or 8 high-roof day cab, pulling solo 28' dry van $C_d A$ = 5.6, C_{rr} = 6.0 kg/ton
Dry van longer than 50 feet	Class 8 high-roof sleeper cab pulling a solo 53' dry van $C_d A$ = 6.0, C_{rr} = 6.0 kg/ton
Refrigerated van 50 feet and shorter	Class 7 or 8 high-roof day cab pulling a solo 28' ref van $C_d A$ = 5.6, C_{rr} = 6.0 kg/ton
Refrigerated van longer than 50 feet	Class 8 high-roof sleeper cab pulling a solo 53' ref van $C_d A$ = 6.0, C_{rr} = 6.0 kg/ton

Based on this table, we are finalizing standard tractor definitions based on tractor type and attributes that reflect the types of tractors used for trailers in each of these subcategories.

Specifically, we are finalizing that tractors for all trailers longer than 50 feet shall use a standard tractor meeting the following criteria for A to B testing: a Class 8, high-roof sleeper cab, tandem axle tractor that meets a Phase 1 or Phase 2 Bin III or better Class 8 high roof sleeper cab tractor aerodynamic level. For all trailers 50 feet and shorter, a standard tractor meeting the following criteria shall be used for A-B testing: Class 7 or 8, high-roof day cab, 4x2 drive axle configuration tractor that meets a Phase 1 or Phase 2 Bin III or better Class 7 or 8 high roof day cab tractor aerodynamic level.

Table 3-13 Characteristics of Standard Tractor for Aerodynamic Assessment of Trailers

TRAILER LENGTH	STANDARD TRACTOR FEATURES
Box trailers 50 feet and longer	Class 8 high roof sleeper cab Dual-axle (6x4) Bin III or better tractor (Phase 1 or Phase 2) Cab Side extenders Fuel tank cover/Chassis Skirts Roof Fairing
Box trailers shorter than 50 feet	Class 7 or 8 high roof day cab Single drive axle (4x2) Bin III or better tractor (Phase 1 or Phase 2) Cab Side extenders Fuel tank covers/Chassis Skirts Roof Fairing

3.2.3.2 Aerodynamic Methods

The comprehensive testing program and analysis of the various test procedures described in the tractor aerodynamics sections above led to finalization of the various aerodynamic test procedures. The trailer program will use the same coastdown, wind tunnel, and CFD test procedures, with very minor differences.

To reduce test burden for trailer manufacturers, we are not considering coastdown as the reference method for the trailer aerodynamic test program. Instead we expect manufacturers will use wind tunnel or CFD for their aerodynamic assessment. Analysis from RIA 2.10 showed that there were not drastic differences between these two aerodynamic methods for measuring wind-averaged drag. As a result, we are finalizing interim provisions allowing methods that meet the wind tunnel and CFD requirements in 40 CFR 1037.527 and 1037.529 to be used to calculate the appropriate $\Delta C_d A$ without correcting to a reference method. See 40 CFR 1037.150(x)

Coastdowns will still be an allowable method for the trailer program. In particular, coastdown tests may be useful for technologies that cannot be modeled with sufficient fidelity in scale wind tunnels or CFD simulations. Additionally, coastdowns will also be options for confirmatory testing or Selective Enforcement Audits (SEA) due to the complications associated with requiring scale models or CFD simulations.

The agencies considered using coastdown as a reference method, similar to the tractor program. However, the use of $\Delta C_d A$ was found to amplify some of the variability from the found in the full-scale coastdown procedure. With the standard error of the $C_d A$ result from coastdowns around 1 percent, this error can propagate significantly when determining $\Delta C_d A$ from two coastdown tests. For example, a coastdown with particular trailer technology measures a drag area of 5.7 m^2 compared to a baseline of 6.0 m^2 for a $\Delta C_d A$ of 0.3 m^2. Assuming a 1 percent standard error on both the baseline and test configurations yields a 0.060 m^2 and 0.057 m^2 standard errors, respectively. The standard error of the $\Delta C_d A$ value is the root mean square of the two uncertainties, or 0.08 m^2, which is about 27 percent of the $\Delta C_d A$ value. This relative standard error of the $\Delta C_d A$ would tend to decrease as $\Delta C_d A$ increases. However, it could require many additional coastdown runs to significantly reduce the uncertainty, which could significantly increase test burden on trailer manufacturers.

The uncertainty propagation, additional test burden, and our results from RIA Chapter 2.10 showing that the near-zero yaw angles of coastdown testing will likely cause an underestimation of $\Delta C_d A$ for some drag-reducing technologies, made us reconsider coastdown as a reference method for the tractor program.

3.2.3.2.1 Simplifications to the Coastdown Test Procedures for the Trailer Program

The trailer coastdown test procedure must meet the requirements in 40 CFR 1037.526, which are very similar to the coastdown procedure for tractors. However, trailer manufacturers will not be responsible for including the tire rolling resistance or spin loss corrections required for tractors. Instead, the agencies have developed default values that trailer manufacturers must apply to their coastdown results. Unlike the tractor tests, default values are reasonable for the trailer program because the same tires and axle (and tractor) must be used between the baseline t and the certification tests, which means the same losses would be subtracted out of the calculations in each case.

As described in Chapter 3.2.2.2, the agencies found a variation of 200 to 219 N in tire rolling resistance increase from the low-speed range to the high-speed range for 53’ box vans. The same analysis showed a range of 140 to 155 N using the approximate weight distribution for an empty single 28’ box van pulled by a 4x2 high-roof day cab tractor. This was a total weight of 25,000 lbs, distributed at 38 percent, 37 percent, and 25 percent over the steer, drive, and trailer axle, respectively. As a result, the agencies are finalizing a default tire rolling resistance force increase of 215 N for long box vans and 150 N for short box vans using the coastdown procedure. Though these are default values to be used in the $\Delta C_d A$ determination for trailers, they must be adjusted for ambient temperature, which is based on the temperature correction in ISO 28580 for truck and bus tires with higher load indices. The temperature correction is necessary because the ambient temperature could be significantly different between the baseline test and the certification configuration test.

The agencies are also finalizing a single default drive axle spin loss increase, ΔF_{spin} for trailer coastdown procedures. Our default value of 110 N is based on a linear extrapolation of the proposed value (100 N) to the lower low-speed range that we are finalizing. No temperature adjustment is required for the drive axle spin loss.

3.2.3.2.2 Wind Considerations in the Coastdown Test Procedures for the Trailer Program

It should be noted that coastdown tests, as described in the tractor program discussions above, do not measure wind-averaged drag. As a result, the $\Delta C_d A$ from coastdown tests may understate the aerodynamic improvements of some devices compared to other methods, given that many trailer technologies are effective at higher yaw angles. The agencies are not requiring manufacturers to adjust their coastdown results to a wind-averaged result, as described in

Chapter 3.2.1.1.3 for tractors. Instead, our interim trailer provisions (40 CFR 1037.150(x)) allow manufacturers to choose to adopt their near-zero yaw $\Delta C_d A$ value from testing for compliance, or correct their test result to a wind-averaged result using good engineering judgment.

Yaw effects are also important in terms variability between baseline (A) and certification (B) results from coastdown tests. Manufacturers performing coastdown tests would follow similar procedures as those outlined in Chapter 3.2.2.2.1 to determine the validity of their coastdown runs. In an effort to reduce variability, we are limiting the difference in the effective yaw angle, ψ_{eff}, between the baseline and test configurations to ±1.0 degrees.

3.3 Tire Rolling Resistance

The agencies are finalizing the use of the ISO 28580 test method to determine rolling resistance and the coefficient of rolling resistance. A copy of the test method can be obtained through the American National Standards Institute.[18] Note that because measurement of rolling resistance is a continuation of the Phase 1 structure and the Phase 1 requirements serve as the baseline for Phase 2, the agencies are not including any additional compliance margins in our analysis of the feasibility of lower rolling resistance tires.

3.3.1 Reason for Using ISO 28580

EPA's SmartWay Partnership Program started to identify equipment and feature requirements for SmartWay-designated Class 8 over-the-road tractors and trailers in 2006. In order to develop a tire rolling resistance specification for SmartWay-designated commercial trucks, EPA researched different test methods used to evaluate tire rolling resistance, reviewing data and information from tire manufacturers, testing laboratories, the State of California, the Department of Transportation, tractor manufacturers, and various technical organizations. After assessing this information, EPA determined that its SmartWay program will use the SAE J1269[19] tire rolling resistance method until the ISO 28580[20] method (at that time under development) was finalized, at which time the Agency will consider moving to this method for its SmartWay program.

During this same time period, the National Highway Traffic Safety Administration (NHTSA) conducted an evaluation of passenger vehicle tire rolling resistance test methods and their variability.[21] Five different laboratory test methods at two separate labs were evaluated. The NHTSA study focused on passenger tires; however, three of the four test methods evaluated can be used for medium-duty and heavy-duty tractor tires. The methods evaluated were SAE J1269, SAE J2452[22] (not applicable for medium-duty or heavy-duty tractor tires), ISO 18164[23] and ISO 28580. The NHTSA study showed significant lab to lab variability between the labs used. The variability was not consistent between tests or types of tire within the same test. The study concluded that a method to account for this variability is necessary if the rolling resistance value of tires is to be compared (NHTSA, 2009). Because of laboratory variability, NHTSA recommended that the use of ISO 28580 is preferred over the other test methods referenced.

ISO 28580 is preferred because the test method involves laboratory alignment between a "reference laboratory" and "candidate laboratory." The ISO technical committee involved in developing this test method also has the responsibility for determining the laboratory that will serve as the reference laboratory. The reference laboratory will make available an alignment tire that can be purchased by candidate laboratories. The candidate laboratory will identify its reference machine. However, at this time, the reference laboratory and alignment tires have not been identified.

3.3.2 Measurement Method and Results

The ISO 28580 test method includes a specific methodology for "light truck, commercial truck and bus" tires, and it has 4 measurement methods, force, torque, deceleration, and power, all of which appear to be suitable for use.

The results of the ISO 28580 test are intended for use in vehicle simulation modeling, such as the model used to assess the effects of various technology options for national greenhouse gas and fuel economy requirements for commercial trucks (see Chapter 4). The results are usually expressed as a rolling resistance coefficient and measured as kilogram per metric ton (kg/metric ton) or as dimensionless units (1 kg/metric ton is the same as the dimensionless unit 0.001). The results are corrected for ambient temperature drum surface and drum diameter as specified in the test method.

3.3.3 Sample Size

The rolling resistance of tires within the same model and construction are expected to be relatively uniform. In the study conducted by NHTSA, only one individual tire had a rolling resistance value that was significantly different from the other tires of the same model. The effect of production variability can be further reduced by conducting three replicate tests and using the average as the value for the rolling resistance coefficient. Tire models available in multiple diameters may have different values of rolling resistance for each diameter because larger diameter tires can produce lower rolling resistance than smaller diameters under the same load and inflation conditions. If the size range within a tire model becomes large enough that a given tire size is no longer "substantially similar" in rolling resistance performance to all other tire sizes of that model, then good engineering judgment should be exercised as to whether the differently-sized tire shall be treated, for testing and vehicle simulation purposes, as a distinct tire model. For Class 8 tractors that typically use tires that fit on 22.5" or 24.5" wheels, this situation might occur with 17.5" tires, more commonly used on moving vans and other applications that require a low floor.

3.3.4 Tire Size

In Phase 2, the agencies will require manufacturers to enter tire revolutions per mile as a GEM input. While this rulemaking does not include tire size among the technologies applied to improve fuel efficiency, this measurement is among the driveline parameters necessary for GEM to calculate a vehicle speed for a given engine speed. Because there is a wide range of possible measurements for revolutions per mile, the agencies are specifying a measurement procedure. In the first 100-200 miles of a tire's useful life, there will be a break-in process during which a commercial tire can "grow" one to two percent, up to 18 mm. Because this growth affects the air pressure in the tire, it's important to specify the air pressure under which the measurement is performed. The Society of Automotive Engineers (SAE) has published recommended practice

J1025 for determining the revolutions per mile of new truck tires.[24] Consistent with that recommended practice, the agencies are finalizing that manufacturers will quantify the revolutions per mile of the drive tire, NIST traceable within ±0.5 percent uncertainty, by measuring the number of revolutions of the loaded tire installed on the vehicle per unit distance to the surface on which it is rolling. Load the tire to the maximum load capacity specified by the manufacturer, at the corresponding air inflation level. See 40 CFR 1037.520(c).

3.4 Duty Cycle

Certification duty cycles have a significant impact on the GHG emissions from a truck and how technologies are assessed. Every truck has a different duty cycle in-use. Therefore, it is very challenging to develop a uniform duty cycle which accurately assesses GHG improvements and fuel efficiency from technologies relative to their performance in the real world.

The duty cycle attributes that impact a vehicle's performance include average speed, maximum speed, acceleration rates, deceleration rates, number of stops, road grade, power take-off operation, and idling time. Average and maximum speeds are the attributes which have the greatest impact on aerodynamic technologies. Vehicle speed also impacts the effect of low rolling resistance tires. The effectiveness of extended idle reduction measures is determined by the amount of time spent idling. Lastly, hybrid technologies demonstrate the greatest improvement on cycles which include a significant amount of stop-and-go driving due to the opportunities to recover braking energy. In addition, the amount of power take-off operation will impact the effectiveness of some vocational hybrid applications.

The ideal duty cycle for a line-haul truck will account for a significant amount of time spent cruising at high speeds. A pickup and delivery truck duty cycle will contain a combination of urban driving, some number of stops, and limited highway driving. Finalizing an ill-suited duty cycle for a regulatory subcategory could drive technologies where they may not see in-use benefits. For example, requiring all trucks to use a constant speed highway duty cycle will drive significant aerodynamic improvements. However, in the real world a pickup and delivery truck may spend too little time on the highway to realize the benefits of aerodynamic enhancements. In addition, the extra weight of the aerodynamic fairings will actually penalize the GHG performance of that truck in urban driving and may reduce its freight carrying capability.

3.4.1 Duty Cycles Considered

In Phase 1, the agencies selected three duty cycles for certification testing: the Transient portion of the California Air Resource Board (CARB) Heavy Heavy-Duty Truck 5 Mode Cycle, 55 mph cruise (without grade), and 65 mph cruise (without grade).

For Phase 2, the agencies carefully considered which duty cycles are appropriate for the different regulatory subcategories. We considered several duty cycles in the development of the rulemaking including EPA's MOVES model; the Light-Duty FTP75 and HFET; Heavy-Duty UDDS; World Wide Transient Vehicle Cycle (WTVC); Highway Line Haul; Hybrid Truck User Forum (HTUF) cycles; and California CARB's Heavy-Heavy-Duty Truck 5 Mode Cycle.

MOVES Medium-Duty and Heavy-Duty schedules were developed based on three studies. Eastern Research Group (ERG) instrumented 150 medium and heavy-duty vehicles, Battelle instrumented 120 vehicles instrumented with GPS, and Faucett instrumented 30 trucks to characterize their in-use operation.[25] ERG then segregated the driving into freeway and non-freeway driving for medium and heavy-duty vehicles, and then further stratified vehicle trips according the predefined ranges of average speed covering the range of vehicle operation. Driving schedules were then developed for each speed bin by creating combinations of idle-to-idle "microtrips" until the representative target metrics were achieved. The schedules developed by ERG are not contiguous schedules which will be run on a chassis dynamometer, but are made up of non-contiguous "snippets" of driving meant to represent target distributions. This gives MOVES the versatility to handle smaller scale inventories, such as intersections or sections of interstate highway, independently.

The FTP75 and HFET duty cycles are used extensively for Light-Duty emissions and CAFE programs. Our assessment is that these cycles are not appropriate for HD trucks for two primary reasons. First, the FTP has 24 accelerations during the cycle which are too steep for a Class 8 combination tractor to follow. Second, the maximum speed is 60 mph during the HWFEC, while the national average truck highway speed is 65 mph.

The Heavy-Duty Urban Dynamometer Driving Cycle was developed to determine the Heavy-Duty Engine FTP cycle. The cycle was developed from CAPE-21 survey data which included information from 44 trucks and 3 buses in Los Angeles and 44 trucks and 4 buses in New York in 1977. The cycle was computer generated and weighted to represent New York non-freeway (254 sec), Los Angeles non-freeway (285 sec), Los Angeles freeway (267 sec), New York non-freeway (254 sec) to produce a nearly 50/50 weighting of highway cruise and urban transient. We believe this cycle is not appropriate for our program for several reasons. The maximum speed on the UDDS is 58 mph which is low relative to the truck speed limits in effect today. The 50/50 weighting of cruise to transient is too low for combination tractors and too high for vocational vehicles and the single cycle does not provide flexibility to change the weightings. Lastly, the acceleration rates are low for today's higher power trucks.

The World Harmonized WTVC was developed by the UN ECE GRPE group. It represents urban, rural, and motorway operation. The cycle was developed based on data from 20 straight trucks, 18 combination tractors, and 11 buses total from Australia, Europe, Japan, and the US. EPA has a desire to harmonize internationally, however, we believe that this single cycle does not optimally cover the different types of truck operation in the United States and does not provide the flexibility to vary the weightings of a single cycle.

The Highway Line Haul schedule was created by Southwest Research Institute, using input from a group of stakeholders, including EPA, Northeastern States for Coordinated Air Use Management (NESCAUM), several truck and engine manufacturers, state organizations, and others, for a NESCAUM heavy truck fuel efficiency modeling and simulation project. The cycle is 103 miles long and incorporates grade and altitude. This cycle is a good representation of line haul operation. However, the altitude changes cannot be incorporated into a chassis dynamometer or track test and the cycle is also too long for a typical chassis dynamometer test.

The Calstart-Weststart Hybrid Truck Users Forum is developing cycles to match the characteristics of truck applications which are expected to be first to market for hybrids. The cycles include the Manhattan Bus Cycle, Orange County Bus Cycle, Class 4 Parcel Delivery, Class 6 Parcel Delivery, Combined International Local and Commuter Cycle (CILCC), Neighborhood Refuse, Utility Service, and Intermodal Drayage cycles. The cycles are very application-specific and appropriately evaluate each vocation. However, the use of these types of application specific cycles in a regulatory scheme will lead to a proliferation of cycles for every application, an outcome that is not desirable.

The CARB 5 Mode cycle was developed by California CARB from heavy-duty truck data gathered from 1997 through 2000.[26] Data was collected from real world driving from randomly selected vehicles. The data was gathered from 140 heavy-duty trucks by Battelle and from 31 heavy-duty trucks in a study conducted by Jack Faucett and Associates. The final data set included 84 of these heavy duty trucks covering over 60,000 miles and 1,600 hours of activity. The cycles were developed to reflect typical in-use behavior as demonstrated from the data collected. The four modes (idle, creep, transient, and cruise) were determined as distinct operating patterns, which then led to the four drive schedules. The cycle is well accepted in the heavy-duty industry. It was used in the CRC E55/59 Study which is the largest HD chassis dynamometer study to date and used in MOVES and EMFAC to determine emission rate inputs; EPA's biodiesel study which used engine dynamometer schedules created from CARB cruise cycle; the HEI ACES Study: WVU developed engine cycles from CARB 4-mode chassis cycles; CE/CERT test; and by WVU to predict fuel efficiency performance on any duty cycle from CARB 5 mode results. The modal approach to the cycles provides flexibility in cycle weightings to accommodate a variety of truck applications. A downside of the cycle is that it was developed from truck activity in California only.

3.4.2 Duty Cycles

3.4.2.1 Highway Cruise Cycles

The agencies analyzed the average truck speed limit on interstates and other freeways to identify the appropriate speed of the highway cruise cycles. State speed limits for trucks vary between 55 and 75 mph, depending on the state.[27] The median urban and rural interstate speed limit of all states is 65 mph. The agencies also analyzed the speed limits in terms of VMT-weighting. The agencies used the Federal Highway Administration data on Annual Vehicle Miles for 2008 published in November 2009 to establish the vehicle miles travelled on rural and urban interstates broken down by state. The VMT-weighted national average speed limit is 63 mph based on the information provided in Table 3-14. The results of this analysis led to the adoption of the High Speed (65 mph) and Low Speed (55 mph) Cruise duty cycles in Phase 1.

Table 3-14 VMT-Weighted National Truck Speed Limit

STATE	RURAL INTERSTATE SPEED LIMIT	URBAN INTERSTATE SPEED LIMIT	RURAL INTERSTATE MILES	URBAN INTERSTATE AND OTHER FREEWAYS MILES	U.S. WEIGHTED VMT FRACTION RURAL	U.S. WEIGHTED VMT FRACTION URBAN	VMT WEIGHTED SPEED LIMIT
AL	70	65	5,643	7,950	0.6%	0.8%	0.968
AK	55	55	803	662	0.1%	0.1%	0.086
AZ	75	65	6,966	13,324	0.7%	1.4%	1.474
AR	65	55	4,510	4,794	0.5%	0.5%	0.591
CA	55	55	17,681	123,482	1.9%	13.1%	8.242
CO	75	65	4,409	11,745	0.5%	1.2%	1.161
CN	65	55	715	13,485	0.1%	1.4%	0.837
DE	55	55	-	1,694	0.0%	0.2%	0.099
DC	55	55	-	813	0.0%	0.1%	0.047
FL	70	65	9,591	37,185	1.0%	3.9%	3.279
GA	70	55	9,433	21,522	1.0%	2.3%	1.958
HA	60	60	110	2,403	0.0%	0.3%	0.160
ID	65	65	2,101	1,250	0.2%	0.1%	0.231
IL	65	55	8,972	23,584	1.0%	2.5%	1.996
IN	65	55	7,140	10,850	0.8%	1.2%	1.126
IA	70	55	4,628	2,538	0.5%	0.3%	0.492
KA	75	75	3,242	5,480	0.3%	0.6%	0.694
KE	65	65	6,566	6,834	0.7%	0.7%	0.925
LA	70	70	5,489	7,708	0.6%	0.8%	0.981
ME	65	65	2,207	958	0.2%	0.1%	0.218
MA	65	65	3,484	18,792	0.4%	2.0%	1.537
MS	70	70	1,257	20,579	0.1%	2.2%	1.623
MI	60	60	5,245	20,931	0.6%	2.2%	1.667
MN	70	60	4,150	12,071	0.4%	1.3%	1.077
MS	70	70	4,103	4,004	0.4%	0.4%	0.602

STATE	RURAL INTERSTATE SPEED LIMIT	URBAN INTERSTATE SPEED LIMIT	RURAL INTERSTATE MILES	URBAN INTERSTATE AND OTHER FREEWAYS MILES	U.S. WEIGHTED VMT FRACTION RURAL	U.S. WEIGHTED VMT FRACTION URBAN	VMT WEIGHTED SPEED LIMIT
MO	70	60	5,972	16,957	0.6%	1.8%	1.524
MT	65	65	2,350	343	0.2%	0.0%	0.186
NE	75	65	2,590	1,653	0.3%	0.2%	0.320
NV	75	65	1,826	5,286	0.2%	0.6%	0.510
NH	65	65	1,235	2,574	0.1%	0.3%	0.263
NJ	65	55	1,609	25,330	0.2%	2.7%	1.590
NM	75	65	4,530	2,667	0.5%	0.3%	0.545
NY	65	55	6,176	37,306	0.7%	4.0%	2.604
NC	70	70	5,957	19,216	0.6%	2.0%	1.871
ND	75	75	1,394	374	0.1%	0.0%	0.141
OH	65	65	9,039	27,830	1.0%	3.0%	2.544
OK	75	70	5,029	7,223	0.5%	0.8%	0.937
OR	55	55	4,109	5,734	0.4%	0.6%	0.575
PA	65	55	10,864	21,756	1.2%	2.3%	2.020
RI	65	55	404	2,948	0.0%	0.3%	0.200
SC	70	70	7,355	6,879	0.8%	0.7%	1.058
SD	75	75	1,960	648	0.2%	0.1%	0.208
TN	70	70	8,686	13,414	0.9%	1.4%	1.642
TX	70	70	15,397	71,820	1.6%	7.6%	6.481
UT	75	65	3,117	6,165	0.3%	0.7%	0.674
VT	65	55	1,216	443	0.1%	0.0%	0.110
VA	70	70	8,764	18,907	0.9%	2.0%	2.056
WA	60	60	4,392	15,816	0.5%	1.7%	1.287
WV	70	65	3,195	3,175	0.3%	0.3%	0.456
WI	65	65	5,197	9,139	0.6%	1.0%	0.989
WY	75	75	2,482	474	0.3%	0.1%	0.235

In establishing the highway cruise cycles in Phase 1, we did not address the effect of road grade on emissions. For Phase 2, where road grade-sensitive technologies like transmission and driveline improvements are expected to be key technologies utilized for compliance, we have altered the High Speed Cruise and Low Speed Cruise modes to reflect road grade. Based on input from trucking fleets and truck manufacturers, we believe this is representative of in-use operation, wherein truck drivers use cruise control whenever possible during periods of sustained higher speed driving and variable road grade.

The U.S. Department of Energy and EPA partnered on a project aimed at evaluating, refining, and developing an appropriate road grade profile for the cruise duty cycles that could be used in the certification of heavy-duty vehicles to the GHG emission and fuel efficiency Phase 2 standards. The National Renewable Energy Laboratory (NREL) led the project which resulted in a refinement of the existing highway cruise duty cycles. In the course of their work, NREL developed several activity-weighted road grade profiles which are representative of U.S. limited-access highways using high-accuracy road grade and county-specific data for vehicle miles traveled. This analysis resulted in a single distance-based road grade profile that is representative of the nation's limited-access highways. To build on the NREL work, the agencies have incorporated data from the NREL analysis into a different methodology, and have developed a road grade profile for use with the 55 mph and 65 mph highway cruise cycles.

This following section describes the development of candidate nationally representative, activity weighted road grade profiles by the agencies as alternatives to the profiles developed by the National Renewable Energy Laboratory (NREL) and described in report entitled "EPA GHG Certification of Medium- and Heavy-Duty Vehicles: Development of Road Grade Profiles Representative of US Restricted Access Highways."[28]

The agencies' profile is based on the same national half hill database that was used by NREL, but relies on a different methodology of defining the parameters of its constituent half hills. It is a goal of the agencies to select the most appropriate road grade profile(s) on the basis of being nationally representative as well as reasonably similar to real-world driving conditions.

The agencies' profile relies on direct characterization of the whole activity weighted national half hill population, not on random sampling from that population. This profile consists of half hills representing unique, yet contiguous segments of that population. Any half hill in this profile is associated with a single such segment and vice versa. The activity assigned to any one of those segments, defined in the NREL report as vehicle miles travelled (VMT) by medium-duty and heavy-duty vehicles on restricted access highways, is calculated as the sum of activities of its constituent half hills. The parameters of each half hill in the profile, such as length, average grade, maximum grade or grade distribution, are based on parameters of the half hills constituting the particular segment. This provides a clear interpretation of why a particular half hill in the profile is associated with a particular length and grade distribution.

The whole national half hill population is split into segments in such a way that the lengths of all half hills in the nationally representative profile are directly proportional to the share of activity their segments represent. This enables proper activity weighting of all profile parameters and characteristics. For the half hill length the process, illustrated in Figure 3-22, starts with defining the length of the longest half hill, as this parameter establishes the total length of the profile. In this particular example, the desired length of the profile was 11 to 12 miles. All half hills spanning the 55 to 75 mph range of truck speed limits in the NREL database were used. Their lengths ranged from 0.01 to 24.98 miles.

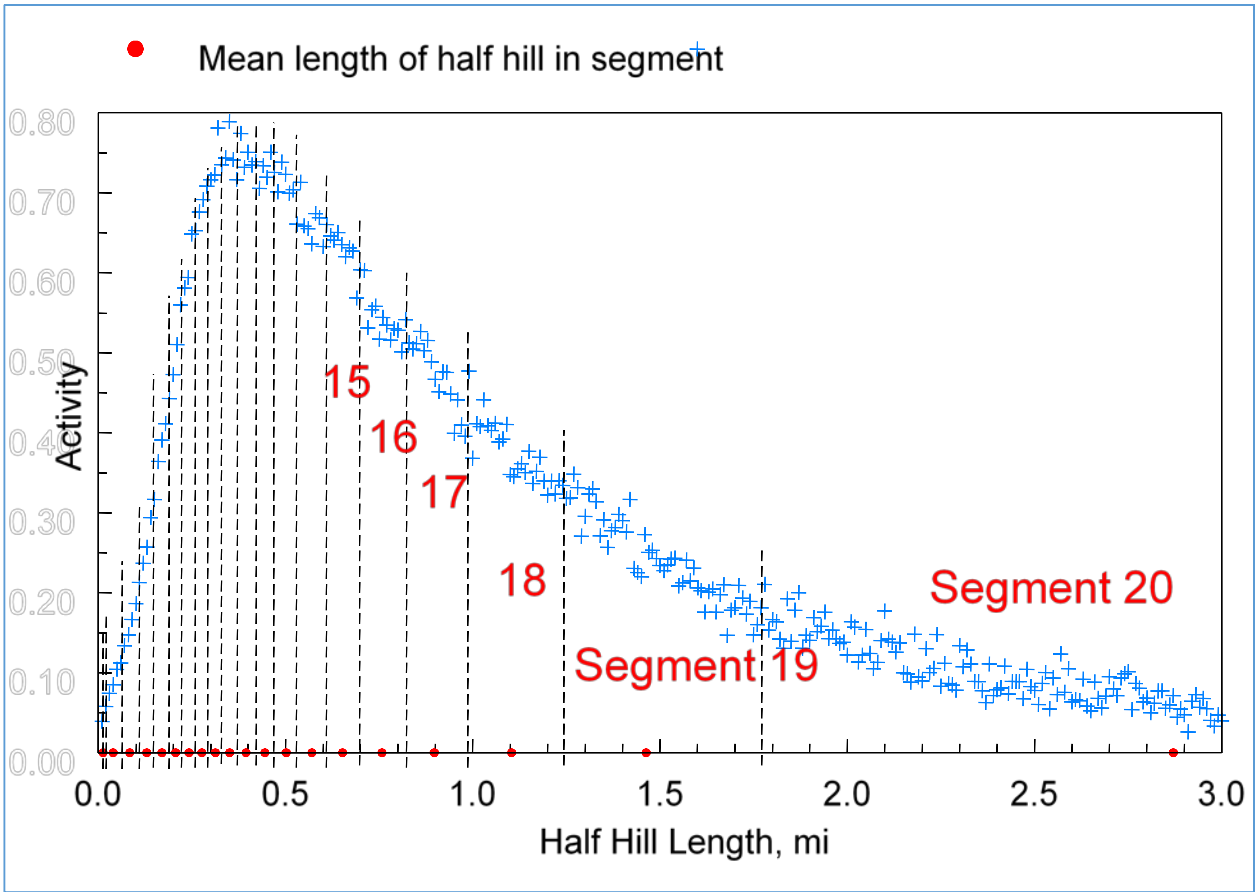


Figure 3-22 Segmentation of the Half Hill Dataset

Based on prior experience with profile designs, it was estimated that the longest half hill in the profile should not exceed 3.0 miles if the above requirement was to be met. After some iteration, the agencies settled on 2.78 miles in this particular example. This half hill length was the arithmetic mean length of the 8,402 longest half hills in the database representing 25 percent of activity. This defined the bounds of Segment 20 (1.77 and 24.98 miles) as shown in Figure 3-22. The ratio of half hill length to normalized activity identified for Segment 20 (namely 2.87/0.25 = 11.48), was subsequently used as the main criterion in defining the lengths of all the remaining half hills of the profile. Specifically, starting with the lower bound of Segment 20 as the upper bound of Segment 19, the lower bound of Segment 19 was shifted left until the ratio of mean half hill length for this segment to normalized activity reached 11.48. This process was successfully repeated until the whole half hill dataset was exhausted in Segment 1. Detailed results of this process are provided in Table 3-15.

Table 3-15 Segmentation of the Half Hill Dataset.

Segment	Activity	Activity (A)	Mean Half Hill Distance (D)	D/A
	%	-	mi	-
1	0.1	0.001	0.01	16.43
2	0.3	0.003	0.04	11.49
3	0.7	0.007	0.08	11.48
4	1.1	0.011	0.13	11.48
5	1.5	0.015	0.17	11.48
6	1.8	0.018	0.21	11.48
7	2.1	0.021	0.24	11.48
8	2.4	0.024	0.28	11.48
9	2.7	0.027	0.31	11.48
10	3.1	0.031	0.35	11.48
11	3.4	0.034	0.39	11.48
12	3.9	0.039	0.44	11.48
13	4.4	0.044	0.50	11.48
14	5.0	0.050	0.57	11.48
15	5.7	0.057	0.65	11.48
16	6.6	0.066	0.76	11.48
17	7.8	0.078	0.90	11.48
18	9.6	0.096	1.10	11.48
19	12.7	0.127	1.46	11.48
20	25.0	0.250	2.87	11.48

The activity weighted distribution of half hills identified in the segmentation process described above is compared in Figure 3-23 to the national activity weighted, cumulative distribution of half hill length. At first look, the two distributions do not match. For example, the first one attains the 100 percent of cumulative activity at 2.87 miles and the other at 24.98 miles. However, the half hills identified in the segmentation process represent ranges of half hill length associated with the respective segments of the national half hill population. The cumulative activity associated with any of those segments is therefore not represented by the mean half hill length but by the upper bounds of the respective segments. This is illustrated in Figure 3-23 using the example of Segment 19. More specifically, the horizontal line representing cumulative activity associated with Segment 19 intersects the upper bound of this segment at a point located on the line representing the national distribution of half hill length. The same is true of all remaining half hills constituting this profile.

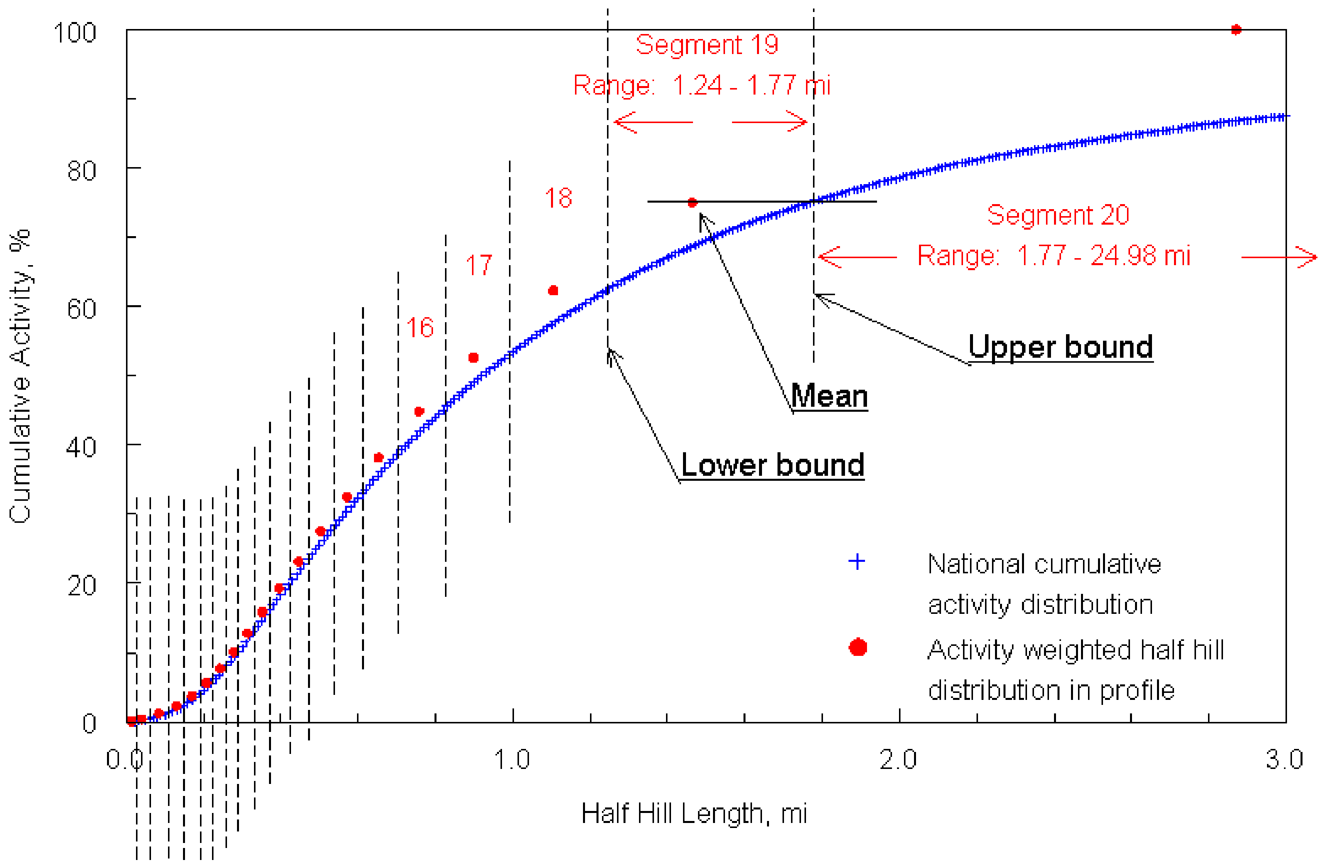


Figure 3-23 Cumulative, Activity Weighted Distributions of Half Hill Lengths in the NREL Database and In the Candidate Profile.

Once the methodology of defining the lengths of half hills in the nationally representative, activity weighted profiles was established, a method of designing road grade contours for the individual half hills was developed. To this end, NREL was requested to generate road grade data in 0.01 mile increments for the half hill population of each segment of the profile. This was done to ensure that the contours of each half hill in the profile would accurately represent the finer details of road grade characteristic of that segment. Activity data were then applied to the grades of those 0.01 mile roadway sections and cumulative distributions of road grade were created for each half hill of the profile. One such distribution is shown in Figure 3-24.

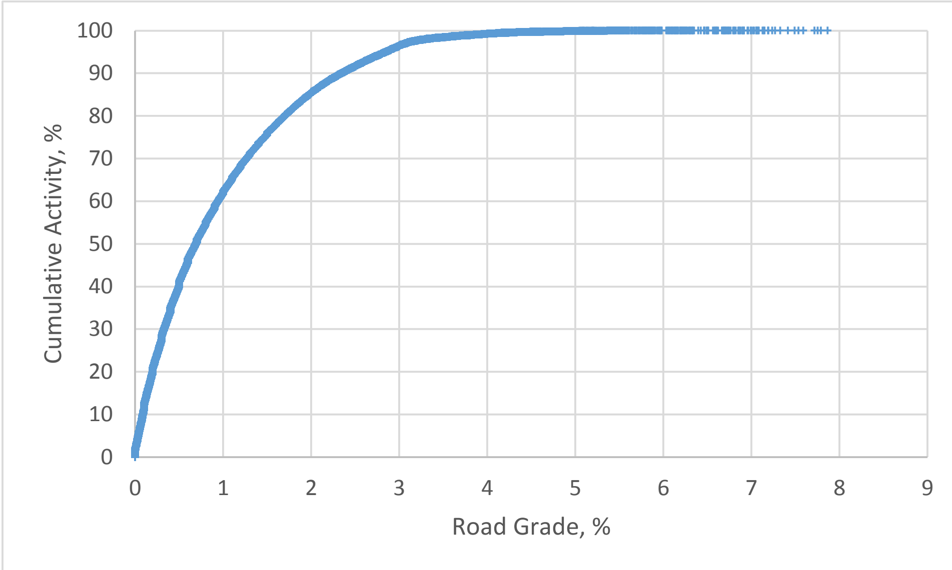


Figure 3-24 Example of Cumulative, Activity Weighted Distribution of Road Grade

These distributions were subsequently applied to the respective half hills of the profile. More specifically, the length of each half hill was split in half and the cumulative distribution of the 0.01 mile road grade sections was superimposed symmetrically onto each half in such a way that activity was now represented by the distance driven along the half hill. The symmetrical arrangement was employed to simulate the shape of half hill contours encountered on roadways and to ensure smooth transition to and from zero slope at each end of the half hill. This arrangement enabled half hill specific, activity weighted road grade to be applied individually to each half hill of the profile. The progression of road grade and the corresponding change in elevation along the length of a 556 m long half hill are illustrated in Figure 3-25 and Figure 3-26. The data are plotted in 2 m increments of half hill distance, a format used in the GEM.

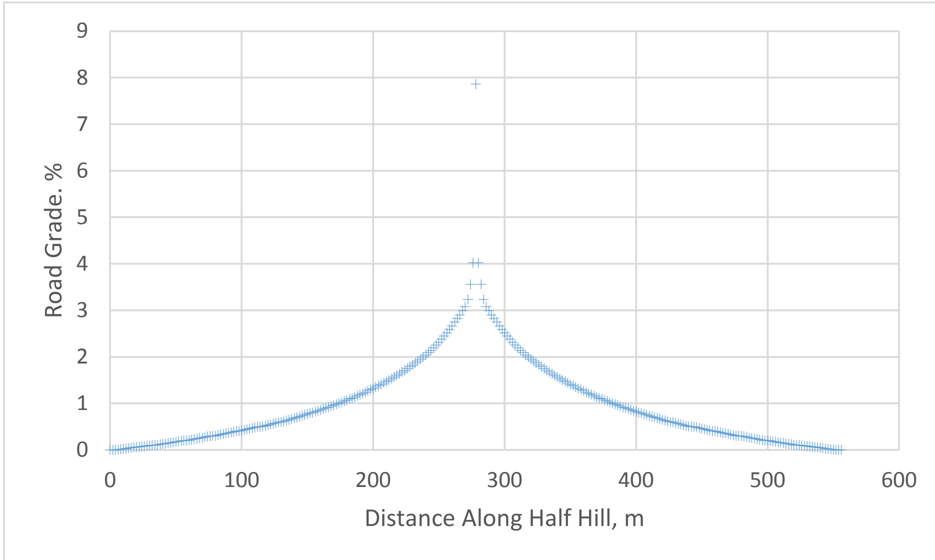


Figure 3-25 Progression of Road Grade along the Length of A Half Hill.

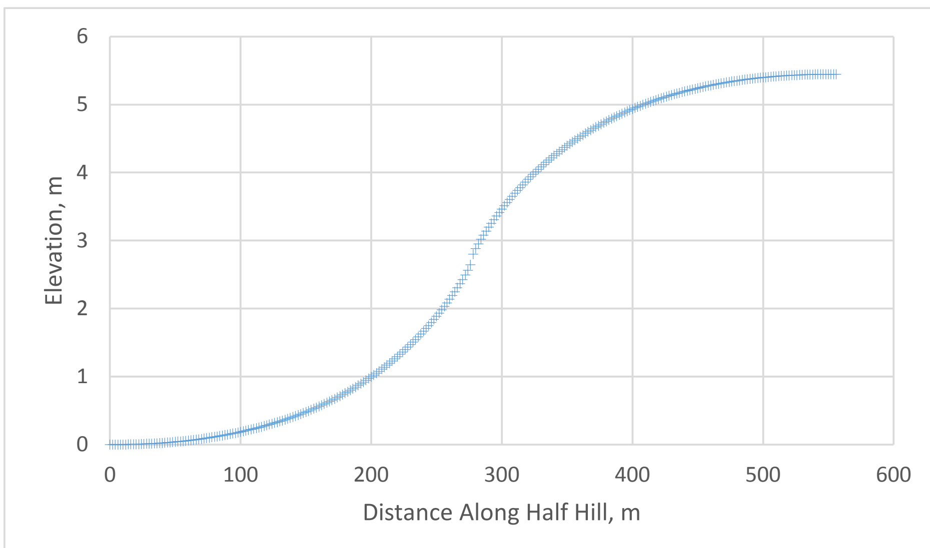


Figure 3-26 Change in Elevation along the Length of A Half Hill.

While accurately representing the distributions characteristic of the respective segments of the half hill population, the road grade contours incorporated in the half hills of the profile included high peaks in the middle section. These peaks were softened by capping them at the 98^{th} percentile of the segment's grade distribution. Hence, grades < 98^{th} percentile were kept unchanged, while grades ≥ 98^{th} percentile were set equal to the 98^{th} percentile. Capping of the grade had an insignificant impact on the overall elevation change. An example of such a modified contour is illustrated in Figure 3-27 and Figure 3-28 for the half hill whose original parameters were shown in Figure 3-25 and Figure 3-26.

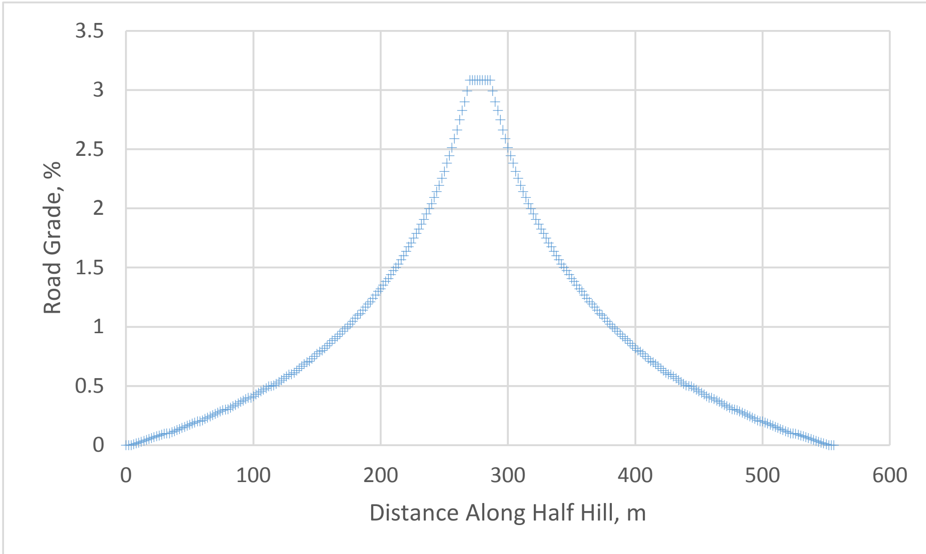


Figure 3-27 Progression of Road Grade along The Length of a Half Hill (98th percentile version).

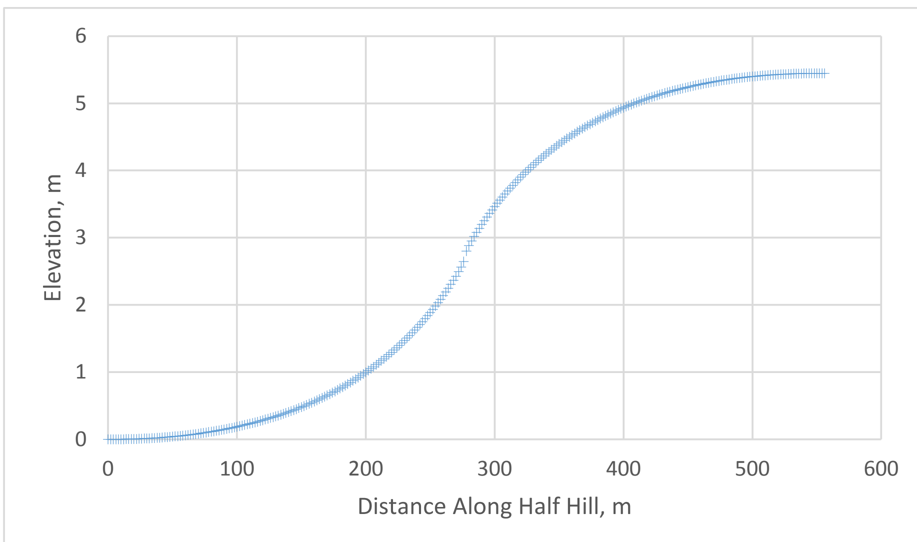


Figure 3-28 Change in Elevation along the Length of a Half Hill (98th percentile version).

Once the lengths and road grade contours of the half hills were defined, they were used to construct various versions of the profile. In the process, the signs of road grade in the consecutive half hills were alternated, though this is not a firm requirement, and the half hills were sequenced in such a way as to ensure that the profile starts and ends at the same elevation. In fact, in neither of the developed profiles did that overall elevation change exceed 10 cm. In all, the following four road grade profiles were constructed:

- Profile A: A 20 km asymmetric profile representing US restricted access highways with truck speed limits of 55 to 75 mph and its reversed version. The progressions of road grade and elevation along the length of this profile are shown in Figure 3-29 and Figure 3-30, respectively.
- Profile B: A 20 km asymmetric profile representing US restricted access highways with truck speed limits of 55 to 60 mph and its reversed version.
- Profile C: A 20 km asymmetric profile representing US restricted access highways with truck speed limits of 65 to 75 mph and its reversed version.
- Profile D: A 20 km symmetric profile representing US restricted access highways with truck speed limits of 55 to 75 mph consisting of a 10 km segment and its reversed twin. The progressions of the road grade along the length of this profile is shown in Figure 3-31.

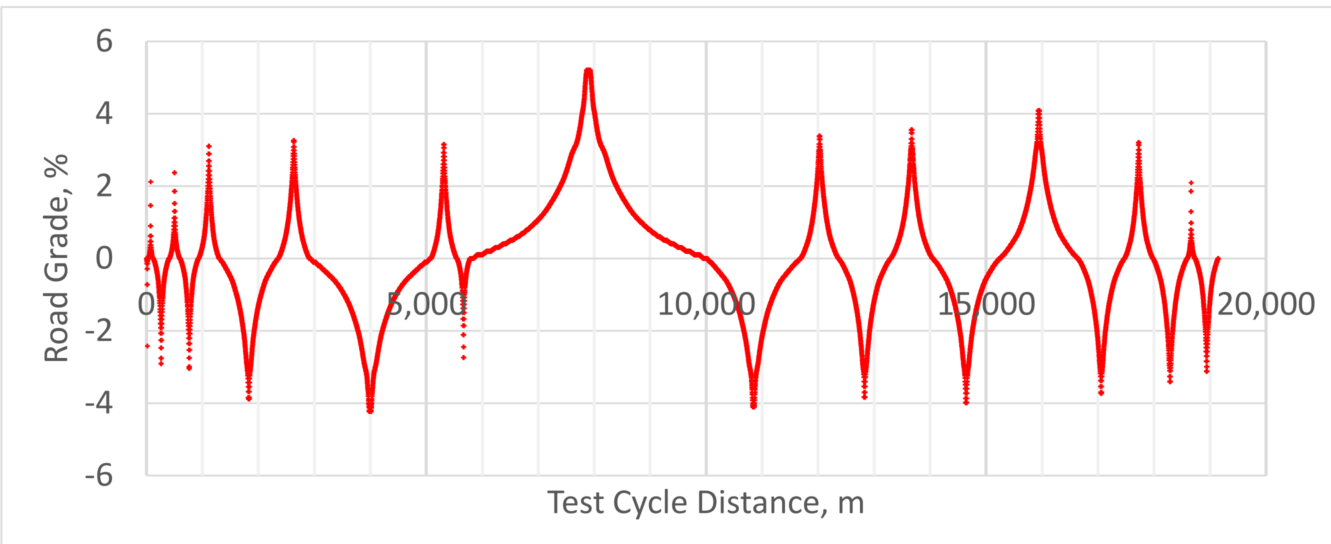


Figure 3-29 Progression of Road Grade along the Length of Profile A.

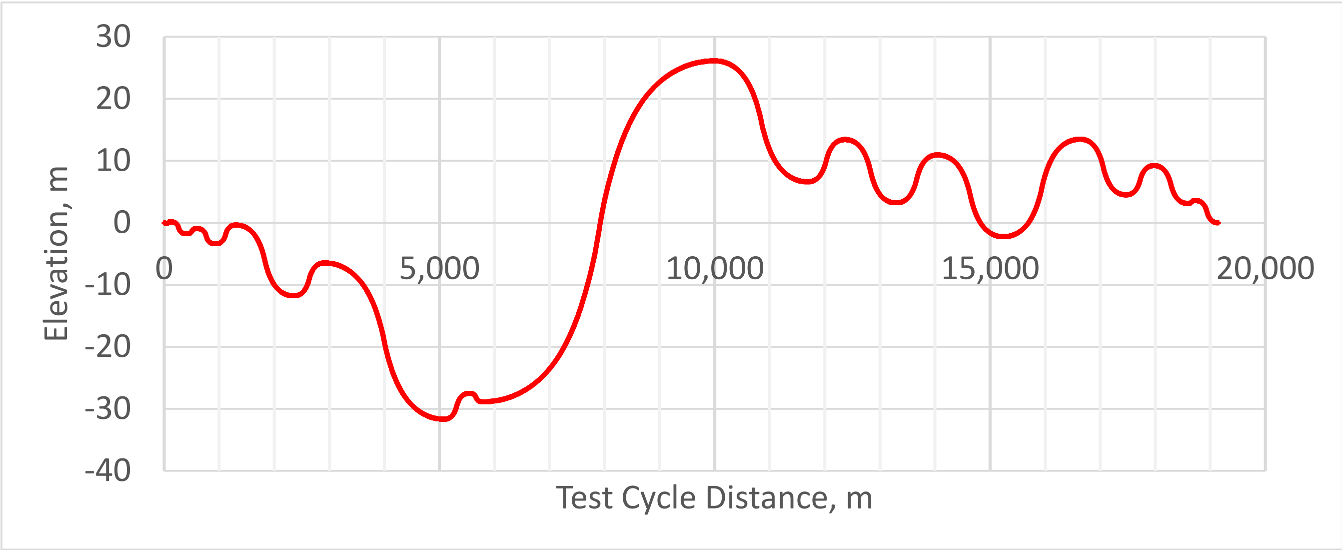


Figure 3-30 Change in Elevation along the Length of Profile A.

All of the above profiles were evaluated in several powertrains and in the GEM. The observed effect of the truck speed limit specific profiles on fuel economy proved to be insignificant both at 55 mph and 65 mph. The asymmetric profiles consistently produced somewhat lower fuel economy results if the longest half hill was driven up the grade, while the symmetric profile D approximated the average fuel economy of the two versions of profile A. Consequently, profile D was selected for use in the regulation. A detailed numerical representation of this profile is provided in metric units in file EPA_SyntheticRoadGradeProfile.xlsx available in the docket.

At proposal the agencies analyzed the effect of different road grade profiles on vehicle performance as simulated in GEM and described these in a memorandum to the docket titled, “Possible Tractor, Trailer, and Vocational Vehicle Standards Derived from Alternative Road Grade Profiles.”

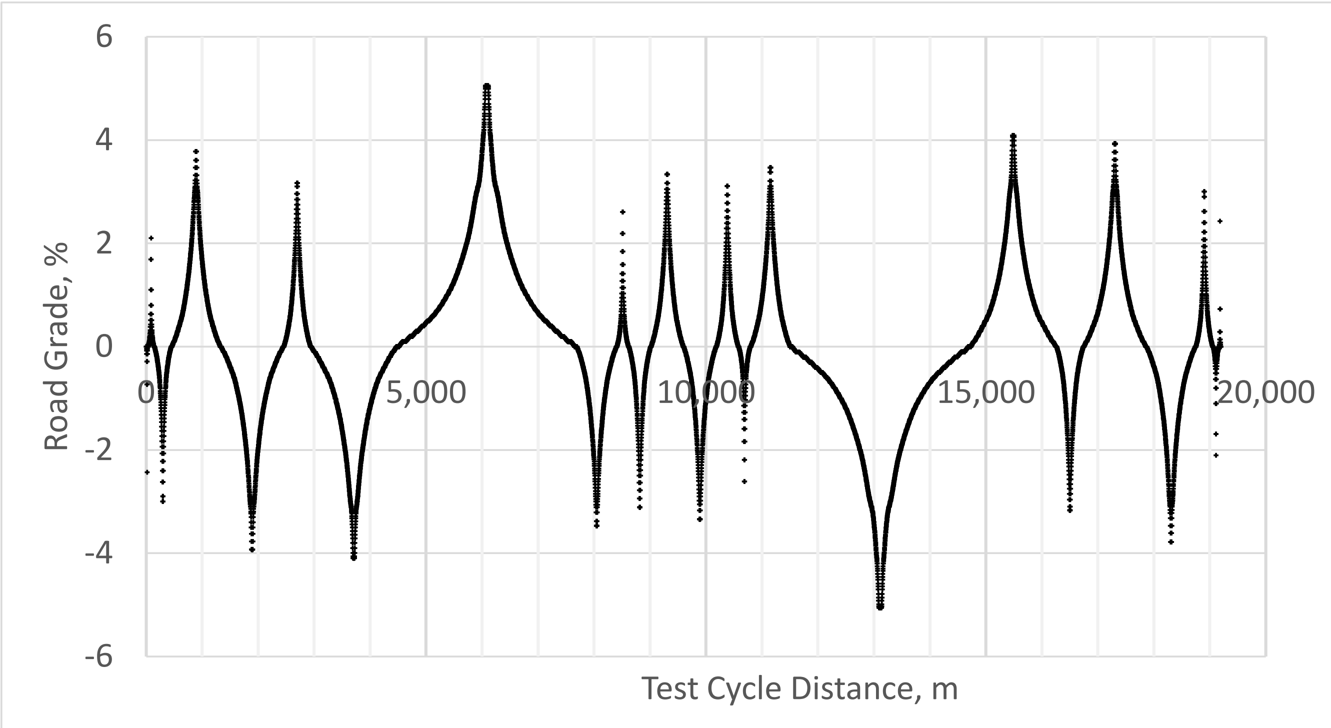


Figure 3-31 Progression of Road Grade along the Length of Profile D.

In addition to the agencies completing a thorough analysis in simulation and powertrain testing, the cycles were shared with manufacturers to evaluate. The summary of this feedback can be boiled down to three main points. The first was that in-use data from thousands of tractors with road grade sensors confirm activity weighted road grade distribution of profile D, as can be seen in Figure 3-32. The second was that compressing the road grade distribution into a 12.5 mile cycle caused unrepresentative rates of change in road grade with distance. The final comment is that with the addition of profile D and the defined vehicle mass for high-roof sleeper cabs the engine operation time at peak torque is unrepresentative of in-use engine operation. To respond to these comments the agencies made the following changes to profile D. The first was to limit the change in grade versus change in distance to 0.015 percent per meter as shown in Figure 3-33. This change had a small effect on the long hills but significantly reduced the peak grade of the shortest half-hills. The second change that was made was adding an additional 1.5 miles at grade equal to or less than 0.5 percent. By doing this the percent time at peak torque better matched the in-use data reported by manufacturers. With these two changes to profile D, the road grade distribution was shifted from the activity weighted road grade distribution shown in Figure 3-34, but this was justified to better align engine operation on the regulatory cycles with actual engine operation. The final road grade profile and elevation can be seen in Figures 3-35 and 36.

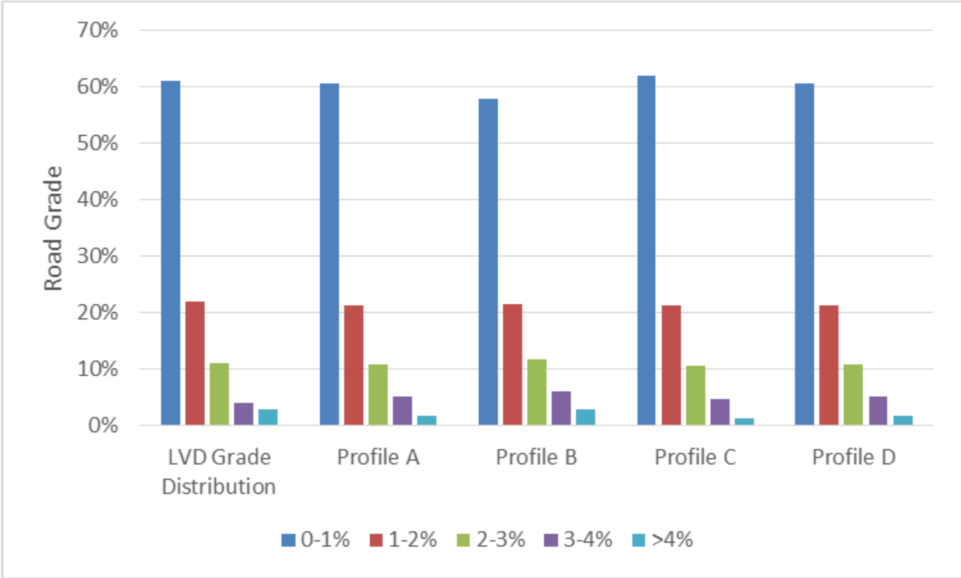


Figure 3-32 Comparison to Road Grade Distribution of Synthetic Cycles to Volvo In-Use Data of Over 8,000 Trucks.

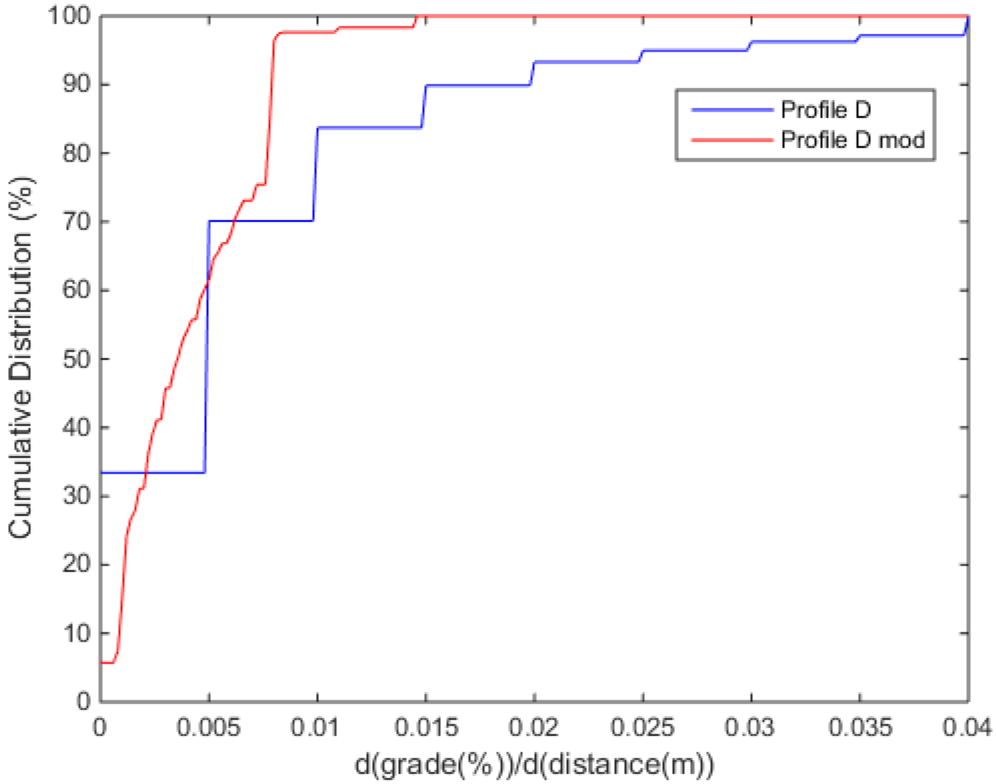


Figure 3-33 Comparison of the Original Profile D Cumulative Road Grade Distribution to the Modified Profile D.

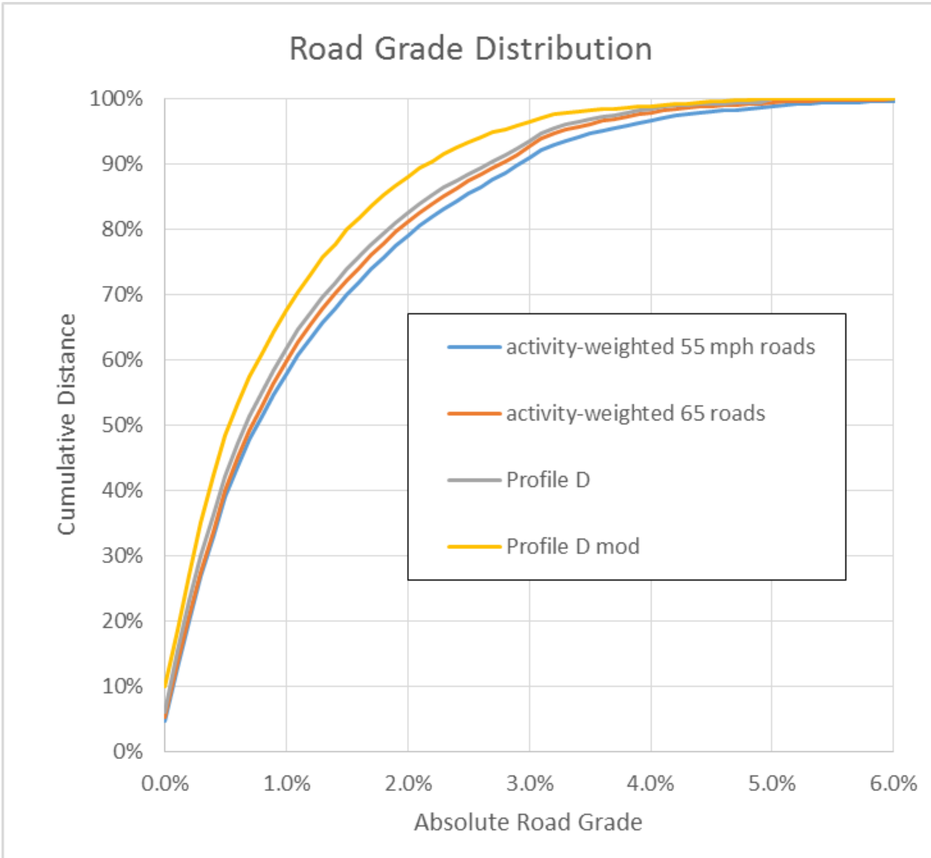


Figure 3-34 Progression of Road Grade along the Length of Profile D.

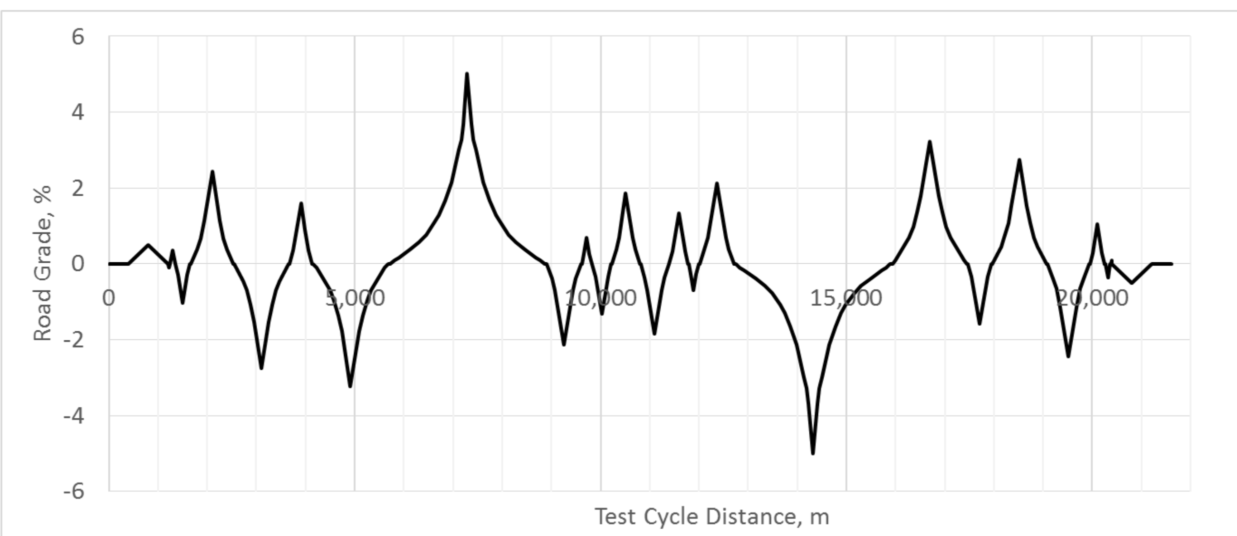


Figure 3-35 Progression of Road Grade along the Length of Modified Profile D.

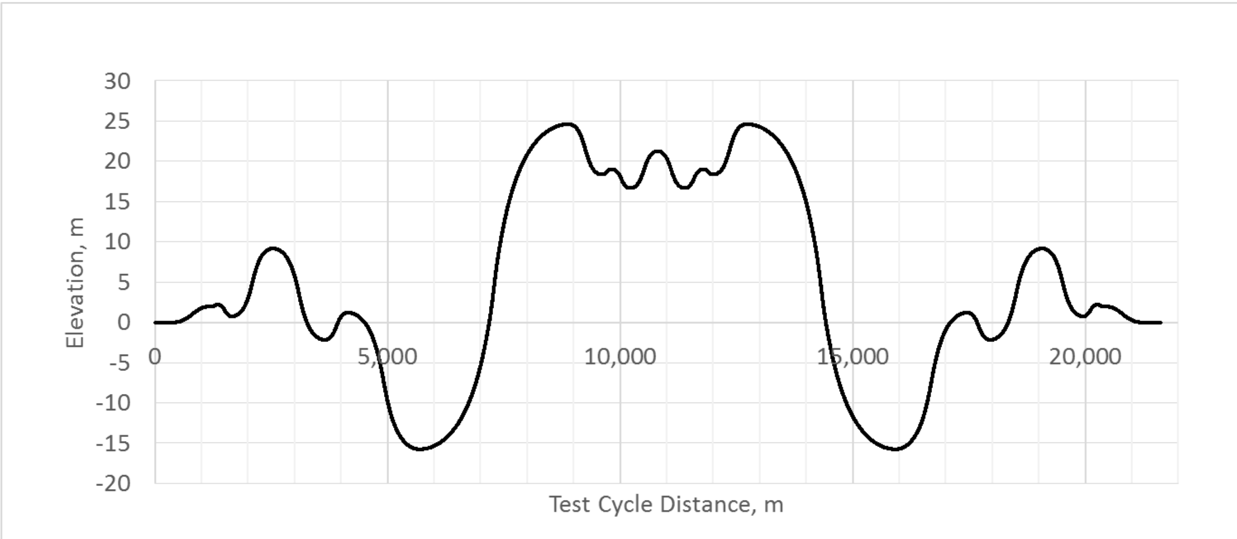


Figure 3-36 Change in Elevation along the Length of Modified Profile D.

3.4.2.2 Transient Cycle

The Phase 1 rule requires use of the Transient portion of the CARB's Heavy Heavy-Duty Truck 5 Mode Cycle. The agencies have found that this cycle reasonably represents transient operation of many heavy-duty vehicles, though it is a very short test cycle - less than 3 miles – and can be driven in roughly 11 minutes. We are not making any changes to that cycle in this final rule, and will continue to use it when certifying vehicles to the Phase 2 standards.

The agencies launched a project at the National Renewable Energy Laboratory (NREL) to determine the extent to which the Transient mode of the CARB Heavy-Duty Truck 5 Mode Cycle is representative of transient operation of Class 2b-8 vocational vehicles. This analysis was performed using NREL's extensive vehicle activity database and a variety of metrics such as average driving speed, kinetic intensity, idle time, maximum driving speed and standard deviation of speed. Although the analysis resulted in the development of a possible new transient duty-cycle, the Preamble Section V.B explains the reasons why the agencies are not adopting the new duty-cycle in this rulemaking. Therefore the agencies will finalize the continued use of the Transient mode of the CARB cycle. The report documenting NREL's vocational duty cycle work, including the development of a possible new transient cycle, is available to the public in the docket.[29]

3.4.2.3 Idle Cycle

We are also finalizing the addition of drive and parked idle-only cycles to determine both fuel consumption and CO_2 emissions when a vehicle is idling in both drive and park in order to recognize technologies that either reduce the fuel consumption rate or shut the engine off (and restart) during short-term idle events during the workday. These cycles will not recognize technologies that allow the main engine to remain off during stationary vehicle operation with a PTO engaged and performing work. Those technologies are recognized over the Hybrid-PTO test procedure defined in 40 CFR 1037.540. In these idle-only cycles, based on user inputs generated through engine testing, GEM will calculate CO_2 emissions and fuel consumption at both zero torque (neutral idle) and with torque set to 100 Nm for use in the CO_2 emission calculation in 40 CFR 1037.510(b). GEM will also calculate reduced CO_2 and fueling for stop-start systems, based on an assumption that the effectiveness will represent a 90 percent reduction of the emissions that will occur if the vehicle had operated at Curb-Idle Transmission Torque over the drive idle cycle. This cycle is applicable only for vocational vehicles using either the Regional, Multi-Purpose, or Urban composite duty cycles. GEM will also calculate reduced CO_2 and fueling for automatic engine shutdown systems, based on an assumption that the effectiveness will represent an 80 percent reduction of the emissions that will occur if the vehicle had operated at Neutral Idle over the parked idle cycle.

3.4.3 Weightings of Each Cycle per Regulatory Subcategory

Table 3-16 presents the Phase 1 final GEM duty cycle composite weightings for vocational vehicles and tractors.

Table 3-16 Phase 1 Vehicle Duty Cycle Composite Weightings

VEHICLE CATEGORY	PHASE 1 COMPOSITE WEIGHTINGS OF DUTY CYCLE MODE		
	Transient	55 mph Cruise	65 mph Cruise
Vocational	42%	21%	37%
Vocational Hybrid Vehicles	75%	9%	16%
Day Cabs	19%	17%	64%
Sleeper Cabs	5%	9%	86%

The agencies received a comment from American Trucking Associations regarding the drive cycle weightings. The agencies believe that the study cited by ATA includes weightings of speed records, which represent the fraction of *time* spent at a given speed. However, our drive cycle weightings represent the fraction of *vehicle miles traveled* (VMT). The agencies used the vehicle speed information provided in the ATA comments and translated the weightings to VMT, as shown below in Table 3-17.

Table 3-17 VMT Weighting of Spot Speed Records

	SPEEDS > 55 MPH	SPEEDS < 55 MPH
time fraction	57%	43%
total driving hours per day	8	8
hours in a day traveling in this speed range	4.6	3.4
assumed speed in that speed range	64	30
miles per day in the speed range	292	103
VMT fraction	74%	26%

Based on our assessment, their findings produce weightings that are approximately 74 percent of the vehicle miles traveled are at speeds greater than 55 mph and 26 percent less than 55 mph. In addition, the study cited by ATA represents "Class 8 trucks" which would include day cab tractors, sleeper cab tractors, and heavy heavy-duty vocational trucks. Based on this assessment, the agencies do not believe this new information is significantly different than the drive cycle weightings that were proposed.

3.4.3.1 Phase 2 Vocational Vehicles

3.4.3.1.1 Derivation of the Composite Weightings of the Vocational Driving Cycles

The U.S. Department of Energy and EPA partnered on a project aimed at identifying possible segments of vehicles with different driving patterns within the vocational vehicle sector, for use in identifying regulatory subcategories as part of the certification of heavy-duty vehicles to the GHG emission and fuel efficiency Phase 2 standards. The National Renewable Energy Laboratory (NREL) led the project which resulted in identification of three distinct clusters of vehicles, each with characteristic driving patterns. In the course of their work, NREL developed distributions of miles accumulated at different speeds by vehicles whose driving statistics most closely matched the medioid of each cluster. The distance histograms for the 50 best matching vehicles in each cluster are summarized in Table 3-18. The development of these histograms is documented in NREL's 2016 vocational drive cycle report.[29]

Table 3-18 Distance Histograms for Vocational Driving Cycles

SPEED BIN	CLUSTER 1 TOP 50 AVERAGE	CLUSTER 2 TOP 50 AVERAGE	CLUSTER 3 TOP 50 AVERAGE
0+ - 2 mph distance (%)	0.20	0.10	0.03
2+ - 4 mph distance (%)	0.69	0.33	0.11
4+ - 6 mph distance (%)	1.18	0.55	0.19
6+ - 8 mph distance (%)	1.64	0.77	0.21
8+ - 10 mph distance (%)	2.16	0.91	0.26
10+ - 12 mph distance (%)	2.66	1.03	0.30
12+ - 14 mph distance (%)	2.98	1.12	0.34

14+ - 16 mph distance (%)	3.22	1.20	0.36
16+ - 18 mph distance (%)	3.48	1.34	0.40
18+ - 20 mph distance (%)	3.82	1.41	0.44
20+ - 22 mph distance (%)	4.26	1.60	0.53
22+ - 24 mph distance (%)	4.48	1.84	0.56
24+ - 26 mph distance (%)	4.75	2.11	0.65
26+ - 28 mph distance (%)	5.06	2.40	0.77
28+ - 30 mph distance (%)	5.63	2.58	0.91
30+ - 32 mph distance (%)	5.98	2.77	1.04
32+ - 34 mph distance (%)	6.29	3.11	1.13
34+ - 36 mph distance (%)	6.11	3.41	1.16
36+ - 38 mph distance (%)	5.69	3.50	1.19
38+ - 40 mph distance (%)	5.11	3.52	1.31
40+ - 42 mph distance (%)	4.45	3.51	1.45
42+ - 44 mph distance (%)	3.94	3.67	1.55
44+ - 46 mph distance (%)	3.45	3.69	1.59
46+ - 48 mph distance (%)	2.57	3.58	1.68
48+ - 50 mph distance (%)	2.28	3.60	1.82
50+ - 52 mph distance (%)	1.79	3.69	2.01
52+ - 54 mph distance (%)	1.77	4.57	2.69
54+ - 56 mph distance (%)	1.48	5.98	4.01
56+ - 58 mph distance (%)	1.02	7.07	6.16
58+ - 60 mph distance (%)	0.83	7.65	9.19
60+ - 62 mph distance (%)	0.65	7.24	10.03
62+ - 64 mph distance (%)	0.30	4.75	16.96
64+ - 66 mph distance (%)	0.06	3.80	23.61
66+ - 68 mph distance (%)	0.01	1.33	4.63
68+ - 70 mph distance (%)	0.00	0.24	0.55
70+ - 72 mph distance (%)	0.00	0.04	0.11
72+ - 74 mph distance (%)	0.00	0.00	0.03
74+ mph distance (%)	0.00	0.00	0.04

3.4.3.1.2 Composite Weightings of the Vocational Cycles

In order to properly weight the driving time of each vehicle subcategory, the distance histograms above have been applied to the agencies' regulatory test cycles. For class 2b-7 Multipurpose vehicles and all Regional vehicles, miles accumulated up to 50 mph have been counted in the weighting for the ARB Transient cycle, miles accumulated between 50 and 60 mph have been counted in the weighting for the 55 mph cycle, and miles accumulated above 60 mph have been counted toward the weighting of the 65 mph cycle. Volvo's data showed that more miles are accumulated in the 55 mph range for class 8 vehicles than were observed by

NREL. Although both NREL and Volvo data showed vehicles whose behavior would logically be classified as Urban, accumulating some miles (from one to seven percent) in the 65 mph range, the agencies are applying a zero weighting factor to the 65 mph cycle for all Urban vehicles for certification purposes. For class 8 Urban vehicles, miles accumulated up to 48 mph have been counted in the weighting for the ARB Transient cycle, and miles accumulated above 48 mph have been counted in the weighting for the 55 mph cycle. For classes 2b-7 Urban vehicles, miles accumulated up to 50 mph have been counted in the weighting for the ARB Transient cycle, and miles accumulated above 50 mph have been counted in the weighting for the 55 mph cycle. For class 8 Multipurpose vehicles, we have applied judgment along with consideration of the weightings that would result from applying cutoffs at 50 mph and 60 mph and data from Volvo from over 12,000 vehicles. Volvo's data showed the class 8 vehicles they believe would likely be classified as Multipurpose accumulate an equal amount of distance in the range of 55 mph as in the range of 65 mph, and an average of transient driving very similar to that observed by NREL for other multipurpose vehicles. If we applied the weightings as calculated using the NREL distance histograms for Multipurpose using the 48 mph and 58 mph cutoffs, the resulting weight of the transient cycle of 50 percent would have been too low compared to Volvo's data (59 percent), and the 55 and 65 weightings would be equal at 25 percent, but this would be too high compared to Volvo's data showing 21 percent each of those cycles. Thus we kept the 54 percent of transient and applied an even 23 percent to both the 55 mph cycle and 65 mph cycle to the class 8 Multipurpose vehicles.

In addition to the miles accumulated while driving, NREL provided data on total zero-speed operation for each cluster of vehicles, as well as percent of a workday spent in out-of-gear parked idle. The final weightings of the drive idle cycle have been adjusted to account for idling that occurs over the transient cycle, which includes 15.6 percent zero speed time. In the Phase 1 rule the duty cycles were weighted by distance to properly reflect the vehicle miles traveled by each category. To incorporate both drive and parked idle emissions, the equation has been modified to allow for the idle emissions to be time weighted with the driving cycles. The result of this is that the weighting factors for the driving cycles will still add up to 100 percent while the total idle weighting factor will be less than 100 percent, reflecting the actual idle time of the vehicles by category. The agencies have modified the equation in 40 CFR 1037.510(b) to accommodate both the distance (non-idle) and time based (drive and parked idle) weighting factors.

The duty cycle weightings for each vocational vehicle test cycle are included in Table 3-19.

Table 3-19 Phase 2 Duty Cycle Mode Composite Weightings

VEHICLE CATEGORY	DUTY CYCLE MODE					
	Transient	55 mph Cruise	65 mph Cruise	Drive Idle	Parked Idle	Non-Idle
Vocational Regional	20%	24%	56%	0%	25%	75%
Vocational Multi-Purpose (2b-7)	54%	29%	17%	17%	25%	54%
Vocational Multi-Purpose (class 8)	54%	23%	23%	17%	25%	54%
Vocational Urban	92%	8%	0%	15%	25%	67%
Vocational Urban (class 8)	90%	10%	0%	15%	25%	67%

3.5 Tare Weights and Payload

We will continue defining the total weight of a truck as the combination of the truck's tare weight, a trailer's tare weight (if applicable), and the payload; as it was defined in the Phase 1 rule. The total weight of a truck is important because it in part determines the impact of technologies, such as rolling resistance, on GHG emissions and fuel consumption. As the HD program is designed, it is important that the agencies define weights which are representative of the fleet while recognizing that the final weights are not representative of a specific vehicle. The sections below describe the agencies' approach to defining each of these weights.

3.5.1 Truck Tare Weights

The tare weight of a truck will vary depending on many factors, including the choices made by the manufacturer in designing the truck (such as the use of lightweight materials, the cab configuration (such as day or sleeper cab), whether it has aerodynamic fairing (such as a roof fairing), and the specific options on the truck.

The Class 8 combination tractor tare weights were developed based on the weights of actual tractors tested in EPA's coastdown program. The empty weight of the Class 8 sleeper cabs with a high roof tested ranged between 19,000 and 20,260 pounds. The empty weight of the Class 8 day cab with a high roof tested was 17,840 pounds. The agencies derived the tare weight of the Class 7 day cabs based on the guidance of truck manufacturers. The agencies then assumed that a roof fairing weighs approximately 500 pounds. Based on this, the agencies are finalizing the tractor tare weights as shown in Table 3-20.

Table 3-20 Tractor Tare Weights

MODEL TYPE	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 7	CLASS 7
Regulatory Subcategory	Sleeper Cab High Roof	Sleeper Cab Mid Roof	Sleeper Cab Low Roof	Day Cab High Roof	Day Cab Low Roof	Day Cab High Roof	Day Cab Low Roof
Tractor Tare Weight (lbs)	19,000	18,750	18,500	17,500	17,000	11,500	11,000

The agencies developed the empty tare weights of the vocational vehicles based on the EDF report[30] on GHG management for Medium-Duty Fleets. The EDF report found that the average tare weight of a Class 4 truck is 10,343 pounds, of a Class 6 truck is 13,942 pounds, and a Class 8 truck is 23,525 pounds. The agencies will continue to use the following tare weights:

- Light Heavy (Class 2b-5) = 10,300 pounds
- Medium Heavy (Class 6-7) = 13,950 pounds
- Heavy Heavy (Class 8) = 23,500 pounds

3.5.2 Trailer Tare Weights

We will continue to define the trailer tare weights used in the tractor program based on measurements conducted during EPA's coastdown testing and information gathered by ICF in the cost report to EPA, as adopted in the Phase 1 rule.[31]

A typical 53 foot box (or van) trailer has an empty weight ranging between 13,500 and 14,000 pounds per ICF's findings. The box trailer tested by EPA in the coastdown testing weighed 13,660 pounds. Therefore, the agencies are defining the empty box trailer weight as 13,500 pounds.

A typical flatbed trailer weighs between 9,760 and 10,760 per the survey conducted by ICF. EPA's coastdown work utilized a flatbed trailer which weighed 10,480 pounds. Based on this, the agencies are defining a flatbed trailer weight of 10,500 pounds.

Lastly, a tanker trailer weight typically ranges between 9,010 and 10,500 pounds based on ICF findings. The tanker trailer used in the coastdown testing weighed 9,840 pounds. The agencies are defining the empty tanker trailer weight of 10,000 pounds.

3.5.3 Payload

The amount of payload by weight that a tractor can carry depends on the class (or GVWR) of the vehicle. For example, a typical Class 7 tractor can carry fewer tons of payload than a Class 8 tractor. Payload impacts both the overall test weight of the truck and is used to assess the "per ton-mile" fuel consumption and GHG emissions. The "tons" represent the payload measured in tons.

M.J. Bradley analyzed the Truck Inventory and Use Survey and found that approximately 9 percent of combination tractor miles travelled empty, 61 percent are “cubed-out” (the trailer is full before the weight limit is reached), and 30 percent are “weighed out” (operating weight equal 80,000 pounds which is the gross vehicle weight limit on the Federal Interstate Highway System or greater than 80,000 pounds for vehicles traveling on roads outside of the interstate system).[32] The Federal Highway Administration developed Truck Payload Equivalent Factors to inform the development of highway system strategies using Vehicle Inventory and Use Survey (VIUS) and Vehicle Travel Information System (VTRIS) data. Their results, as shown in Table 3-21, found that the average payload of a Class 8 truck ranged from 29,628 to 40,243 pounds, depending on the average distance travelled per day.[33] The same results found that Class 7 trucks carried between 18,674 and 34,210 pounds of payload also depending on average distance travelled per day.

Table 3-21 National Average Payload (lbs.) per Distance Travelled and Gross Vehicle Weight Group (VIUS)[34]

	CLASS 3	CLASS 4	CLASS 5	CLASS 6	CLASS 7	CLASS 8
< 50 miles	3,706	4,550	8,023	10,310	18,674	29,628
51 to100 miles	3,585	4,913	6,436	10,628	23,270	36,247
101 to 200 miles	4,189	6,628	8,491	12,747	30,180	39,743
201 to 500 miles	4,273	7,029	6,360	10,301	25,379	40,243
> 500 mile	3,216	8,052	6,545	12,031	34,210	40,089
Average	3,794	6,234	7,171	11,203	26,343	37,190

The agencies are prescribing a fixed payload of 25,000 pounds for Class 7 tractors and 38,000 pounds for Class 8 tractors for their respective test procedures. These payload values represent a heavily loaded trailer, but not maximum GVWR, since as described above the majority of tractors "cube-out" rather than "weigh-out.”

NHTSA and EPA will continue to use the payload requirements for each regulatory subcategory in the vocational vehicle category that were finalized in the Phase 1 rule. The payloads were developed from Federal Highway statistics based on the averaging the payloads for the weight classes of represented within each vehicle category.[35] The payload requirement is 5,700 pounds for the Light Heavy trucks based on the average payload of Class 3, 4, and 5 trucks from Table 3-21. The payload for Medium Heavy trucks is 11,200 pounds per the average payload of Class 6 trucks as shown in Table 3-21. Lastly the agencies are defining 38,000 pounds payload for the Heavy Heavy trucks based on the average Class 8 payload in Table 3-21.

3.5.4 Total Weight

In summary, the total weights of the combination tractors are shown in Table 3-22.

Table 3-22 Combination Tractor Total Weight

MODEL TYPE	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 8	CLASS 7	CLASS 7	CLASS 7
Regulatory Subcategory	Sleeper Cab High Roof	Sleeper Cab Mid Roof	Sleeper Cab Low Roof	Day Cab High Roof	Day Cab Mid Roof	Day Cab Low Roof	Day Cab High Roof	Day Cab Mid Roof	Day Cab Low Roof
Tractor Tare Weight (lbs)	19,000	18,750	18,500	17,500	17,100	17,000	11,500	11,100	11,000
Trailer Weight (lbs)	13,500	10,000	10,500	13,500	10,000	10,500	13,500	10,000	10,500
Payload (lbs)	38,000	38,000	38,000	38,000	38,000	38,000	25,000	25,000	25,000
Total Weight (lbs)	70,500	66,750	67,000	69,000	65,100	65,500	50,000	46,100	46,500

The total weights of the vocational vehicles are shown in Table 3-23.

Table 3-23 Vocational Vehicle Total Weights

REGULATORY SUBCATEGORY	LIGHT HEAVY	MEDIUM HEAVY	HEAVY HEAVY
Truck Tare Weight (lbs)	10,300	13,950	27,000
Payload (lbs)	5,700	11,200	15,000
Total Weight (lbs)	16,000	25,150	42,000

3.6 Powertrain Test Procedures

In the Phase 1 rule the agencies introduced a powertrain test procedure to allow manufacturers to generate credits for selling advanced powertrains that reduced CO_2 emissions and fuel consumption. In Phase 2 we bring the powertrain test procedure into the main program and project that 15 to 30 percent of the vocational vehicles (including both hybrid and non-hybrid applications) will certify using this method. To accommodate this change we are finalizing a number of improvements to the test procedure in 40 CFR 1037.550 and reducing the test burden by only requiring testing of the powertrain that is to be certified. The agencies are also finalizing modifications to 40 CFR 1037.550 to separate out the hybrid specific testing protocols.

3.6.1 Reason Behind Use Of Powertrain Test Method for Conventional and Hybrid Powertrain Certification

The agencies are finalizing a powertrain test option to afford a robust mechanism to quantify the benefits of CO_2 reducing technologies that are a part of the powertrain (conventional or hybrid), that are not captured in the GEM simulation. Among these technologies are integrated engine and transmission control and hybrid systems. The largest change from the Phase 1 powertrain procedure is that only the advanced powertrain will need to be tested – as opposed to the Phase 1 approach that calculated an improvement factor from the powertrain results of both the advanced powertrain and a conventional powertrain (often called A-to-B testing). This change is possible because the GEM simulation tool has been modified to use powertrain test results in place of the engine fuel map and torque curve of the vehicle that is to be certified, and thus it can simulate absolute performance of the advanced powertrain.

3.6.2 Use of Generic Vehicles to Apply Measurements Broadly Across All Vehicles That the Powertrain Will Be Installed In

To limit the amount of testing under this rule, powertrains can be divided into families and are tested in a limited number of simulated vehicles that will cover the range of vehicles in which the powertrain will be used.

A matrix of 8 to 9 tests (6 for heavy haul) will be needed per vehicle cycle, to enable the use of the powertrain results broadly across all the vehicles in which the powertrain will be installed. The individual tests differ by the vehicle that is being simulated during the test. Table 3-24,

Table 3-25, and Table 3-26 define the unique vehicles being finalized that will cover the range of coefficient of drag, coefficient of rolling resistance, vehicle mass and axle ratio of the vehicles that the powertrain will be installed in.

To allow for a generic tire size definition that will cover the tires and axles installed on the certified vehicles, the agencies are finalizing that each tire radius will be set so that when the vehicle is cruising at 65 mph the engine speed will equal the corresponding minimum NTE exclusion speed as defined in 40 CFR part 86.1370(b)(1), intermediate test speed (A, B, or C), or maximum test speed defined in 40 CFR part 1065. To calculate the tire radius, use the equation in 40 CFR 1037.550. In case the manufacturer knows the minimum and maximum powertrain rotational speed to vehicle speed, we are finalizing that the manufacturer may use these known tire sizes and axle ratios along with one or two equally spaced intermediate points instead of the predefined tire sizes and axle ratios that are based on engine speed.

Table 3-24 Generic Vehicle Definitions for Class 2b-7 Vehicles

	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8
Mass (kg)	7,257	11,408	7,257	11,408	7,257	11,408	7,257	11,408
C_dA	6.2	7.7	6.2	7.7	6.2	7.7	6.2	7.7
Tire C_{rr} (kg/ton)	6.4	7.7	6.4	7.7	6.4	7.7	6.4	7.7
Rotating Inertia (kg)	340	340	340	340	340	340	340	340
Axle Gear Efficiency (%)	95.5	95.5	95.5	95.5	95.5	95.5	95.5	95.5
Axle ratio or tire radius CI engines at engine speed	A	A	B	B	C	C	Maximum engine speed	Maximum engine speed
Axle ratio or tire radius SI engines at engine speed	Minimum NTE exclusion speed	Minimum NTE exclusion speed	A	A	B	B	C	C

Table 3-25 Generic Vehicle Definitions for Tractors and Class 8 Vocational Vehicles—General Purpose

	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8	TEST 9
Mass (kg)	31,978	25,515	19,051	31,978	25,515	19,051	31,978	25,515	19,051
C_dA	5.4	4.7	4.0	5.4	4.7	4.0	5.4	4.7	4.0
Tire C_{rr} (kg/ton)	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
Rotating Inertia (kg)	1,021	794	794	1,021	794	794	1,021	794	794
Axle Gear Efficiency (%)	95.5	95.5	95.5	95.5	95.5	95.5	95.5	95.5	95.5
Axle ratio or tire radius at engine speed	Minimum NTE exclusion speed	Minimum NTE exclusion speed	Minimum NTE exclusion speed	B	B	B	Maximum engine speed	Maximum engine speed	Maximum engine speed

Table 3-26 Generic Vehicle Definitions for Class 8 Combination— Heavy-Haul Vehicle

	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6
Mass (kg)	53,751	31,978	53,751	31,978	53,751	31,978
C_dA	5.0	5.4	5.0	5.4	5.0	5.4
Tire C_{rr} (kg/ton)	6.9	6.9	6.9	6.9	6.9	6.9
Rotating Inertia (kg)	1,021	1,021	1,021	1,021	1,021	1,021
Axle Gear Efficiency (%)	95.5	95.5	95.5	95.5	95.5	95.5
Axle ratio or tire radius at engine speed	Minimum NTE exclusion speed	Minimum NTE exclusion speed	B	B	Maximum engine speed	Maximum engine speed

The main outputs of this matrix of tests is grams of fuel, the average transmission output shaft speed divided by the average vehicle speed, and positive work measured at the output shaft of the powertrain. This matrix of test results will then be used to calculate the vehicle's CO_2 emissions in GEM taking the work per ton-mile from the GEM simulation and multiplying it by the interpolated work specific CO_2 mass emissions from the powertrain test.

3.6.3 Measurement Method and Results

The agencies are expanding upon the test procedures defined 40 CFR 1037.550 for Phase 1. The Phase 2 expansion will migrate the current Phase 1 test procedure to a new 40 CFR 1037.555 and will modify the current test procedure in 40 CFR 1037.550, allowing its use for Phase 2 only. The Phase 2 modifications to 40 CFR 1037.550 include the addition of the rotating inertia of the driveline and tires, and the axle efficiency. This revised procedure also requires that each of the powertrain components be cooled so that the temperature of each of the components is kept in the normal operation range.

In addition to changing the vehicle model, we are finalizing changes to the drive model. The first of these changes is to compensate for the powertrain getting ahead or falling behind in the duty cycle. Use of this compensation algorithm will ensure that every powertrain drives the complete distance of the cycle, regardless of whether or not it can maintain the target speed of the cycle at a given moment in time. The second change that we are finalizing is to allow overspeeding of the cruise cycle's target speed by 3 mph when the grade is negative. This change aligns the driver model in GEM with the driver model required for powertrain testing.

Lastly, we are extending the use of the powertrain procedure to PHEV powertrains in response to comments requesting a defined pathway for demonstration of PHEV emission reductions. When using this procedure, prior approval of the utility factor curve is required, due to the diversity of heavy-duty vehicle duty cycles, including miles driven per day. The utility factor curve must be representative of the daily distance traveled by the vehicles that the PHEV powertrain will be installed in. The procedure references SAE J2711[A], for determining when to stop testing, and for the determination of the split between charge-depleting and charge-sustaining operation.

Although detailed equations for the vehicle and driver models can be found in 40 CFR 1037.550, the agencies are recommending that manufacturers use the MATLAB and Simulink models provided by the agencies. These models can be found at *http://www3.epa.gov/otaq/climate/gem.htm*.

Powertrain Test Setup

Powertrain testing contains many of the same requirements as engine dynamometer testing. The main differences are where the test article connects to the dynamometer and the software that is used to command the dynamometer and operator demand setpoints. The powertrain procedure finalized in Phase 2 allows for the dynamometer(s) to be connected to the powertrain either upstream of the drive axle or at the wheel hubs. The output of the transmission is upstream of the drive axle for conventional powertrains. In addition to the transmission, a hydraulic pump or an electric motor in the case of a series hybrid may be located upstream of the drive axle for hybrid powertrains. If optional testing with the wheel hub is used, two dynamometers will be needed, one at each hub. Beyond these points, the only other difference between powertrain testing and engine testing is that for powertrains, the dynamometer and throttle setpoints are not set by fixed speed and torque targets prescribed by the cycle, but are calculated in real time by the vehicle model. The powertrain test procedure requires a forward calculating vehicle model, thus the output of the model is the dynamometer speed setpoints. The vehicle model calculates the speed target using the measured torque at the previous time step, the simulated brake force from the driver model, and the vehicle parameters (tire rolling resistance, drag area, vehicle mass, rotating mass, and axle efficiency). The operator demand that is used to change the torque from the engine is controlled such that the powertrain follows the vehicle speed target for the cycle instead of being controlled to match the torque or speed setpoints of the cycle. The emission measurement procedures and calculations are identical to engine testing.

Conventional Powertrain Test Results

The agencies have performed internal test programs, contracted with outside labs, as well as collaborated with manufacturers to test out the improvements to the powertrain test procedure. The following paragraphs summarize some of that work.

The data presented in Figure 3-37 is from a conventional powertrain that consisted of a Cummins ISX engine and Eaton 10 speed automated manual transmission that was tested in one of these test programs. This data summarizes the results from three different types of tests. The first set of data, labeled “Engine Only,” was collected from engine tests where the speed and torque setpoints were determined by GEM. The simulations were done with 9 different vehicle configurations over the three duty cycles that are being finalized as the certification duty cycles (55 mph with grade, 65 mph with grade and ARB transient cycle). The “GEM Model” data

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[A] SAE J2711, Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid-Electric and Conventional Heavy-Duty Vehicles, issued September 2002.

contains the CO_2 emissions as determined by GEM using the engine's fuel map and the transmission's gear ratios using the default shift strategy. The x-axis defines the Powertrain test results. The data shows that across all three test cycles the powertrain test procedure produces 2.5 percent less CO_2 emission than the GEM simulation predicted. One must, however, take into account the fact that the GEM simulation was done using the engine steady-state fuel map; thus, the GEM results don't fully take into account the effect of transient fueling on CO_2 emissions. This is evident when looking at the data collected when operating over the transient test cycles (highest CO_2 g/ton-mile results). Here you see that the engine consumed greater than 3 percent more fuel than GEM predicted. When taking the transient test results into account, the powertrain performed 5 to 8 percent better than GEM predicted.

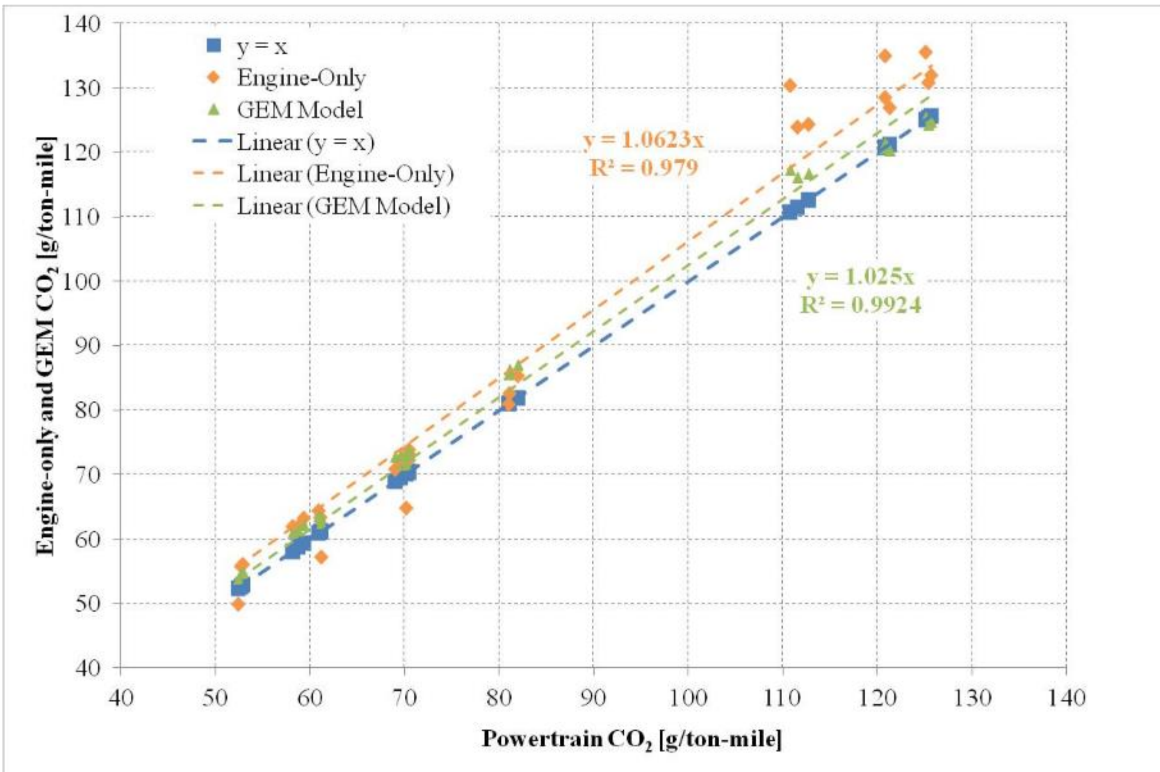

Figure 3-37 Engine only and GEM CO_2 Results vs. Powertrain.

Since the proposal, the engine and powertrain testing at Oakridge National Laboratory (ORNL) has been completed. A 2012 Cummins ISX was tested as part of this work using the engine fuel mapping procedures finalized in this rule; 40 CFR 1036.535 and 1036.540. In addition to the engine testing, the same engine was paired with an Eaton 10 speed Ultra ShiftPlus automated manual transmission and an Allison TC10 automatic transmission and tested using the powertrain procedure in 40 CFR 1037.550. The engine was tested with both the parent rating of 450 Hp and a child rating for the engine of 400 Hp. In addition to the vehicles defined in 40 CFR 1036.540, the powertrains and engine were tested with additional vehicles to test the fit of the cycle-average and powertrain fuel map. From these results the following conclusions were made in the final report:[B]

1. The powertrain test procedure as defined in 40 CFR 1037.550 is an efficient way to use a limited amount of test data to predict fuel consumption from many vehicles including vehicles incorporating child ratings of the engine.
2. The powertrain procedure constrains variations in drive behavior and dynamometer speed control to produce representative and repeatable results with a coefficient of variation of less than 0.5 percent for measured fuel consumption.
3. The linear fit of fuel, as a function of powertrain N/V and work, fits the powertrain data well with low error.
4. The use of a generic powertrain in GEM rather than using the engine's actual torque curve and transmission's actual gear ratios, has negligible effect on the N/V and work used to calculate fuel from the powertrain map.
5. The maximum torque from a powertrain test over the regulatory cycles, is less than half the theoretical maximum torque determined by multiplying the first gear ratio by the maximum torque of the engine.

3.6.4 Powertrain Family Definition

To complement the agencies powertrain procedures we are finalizing criteria for defining a powertrain family. The specifics of these criteria can be found in 40 CFR 1037.231 but nominally a powertrain family is made up of one engine family and one transmission family.

3.6.4.1 Criteria for Powertrain Families

The regulations in 40 CFR 1037.231 outline the criteria for grouping transmission models into powertrain families sharing similar emission characteristics. A few of these defining criteria include the transmission's architecture (manual, automatic, automated manual, dual-clutch and hybrid), number of gears in the front box, number of meshes in the back box and dry sump versus regular sump. In addition to the criteria for the transmission, all of the engines in the powertrain family have to be from the same engine family.

3.6.4.2 Emissions Test Powertrain

We are finalizing that manufacturers select at least one powertrain per powertrain family for emission testing. The methodology for selecting the test powertrain(s) should be consistent with 40 CFR 1037.231. The test powertrain(s) should consist of the engine and transmission combination that results in the highest CO_2 emissions.

3.6.5 Vehicle Certification with Powertrain Results in GEM

For manufacturers that choose to use the powertrain method when certifying a vehicle, the powertrain results from the test will be input into GEM instead of the engine's fuel map,

[B] Oakridge National Laboratory July 2016, "Powertrain Test Procedure Development for EPA GHG Certification of Medium- and Heavy-Duty Engines and Vehicles."

torque curve, motoring curve and the transmissions gear ratios. GEM will use the default powertrain inputs, as described in Table 3-27, and the inputs of the to-be certified vehicle to calculate the cycle work (*W*) of the powertrain and the ratio of rotational speed over the vehicle speed (*N*/*V*) as defined by the tire radius and drive-axle ratio.

Table 3-27 GEM Default Parameters for Vehicle Certification Using Powertrain Testing.

REGULATORY CLASS		ENGINE	TRANSMISSION	GEAR RATIOS
Class 8 Combination	Heavy-Haul	2017 MY 15L Engine with 600 HP	13 speed Automated Manual Transmission	12.29, 8.51, 6.05, 4.38, 3.20, 2.29, 1.95, 1.62, 1.38, 1.17, 1.00, 0.86, 0.73
	Sleeper Cab - High Roof	2017 MY 15L Engine with 455 HP	10 speed Automated Manual Transmission	12.8, 9.25, 6.76, 4.9, 3.58, 2.61, 1.89, 1.38, 1, 0.73
	Sleeper Cab - Mid Roof			
	Sleeper Cab - Low Roof			
	Day Cab - High Roof			
	Day Cab - Mid Roof			
	Day Cab - Low Roof			
Class 7 Combination	Day Cab - High Roof	2017 MY 11L Engine with 350 HP		
	Day Cab - Mid Roof			
	Day Cab - Low Roof			
HHD Vocational	Regional Duty Cycle	2017 MY 15L Engine with 455 HP		
	Multi-Purpose Duty Cycle	2017 MY 11L Engine with 350 HP	5 speed HHD Automatic Transmission	4.6957, 2.213, 1.5291, 1, 0.7643
	Urban Duty Cycle			
MHD Vocational	Regional Duty Cycle	2017 MY 7L Engine with 270 HP	5 speed MLHD Automatic Transmission	3.102, 1.8107, 1.4063, 1, 0.7117
	Multi-Purpose Duty Cycle			
	Urban Duty Cycle			
LHD Vocational	Regional Duty Cycle	2017 MY 7L Engine with 200 HP		
	Multi-Purpose Duty Cycle			
	Urban Duty Cycle			

In GEM the cycle work from the powertrain testing will be corrected for the electrical and mechanical accessory power according to the following equation. The accessory power is defined for each vehicle category in Chapter 4 of this RIA.

$$W_{\text{powertrain corrected}} = W_{\text{test}} - P_{\text{acc}} \cdot t_{\text{test}} \cdot \frac{W_{\text{trans.out or wheel hub(+)}}}{W_{\text{engine(+)}}}$$

GEM will use the calculated cycle work and *N*/*V* of the powertrain for the to-be certified vehicle to interpolate the powertrain input table. For vehicle configurations that have cycle work or *N*/*V* outside of the powertrain input table, we are finalizing that the closest end points of the table be used instead of extrapolating. GEM will then use the following equation to calculate the CO_2 g/ton-mile result per cycle before any technology inputs are applied. Finally the technology inputs are applied, all the cycles are weighted and the gallons of fuel are then calculated from the mass of CO_2.

$$e_{CO_2} = e\left[\frac{g_{\mathrm{fuel}}}{kWh}\right]_{\mathrm{interpolated}} \cdot W_{\mathrm{GEM}} \cdot \frac{1}{miles_{\mathrm{GEM}} \cdot payload} \cdot \frac{m_{\mathrm{CO_2}}}{m_{\mathrm{fuel}}}$$

3.7 Hybrid Powertrain Test Procedures

As discussed in Section V of the Preamble, the agencies see an opportunity to help drive the technology's advancement by predicating the vocational vehicle standards on a small adoption rate of hybrid powertrains in this rulemaking. However, since the projected effectiveness of this technology over the Urban vocational duty cycle is up to 25 percent, the agencies believe it is no longer appropriate to provide a 1.5 multiplier for credits generated by vehicles applying this technology. EPA and NHTSA are finalizing two methods to demonstrate benefits of a hybrid powertrain – powertrain and engine testing.

3.7.1 Measurement Method and Results

The agencies are finalizing that hybrid powertrains be tested just like conventional powertrains, with the dynamometer connected at either the input shaft of the drive axle or the input shaft to the wheels, using the powertrain method described in Chapter 3.6 with some additional requirements for the rechargeable energy storage systems (RESS) net energy change (NEC) over the test.

We are finalizing the testing of hybrids using the procedures outlined in 40 CFR 1066.501 to determine End-of-Test for charge-depleting operation. The NEC of the RESS must meet the requirements of SAE J2711 for each test.

3.7.2 Engine Hybrid Method

To address hybrid powertrain system performance for hybrids that recover energy between the engine and transmission, the agencies will retain the engine hybrid procedures defined in 40 CFR 1036.525. The control volume for these hybrids is drawn so as to include the battery, battery support and control systems, power electronics, the engine, motor generator and hybrid control module. The performance of this system is an engine based evaluation in which emission rates are determined on a brake-specific work basis. As such, the duty cycles being finalized to assess this system performance are engine speed and torque command cycles that are similar but not identical to the cycles used for criteria pollutant standards. In addition to the cycles being slightly different between the test for GHG emissions and the test for criteria emissions, the system boundary of the engine for the criteria emission test will remain unchanged and will not include the hybrid components. It is expected that, parallel engine hybrids will be the most likely choice for engine-based hybrid certification. Details related to engine hybrid test procedures may be found in 40 CFR 1036.525.

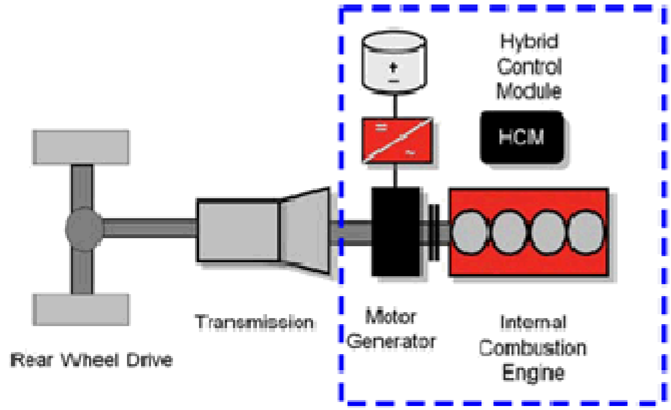

Figure 3-38 Engine Hybrid Test Configuration

3.7.3   Removal of the Chassis Test Option for Hybrids

In the Phase 1 rule the agencies finalized a powertrain and chassis test option for hybrid testing. The agencies will remove the chassis test option for the Phase 2 program because it appears to be incompatible with the changes regarding use of results from the hybrid test procedure. In the procedure, the output of the hybrid test is brake specific CO_2 emission where the positive work is measured at the output shaft of the hybrid powertrain.   Since work cannot be measured at this location on a chassis dynamometer without modifying the vehicle, the agencies are finalizing the removal of the chassis testing option. Another reason for the removal of the chassis test option is that there are a number of additional sources of variability when testing a vehicle on a chassis dynamometer. These include electrical and mechanical accessory load, tire temperature and driver variability to name a few.

3.7.4   Electrified PTO Test Method

A power take off (PTO) is a system on a vehicle that allows energy to be drawn from the vehicle’s drive system and used to power an attachment or a separate machine. Typically in a heavy-duty truck, a shaft runs from the transmission of the truck and operates a hydraulic pump. The operator of the truck can select to engage the PTO shaft in order for it to do work, or disengage the PTO shaft when the PTO is not required to do work. The pressure and flow from this hydraulic fluid can be used to do work in implements attached to the truck. Common examples of this are utility trucks that have a lift boom on them, refuse trucks that pick up and compact trash, and cement trucks that have a rotating barrel. In each case the auxiliary implement is typically powered by a PTO that uses energy from the truck’s primary drive engine.

In most PTO equipped trucks, it is necessary to run the primary drive engine at all times when the PTO might be needed. This is an unoptimized configuration. Typical PTO systems require no more than 19 kW at any time, which is far below the optimal operation range of the primary drive engine of most trucks. Furthermore, in intermittent operations, the primary drive engine is kept running at all times in order to ensure that the PTO can operate instantaneously. This results in excess GHG emissions and fuel consumption due to idle time. Additionally, idling a truck engine for prolonged periods of time while operating auxiliary equipment like a PTO could cause the engine to cycle into a higher idle speed, wasting even more fuel.

Hybridization and changing the operation of a conventional PTO equipped truck are two viable means to lower the GHG emissions and fuel consumption in the real world. The test procedures will allow for manufacturers to quantify the reduction of CO_2 emissions and fuel consumption from more efficient PTO systems.

In Phase 1, hybrid PTO testing was performed either via chassis or powertrain testing of both the conventional and hybrid systems over the PTO duty cycles described in Appendix II of 40 CFR 1037, in addition to the vehicle duty cycles. An improvement factor was then generated as described in 40 CFR 1037.615 and applied to the g/ton-mile CO_2 emission rate resulting from the GEM output for the hybrid vehicle as described in 40 CFR 1037.540.

EPA and NHTSA will continue the Phase 1 testing methodology outlined in 40 CFR 1037.540 where A to B testing is used to generate an improvement factor either via powertrain or chassis testing, but with two changes. The first is how the results are used to calculate the vehicle's emission result. For Phase 2, the agencies are finalizing that the reduction in emissions from the electrified PTO system versus the conventional PTO system be subtracted from the composite emissions result. The second change to the procedure for both Phase 1 and 2, is that the agencies are now allowing plug-in hybrids to use the results from both the charge sustaining tests and charge depleting tests to calculate the fuel consumed by the electrified PTO system. Specifics on the applicability of testing for improved PTOs is discussed further in Chapter V.C of the Preamble.

With the expansion of the PTO procedure for PHEV PTO systems, NREL and EPA partnered to develop a utility factor curve to weight fuel consumption from charge-sustaining tests and charge-depleting tests.[C] The utility factor curve was developed by analyzing driving, idling and PTO operation from 85 vehicles over 11 months, resulting in greater than 1500 vehicle days of operation and greater than 70k miles. Once the operation was broken up into driving, idling and PTO operation, a cumulative distribution of PTO hours per day was created. Since this distribution contained about ten percent of work days when the PTO was not used, those days were removed before creating the utility factor curve. Removing the days without PTO operation was justified because the utility factor curve is only intended to represent the daily PTO operating time. The second justification for this is that plug-in PTO systems only provide reduction in fuel consumption when the PTO system is used. Figure 3-39 is a plot of the utility factor fraction versus charge-depleting PTO operating time that has been finalized in the Appendix of 40 CFR 1037.

[C] National Renewable Energy Laboratory July 2016, "Characterization of PTO and Idle Behavior for Utility Vehicles" NREL/TP-5400-66747.

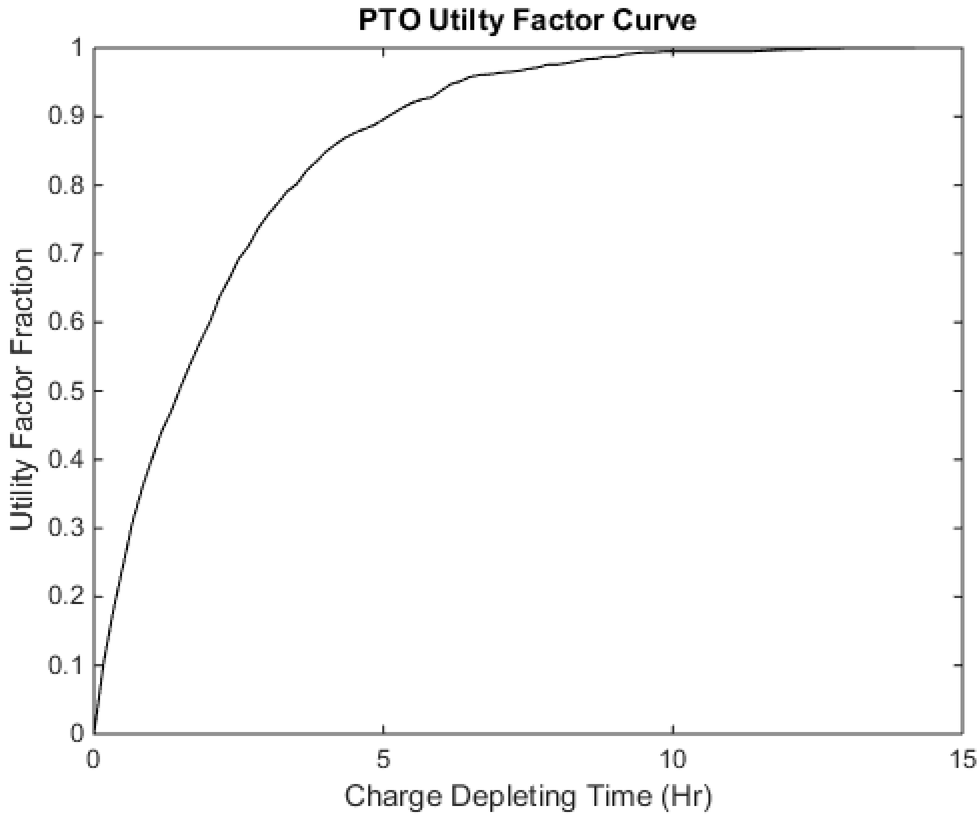

Figure 3-39 Utility Factor Curve for PTO Operating Time

3.8 Axle Efficiency Test

The agencies are also finalizing a test procedure to measure axle efficiency. See 40 CFR 1037.560. This procedure was developed in part using the draft JRC method incorporated into their CO_2 monitoring of HD vehicles procedure and incorporates modifications based on consultations with the axle manufacturers. This procedure ultimately provides for the determination of torque loss versus input speed and input torque for use in the GEM simulation tool. The procedure prescribes dynamometer set ups for axles with and without lockable differentials as well as drive-through axles. This procedure puts limitations on the test cell ambient temperature, sump oil temperature, and requires the use of representative commercially available axle lubricating oil. The mapping process requires that you map the axle by testing with an input torque in the range of 0 to 4000 Nm in 1000 Nm steps for tractor and vocational class 8 single drive axle applications (2000 Nm max for tractor tandem drive and vocational class 2B through 7 single drive axles) at wheel speeds that range from 50 rpm to the maximum wheel speed in 100 rpm steps. Statistical analysis of the results are performed based on a 95 percent confidence interval and the result of the analysis is compared against an error limit of 0.10 percent (loaded axle test) and 0.05 percent (unloaded axle test) to minimize testing variability.

3.9 Transmission Efficiency Test

The agencies are also finalizing a procedure for mapping transmission efficiency. See 40 CFR 1037.565. This procedure ultimately provides for the determination of transmission spin and total power loss for use in the GEM simulation tool. The procedure prescribes a dynamometer test set up for transmissions. This procedure puts limitations on the test cell ambient temperature, sump oil temperature, and requires the use of representative commercially available axle lubricating oil. Transmission spin loss is determined at transmission input shaft speeds that include the maximum rated input shaft speed, 600 rpm, and three equally spaced intermediate speeds up to maximum wheel speed as defined by 40 CFR 1065.510. Transmission torque loss is determined at one loaded torque setpoint in the range of 75 percent to 105 percent of the maximum transmission input torque and at one unloaded (zero-torque) setpoint. Statistical analysis of the results are performed based on a 95 percent confidence interval and the result of the analysis is compared against an error limit of 0.10 percent (loaded torque setpoint) and 0.05 percent (unloaded torque setpoint) to minimize testing variability.

3.10 HD Pickup Truck and Van Chassis Test Procedure

The agencies are finalizing that HD pickup trucks and vans continue to demonstrate compliance using the 40 CFR part 1066 chassis test procedures. For each test vehicle from a family required to comply with the GHG and fuel consumption requirements, the manufacturer will supply representative road load forces for the vehicle at speeds between 15 km/hr (9.3 mph) and 115 km/hr (71.5 mph). The road load force will represent vehicle operation on a smooth level road, during calm winds, with no precipitation, at an ambient temperature of 20 °C (68 °F), and atmospheric pressure of 98.21 kPa. Road load force for speeds below 9.3 mph may be extrapolated.

The dynamometer's power absorption will be set for each vehicle's emission test sequence such that the force imposed during dynamometer operation matches actual road load force at all speeds. Required test dynamometer inertia weight class selections are determined by the test vehicle test weight basis using adjusted loaded vehicle weight from which the corresponding equivalent test weight is determined.

3.10.1 LHD FTP and HWFE Testing

The FTP dynamometer schedule consists of two tests, a “cold” start UDDS test after a minimum 12-hour and a maximum 36-hour soak according to the provisions of 40 CFR 1066.801, 1066.815, and 1066.816, and a “hot” start test following the “cold” start after a 10 minute soak. Engine startup (with all accessories turned off), operation over the UDDS, and engine shutdown constitutes a complete cold start test. Engine startup and operation over the first 505 seconds of the driving schedule complete the hot start test. The driving schedule for EPA’s Urban Dynamometer Driving Schedule is contained in Appendix I of 40 CFR part 86. The driving schedule is defined by a smooth trace drawn through the specified speed versus time relationship. The schedule consists of a distinct non-repetitive series of idle, acceleration, cruise, and deceleration modes of various time sequences and rates.

The Highway Fuel Economy Dynamometer Procedure (HFET) consists of preconditioning highway driving sequence and a measured highway driving sequence. The HFET is designated to simulate non-metropolitan driving with an average speed of 48.6 mph and a maximum speed of 60 mph. The cycle is 10.2 miles long with 0.2 stops per mile and consists of warmed-up vehicle operation on a chassis dynamometer through a specified driving cycle. The Highway Fuel Economy Driving Schedule is set forth in Appendix I of 40 CFR Part 600, while the test is carried out according to 40 CFR 1066.840. The driving schedule is defined by a smooth trace drawn through the specified speed versus time relationships.

Practice runs over the prescribed driving schedules may be performed, provided an emission sample is not taken, for the purpose of finding the appropriate throttle action to maintain the proper speed-time relationship, or to permit sampling system adjustment. Both smoothing of speed variations and excessive accelerator pedal perturbations are to be avoided. The driver should attempt to follow the target schedule as closely as possible. The speed tolerance at any given time on the dynamometer driving schedules specified in Appendix I of parts 86 and 600 is defined by upper and lower limits in 40 CFR 1066.425. The upper limit is 2 mph higher than the highest point on trace within 1 second of the given time. The lower limit is 2 mph lower than the lowest point on the trace within 1 second of the given time. Speed variations greater than the tolerances (such as may occur during gear changes) are acceptable provided they occur for less than 2 seconds on any occasion. Speeds lower than those prescribed are acceptable provided the vehicle is operated at maximum available power during such occurrences.

3.10.2 LHD FTP and HWFE Hybrid Testing

Since LHD chassis certified vehicles share test schedules and test equipment with much of Light-Duty Vehicle testing, EPA believes it is appropriate to continue to use the Phase 1 test procedure which references SAE J1711 "Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-in Hybrid Vehicles" instead of SAE J2711 "Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid-Electric and Conventional Heavy-Duty Vehicles."

3.10.2.1 Hybrid Charge Sustaining Operation – FTP or "City" Test and HFET or "Highway" Test

The agencies will continue incorporating by reference SAE J1711 Chapters 3 and 4 for definitions and test procedures, respectively, where appropriate, with the following exceptions and clarifications.

The agencies are adopting the 1 percent of fuel energy NEC state of charge criteria as expressed in SAE J1711 and described in 40 CFR 1066.501. The Administrator may approve alternate NEC tolerances and state of charge correction factors.

Preconditioning special procedures are optional for traditional "warm" test cycles that are now required to test starting at full RESS charge due to charge depleting range testing. If the vehicle is equipped with a charge sustain switch, the preconditioning cycle may be conducted per 40 CFR 600.111 provided that the RESS is not charged. Exhaust emissions are not taken in preconditioning drives. Alternate vehicle warm up strategies may be approved by the Administrator.

State of Charge tolerance correction factors may be approved by the Administrator as described in 40 CFR 1066.501. RESS state of charge tolerances beyond the 1 percent of fuel energy may be approved by the Administrator.

Due to the nature of PHEV and EV operation, testing may require many more vehicle miles than conventional vehicles. Furthermore, EVs and PHEVs either do not have engines or may use the engine for only a fraction of the miles driven.

Electric Vehicles and PHEVs are to be recharged using the supplied manufacturer method provided that the methods are available to consumers. This method could include the electricity service requirements such as service amperage, voltage, and phase. Manufacturers may employ the use of voltage regulators in order to reduce test to test variability with prior Administrator approval.

References

[1] For more information, see CFR Title 40, Part 86.004-28.
[2] Zhang, H., Sanchez, J., and Spears, M., "Alternative Heavy-Duty Engine Test Procedure for Full Vehicle Certification," SAE Int. J. Commer. Veh. 8(2):364-377, 2015, doi:10.4271/2015-01-2768.
[3] Salemme, G., Dykes, E., Kieffer, D., Howenstein, M. et al., “An Engine and Powertrain Mapping Approach for Simulation of Vehicle CO2 Emissions,” SAE Technical Paper 2015-01-2777, 2015, doi:10.4271/2015-01-2777.
[4] Zhang, H., Sanchez, J., and Spears, M., "Alternative Heavy-Duty Engine Test Procedure for Full Vehicle Certification," SAE Int. J. Commer. Veh. 8(2):364-377, 2015, doi:10.4271/2015-01-2768.
[5] U.S. E.P.A. Supplemental Aerodynamic Data from EPA Testing, Docket Identification Number EPA-HQ-OAR-2014-0827-1624, Feb 2016.
[6] McAuliffe, Brian. Improving the Aerodynamic Efficiency of Heavy Duty Vehicles: Wind Tunnel Test Results of Trailer-Based Drag-Reduction Technologies. National Research Council Canada Report LTR-AL-2015-0272. July 2015.
[7] ICF International, Aerodynamic Trailer Component Assessment and Impact on the Greenhouse Gas Emissions from Heavy-Duty Combination Vehicles - Computational Fluid Dynamics Simulation, July 2016.
[8] Southwest Research Institute, Heavy Duty Tractor Coastdown and Constant Speed Testing – Final Report, July 2016.
[9] National Renewable Energy Laboratory, 2014. Technical Report: Appending High-Resolution Elevation Data to GPS Speed Traces for Vehicle Energy Modeling and Simulation. http://www.nrel.gov/docs/fy14osti/61109.pdf.
[10] R.M. Young. Product specifications for Ultrasonic Anemometer Model 81000. http://www.youngusa.com/products/6/3.html.
[11] McAuliffe, B. and Chuang, D. Coast-down and Constant-speed Testing of a Tractor-trailer Combination in Support of Regulatory Developments for Greenhouse Gas Emissions. National Research Council Canada Report LTR-AL-2016-0019. May 2016. (Pending publication).
[12] 2010 NAS Report. Finding 2-4 on page 39.
[13] DG Clima, European Commission, 2014. Development and Validation of a Methodology for Monitoring and Certification of Greenhouse Gas Emissions from Heavy Duty Vehicles through Vehicle Simulations. http://ec.europa.eu/clima/policies/transport/vehicles/heavy/docs/final_report_co2_hdv_en.pdf.
[14] Ben Sharpe (ICCT) and Mike Roeth (North American Council for Freight Efficiency), “Costs and Adoption Rates of Fuel-Saving Technologies for Trailer in the North American On-Road Freight Sector”, Feb 2014.
[15] Frost & Sullivan, “Strategic Analysis of North American Semi-trailer Advanced Technology Market”, Feb 2013.
[16] SAE International, 2013, Guidelines for Aerodynamic Assessment of Medium and Heavy Commercial Ground Vehicles Using Computational Fluid Dynamics, SAE J2966, 2013-09.
[17] EPA, 2011, HD Phase 1 Regulatory Impact Analysis, Figure 3-16. EPA-420-R-11-901.
[18] (http://webstore.ansi.org/RecordDetail.aspx?sku=ISO+28580%3a2009).
[19] SAE International, 2006, Rolling Resistance measurement Procedure for Passenger Car, Light Truck, and Highway Truck and Bus Tires, SAE J1269, 2006-09.
[20] ISO, 2009, Passenger Car, Truck, and Bus Tyres – Methods of Measuring Rolling Resistance – Single Point Test and Correlation of Measurement Results: ISO 28580:2009(E), First Edition, 2009-07-01.
[21] NHTSA, 2009. “NHTSA Tire Fuel Efficiency Consumer Information Program Development: Phase 1 – Evaluation of Laboratory Test Protocols.” DOT HS 811 119. June. (www.regulations.gov, Docket ID: NHTSA-2008-0121-0019).
[22] SAE International, 1999, Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance, SAE J2452, 1999-06.
[23] ISO, 2005, Passenger Car, Truck, Bus, and Motorcycle Tyres – Methods of Measuring Rolling Resistance, ISO 18164:2005(E).
[24] SAE International, 2012, Test Procedures for Measuring Truck Tire Revolutions per Kilometer/Mile, SAE J1025, 2012-08.
[25] Based on MOVES analysis.

[26] Gautam, M., N. Clark, W. Riddle, R. Nine, S. Wayne, H. Maldonado, A. Agrawal, M. Carlock. "Development and Initial Use of a Heavy-Duty Diesel Truck Test Schedule for Emissions Characterization." SAE Paper 2002-01-1753. 2002.
[27] Governors Highway Safety Association. Speed Limit Laws May 2011. Last viewed on May 9, 2011 at http://www.ghsa.org/html/stateinfo/laws/speedlimit_laws.html.
[28] NREL May 2015, "EPA GHG Certification of Medium- and Heavy-Duty Vehicles: Development of Road Grade Profiles Representative of US Controlled Access Highways," NREL/TP-5400-63853.
[29] NREL June 2016, "The Development of Vocational Vehicle Drive Cycles and Segmentation," NREL/TP-5400-65921.
[30] Environmental Defense Fund. "Greenhouse Gas Management for Medium-Duty Truck Fleets." Viewed at http://edf.org/documents/10860_fleets-med-ghg-management.pdf. Page 6.
[31] ICF International. Investigation of Costs for Strategies to Reduce Greenhouse Gas Emissions for Heavy-Duty On-Road Vehicles. July 2010. Pages 4-16. Docket Identification Number EPA-HQ-OAR-2010-0162-0044.
[32] M.J. Bradley & Associates. Setting the Stage for Regulation of Heavy-Duty Vehicle Fuel Economy and GHG Emissions: Issues and Opportunities. February 2009. Page 35. Analysis based on 1992 Truck Inventory and Use Survey data, where the survey data allowed developing the distribution of loads instead of merely the average loads.
[33] The U.S. Federal Highway Administration. Development of Truck Payload Equivalent Factor. Table 11. Last viewed on March 9, 2010 at http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports9/s510_11_12_tables.htm.
[34] Excerpted from The U.S. Federal Highway Administration. Development of Truck Payload Equivalent Factor. Table 11. Last viewed on March 9, 2010 at http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports9/s510_11_12_tables.htm.
[35] The U.S. Federal Highway Administration. Development of Truck Payload Equivalent Factor. Table 11. Last viewed on March 9, 2010 at http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports9/s510_11_12_tables.htm.

Chapter 4: Vehicle Simulation Model

4.1 Purpose and Scope

In designing a regulatory GHG emission control and fuel consumption program, it is necessary to estimate the performance of technologies, verify compliance with the regulatory standards, and estimate overall benefits of the program. The agencies developed the Greenhouse gas Emission Model (GEM) to serve these purposes for Phase 1, consistent with recommendations by the National Academies of Sciences (NAS) to use vehicle simulation to demonstrate compliance.[1] GEM is currently being used to certify the fuel consumption and CO_2 benefits of the Phase 1 rulemaking for all heavy duty vehicles except for HD pickups and vans, which require a chassis dynamometer test for certification. While the version of GEM used in Phase 1 contained most of the technical and mathematical features needed to run a vehicle simulation, the model was limited. For example:

- Only manual transmissions were used in the model for all tractor and vocational vehicle simulations, which is not always the case for real world applications, especially for vocational vehicle applications
- The model did not include engine torque interruption during gear shifting
- Engine controls were simplified, with no fueling cut-off features
- Only the agencies' pre-specified engine fuel maps were used

The Phase 1 certification process only required up to five user inputs, and all other vehicle parameters and their inputs were pre-specified by the agencies.[7] Phase 1 GEM only recognized the benefits of aerodynamics improvement, tire rolling resistance, vehicle speed limiter, weight reduction, and idle reduction (only for high roof sleeper tractors).

Because the Phase 2 standards are predicated on the performance of a broader range of technological improvements than Phase 1, including changes to transmissions and better integration of engines and transmissions, a more comprehensive vehicle simulation model is required to recognize these technologies' performance.[A] This chapter describes a new version of this vehicle simulation model, referred to as Phase 2 GEM.

4.1.1 Summary of GEM Changes between Phase 1 and Phase 2 NPRM

Prior to the proposal, the agencies created an initial version of Phase 2 GEM referred named "GEM P2v1.0." This version would require manufacturers to perform a new engine "mapping" test procedure to generate steady-state and transient engine fuel consumption inputs to represent the actual engine in a vehicle. It also would require entering into GEM new inputs to describe the vehicle's transmission type and its number of gears and gear ratios. In order to meet Phase 2 rulemaking requirements in recognizing most of the technologies that are measured

[A] Under Phase 1, these technologies could be innovative technology credited under that mechanism, but this mechanism is not generally suited with respect to technologies on whose performance standards are predicated. Since transmission, driveline, and engine-transmission integration are key parts of projected compliance pathways for many of the Phase 2 standards, it is appropriate for GEM to recognize these technologies' performance.

in both engine and chassis dynamometers, GEM has been considerably enhanced as opposed to Phase 1 GEM. Specifically, the agencies implemented the following key technical features into Phase 2 GEM:

- An upgraded engine model, which includes engine fuel cut-off during braking and deceleration as well as more realistic torque response.
- Newly developed automatic and automated manual transmissions, with adaptive shifting algorithms and the option of utilizing manufacturer supplied transmission loss data.
- An upgraded driver model with a distance-compensated driver that will drive the certification drive trace over a prescribed distance regardless of increased drive time due to vehicle under-performance, for example.
- New axle model featuring the option of utilizing manufacturer supplied loss data.
- Simulation of start-stop, neutral idle, and automatic engine shutdown technologies in applicable vocational vehicles.
- Road grade on 55 and 65mph cruise speed cycles

4.1.2 Summary of GEM Changes between Phase 2 NPRM and Phase 2 FRM

The agencies have continued to make modifications to GEM since proposal. Many of these iterations were made available for comment, in meetings[2,3,4,5,6], and, most recently, via NODA y. The agencies received helpful comment on many of these iterations, which comments are reflected in the promulgated version of GEM. The following summarizes the major changes of GEM in response to those comments and data submitted to the agencies since the Phase 2 proposal:

- Modified road grade profile for 55- and 65-mph cruise cycles
- Revised idle cycles into overall vocational vehicles with new vocational cycle weightings
- Made significant changes on the input file structures. Examples includes additions of columns for axle configuration (“6x2,” “6x4,””6x4D,” “4x2”), and additions of a few more technology improvement inputs, such as “Neutral Idle and Start/Stop.”
- Made significant changes on output file structures. Examples includes an option to allow the user to output detailed results on average speed, average work before and after transmissions, and the numbers of shift for each phase (55 and 65mph cycles and ARB cycle).
- Added input file for axle power losses (function of axle output speed and torque) and replaced single axle efficiency in model with lookup table of torque loss
- Added simulation of engine torque response with fast response region defined by engine displacement, and slower torque increase in boosted region with fast falloff on available torque
- Added regression models for all certification cycles to allow the user to simulate vehicle with cycle average approach
- Added different fuel properties according to 1036.530.
- Significantly improved shift strategy based on testing data
- Adjusted transmission loss & inertia scale factors per regulatory subcategory

- Added optional input table for transmission power loss data
- Added minimum torque converter lock-up gear input for AT
- Retuned the default transmission mechanical efficiency based on the testing data
- Added neutral idle and start/stop features during simulation
- Adjusted shift and torque converter lockup strategy

4.2 Model Code Description

4.2.1 Engineering Foundations of the Model

EPA developed GEM to be a forward-looking Matlab/Simulink-based model for heavy-duty (Class 2b-8) vehicle compliance in 2011.[7] A more detailed description of this model and its engineering foundation can be found in Reference 7. The underlying GEM code was originally developed to simulate a broad range of vehicle speeds over essentially any in-use duty cycle. However, the official version that is used for determining compliance with the Phase 1 standards incorporates the regulatory duty cycles into the code. In other words, manufacturers cannot run other duty cycles with the official version of GEM. We will continue this approach for Phase 2.

4.2.2 Model Components

The GEM architecture is comprised of four systems: Ambient, Driver, Powertrain, and Vehicle as seen in Figure 4-1. With the exception of Ambient and Driver, each system consists of one or more subcomponents. The function of each system and its respective component models, wherever applicable, is discussed in this chapter. Many changes and modifications described in this chapter have resulted from numerous constructive comments from both public comments[8,9,10,11,12,13] and GEM peer reviews.[14] The model has been upgraded to improve its fidelity and better match the function of the simulated vehicles, which also meets our primary goal to accurately reflect changes in, and performance of, technology for both stringency standard development and compliance.

As part of this effort, the agencies devoted substantial effort to accurately track and audit power flows through the model to ensure conservation of energy. This is critical because this can allow the user to understand how the energy is balanced across entire vehicle system, and also help the user to understand which component of the vehicle system contribute the most and the least energy loss, so that a systematic optimization on a total vehicle can be conducted.

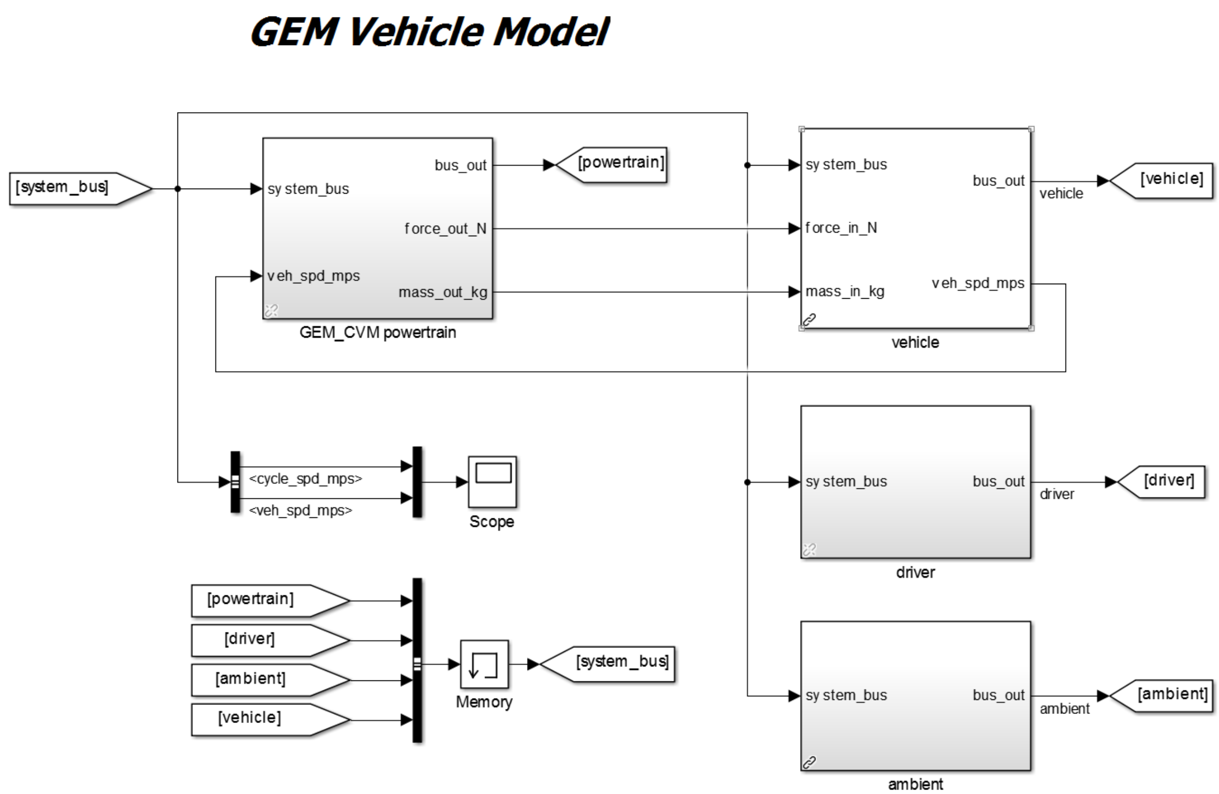

Figure 4-1 GEM model structure

4.2.2.1 Ambient Subsystem

This system defines ambient conditions such as pressure, temperature, and road gradient, where vehicle operations are simulated. Just as in Phase 1 GEM, the ambient conditions have been maintained in accordance with standard SAE practices. The road gradient has been modified to accept a road grade that varies as a function of distance traveled.

4.2.2.2 Driver Subsystem

The driver model in Phase 2 GEM has been substantially reorganized to simplify operation and to add support for distance compensated drive cycles. The result is a purely proportional-integral control driver that features a small look ahead to anticipate the drive cycle, especially useful at launch where the vehicle response may be delayed due to the large effective inertia in low gears. The target drive cycle consists of a road grade versus distance and a vehicle speed target as a function of the time required to achieve those speeds as a function of distance (i.e. desired cycle time). The drive cycle speed can be converted to a target speed versus distance travelled; however, such a conversion involves the complication of tracking vehicle stop times separately since they necessarily occur over zero distance.

Because the simulation itself is time-based, we consider the driver to be distance-compensated rather than distance-based. The driver always operates in the time domain. To implement the distance compensated driver, the cycle position is tracked separately from simulation time, based on the ability of the target vehicle to meet the target speed trace. If the vehicle meets the target speed trace then cycle position is equivalent to simulation time as there is no difference in the distance travelled. If the vehicle under-performs the drive cycle, then cycle position proceeds more slowly than simulation time, forcing the vehicle to drive for a longer amount of time in order to cover an equivalent distance.

In terms of implementation, to apply distance compensation at each time step, the current model vehicle speed is divided by the target speed from the drive cycle. This value is integrated to produce the current cycle time and an updated speed target. The result is that if a simulated vehicle is traveling at half the drive cycle speed, the simulation will progress through the drive cycle at half the rate. This behavior is disabled at speeds below 1 meter per second to provide reasonable launch behavior (which necessarily occurs over short distances), and to maintain vehicle stop times independent of small discrepancies in total distance travelled.

The addition of distance compensation allows all simulated vehicles to complete an equivalent trip such as traveling from point A to point B. Without distance compensation, under-powered vehicles might complete the drive cycle by time but not distance and would have done less work, as measured in ton-miles, than higher powered vehicles. Distance compensation also allows for the variation in road grade to be kept in synchronization with the drive cycle speed trace.

The driver behavior during the steady state cruise cycles has also been modified. To be more representative of in-use operation for vehicles on descending grades, the modified driver model will no longer apply the brakes immediately to maintain the speed target. Instead, the vehicle is allowed to exceed the speed target by 3 mph before the brakes are applied. This allows the vehicle to carry additional momentum into the next hill.

4.2.2.3 Powertrain Subsystem

The engine, transmission, electric accessories, and portions of the vehicle models from Phase 1 GEM have been upgraded and merged into a conventional vehicle powertrain system as shown in Figure 4-2. The conventional powertrain system contains sub-models representing the engine, transmission, electric accessories, and driveline. Only conventional powertrains are modeled in Phase 2 GEM, and thus no hybrid power systems are modeled and certified with GEM. Rather, hybrid powertrains will be certified through the powertrain dynamometer tests described in Chapter 3 of the RIA.

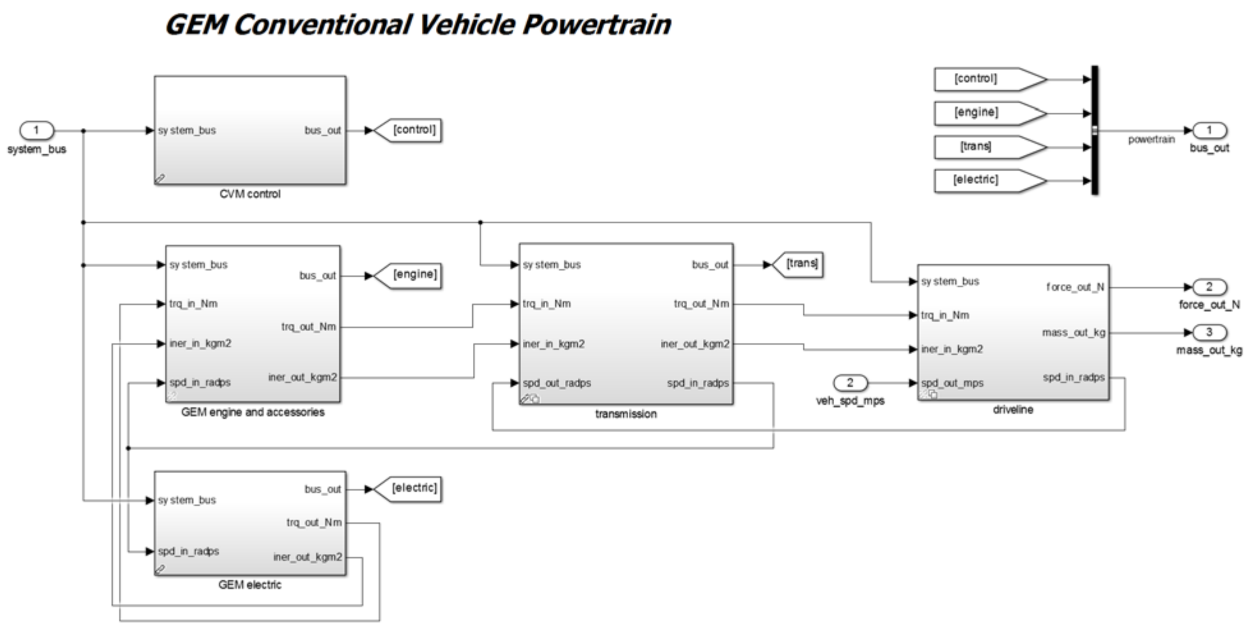

Figure 4-2 GEM Powertrain Model

4.2.2.3.1 Engine Subsystem

The engine model is based on a steady-state fuel map and a cycle average fuel map covering all engine speed and torque conditions with torque curves for wide open throttle (full load) and closed throttle (no load). The engine fuel map in Phase 2 is the input provided by users. The steady-state engine fuel map features three sets of data: engine speed, torque, and fueling rate at pre-specified engine speed and torque intervals, and is being used for 55 and 65mph cruise speed cycles with the road grade. The cycle-average engine fuel map features three sets of data: ratio of average engine speed to average vehicle speed, work, and fueling rate over the ARB transient cycle at pre-specified vehicle configurations, and it is only applied to ARB cycle. As an option, the cycle average map could be also applied to 55 and 65mph cruise speed cycles (i.e. steady state). In-cylinder combustion processes are not modelled. The engine speed at a given point in the drive cycle is calculated from the physics of the downstream speeds. The quantity of torque required is calculated from the driver model accelerator demand, an idle speed governor, and requests from the transmission during shifts. The torque request is then limited by a torque response model which is calculated from engine displacement and the maximum torque curve of the parent engine. Then, torque is limited by the maximum torque curve for the particular engine calibration provided. The resulting engine torque and speed are used to interpolate a fuel rate from the fuel map.

The engine model also includes a constant power loss to simulate mechanical accessories. Most vehicles run a number of accessories that are driven *via* mechanical power from the engine. Some of these accessories are necessary for the vehicle to run, like the engine coolant pump or power steering, while others are only used occasionally and at the operator’s discretion, such as the air conditioning compressor. Some heavy-duty vehicles also use Power Take Off (PTO) to operate auxiliary equipment, such as refuse compactors or lift forks. These will also be modeled as a mechanical accessory. The mechanical accessory load is fixed for all vehicles based on regulatory subcategory, as shown below in Table 4-8, Table 4-9, and Table 4-13. The actual power consumed for this loss would differ for actual vehicle configurations, but the agencies will not allow users to change this value in GEM. If a manufacturer uses a hybrid system for power take-off devices, it may make use of the hybrid-PTO test procedure. See 40 CFR 1037.540.

4.2.2.3.2 Electric Subsystem

The electric subsystem is modeled as a constant power loss. The power consumed for this loss is based on the vehicle subcategory. It represents the power loss associated with the starter, electric energy system, alternator and the electrically driven accessories. The simplification has a negligible impact on the fuel consumption and CO_2 emissions results. The power losses for different vehicles are shown in tables from Table 4-7 to Table 4-15.

4.2.2.3.3 Transmission Subsystem

The transmission subsystem features three different variants representing the major types of transmissions that are currently in use in the heavy-duty sector, which are the transmission types on whose performance the various standards are partially predicated. The different transmission models are built from similar components, but each features a unique control algorithm matching behaviors observed during vehicle testing.[15]

4.2.2.3.3.1 Transmission Gear Selection

All of the transmission models use a dynamic shift algorithm to determine the operating gear over the cycle.[15] This employs a rule based approach utilizing the engine torque curve and fuel map to select gears that optimize efficient engine operation and provide a torque reserve as a traditional transmission calibration would. The algorithm in GEM attempts to select the minimum fuel consumption gear after applying constrains on engine speed and torque reserve. It also allows downshifts due to high driver demand. A detailed description on the shifting strategy can be seen in the cited article. [15]

4.2.2.3.3.2 Clutch

The clutch model in Phase 2 GEM replaces the simplified model found in Phase 1 GEM. The original clutch model had no transition between the fully engaged and fully disengaged states and provided no commensurate torque impulse to the driveline. In the new clutch model, engagement and disengagement occur over time, torque is conserved across the clutch, and the inertial effects of accelerating and decelerating the upstream inertias are captured.

4.2.2.3.3.3 Gearbox

The gearbox model has also been substantially revised in Phase 2 GEM to provide more realistic operation when shifting. The gearbox contains gear ratios, which are provided by the user in the transmission input file. In order to model power loss through transmission, a look-up table that contains the power loss as function of gear number, input speed and input torque is used. If users provide their own power loss table, this table will incorporate the user-provided data. The power loss table can be obtained by following the test procedure 40 CFR 1036.565. If users do not specify the power loss, a default power loss table will be selected within GEM based on the transmission type, number of gears, gear ratios and engine torque rating. GEM assumes a higher efficiency for direct drive than in any other gear.

Shifting behavior is more realistic than in Phase 1 GEM with appropriate delays provided by a synchronizer clutch model. The layout of the gearbox model is most similar to a manual transmission, but the application for a planetary gearbox is a reasonable approximation as this type of gearbox can utilize a variety of topologies.

The gearbox rotational inertias are split between a common input inertia, common output inertia and a gear specific inertia. The common inertias represent rotational inertia always coupled to the input or output shafts. The gear specific inertias are added or removed as gears are engaged or disengaged and incur additional losses.

4.2.2.3.3.4 Hydrodynamic Torque Converter

The torque converter model in Phase 2 GEM simulates a lockup-type torque converter. The torque multiplication and resulting engine load are calculated via torque ratio and K-factor curves that vary as a function of speed ratio. A base torque ratio curve is used for all simulations and the K-factor curve is scaled based on the engine torque curve to provide a good match between the torque converter stall speed and the engine's speed at maximum torque. This approximation could result in some simulation differences for highly specialized vehicles equipped with torque converters matched to their specialized duty cycle, but for the vast majority of vehicles the effect of this approximation on simulated CO_2 emissions is negligible.

The lockup behavior of the torque converter is accomplished by integrating a clutch model similar to the one discussed in Chapter 4.2.2.3.3.2. The torque converter model also contains a pump loss torque that varies with input speed and torque to simulate the power required to operate the pump on an automatic transmission.

4.2.2.3.3.5 Automatic Transmission & Control

The automatic transmission (AT) is composed of the torque converter and gearbox systems discussed above. The gearbox gear specific inertias and spin loss torques are higher as would be expected from a conventional planetary automatic transmission gearbox. The AT is allowed to shift under load. During upshifts and torque converter lockup the engine output torque is slightly reduced to minimize the resultant torque pulse encountered by decelerating the engine inertia.

The torque converter lockup clutch command is determined based on transmission gear and gearbox input speed. The threshold at which lockup and unlock are triggered is calculated from the engine torque curve. In the transmission file the user may specify the minimum gear in which torque converter lockup may occur. If the value is not specified 3rd gear will be assumed as the default.

4.2.2.3.3.6 Automated Manual Transmission & Control

The automated manual transmission (AMT) is composed of the clutch and gearbox systems discussed above with the addition of an inertia brake to slow the gearbox input inertia during upshifts. The AMT features a low speed clutch engagement routine that feathers the clutch to get the vehicle moving. The available torque in each gear is constrained based on data provided by the user in the transmission input file.

Upshifts in tractors and HHD vocational vehicles are handled by limiting the engine load, disengaging the clutch and shifting the gearbox to neutral. The inertia brake is then applied to slow the transmission input inertia before the gearbox engages the new gear. With the new gear engaged the clutch is reengaged and the engine is again allowed to operate at full load. For LHD and MHD vocational vehicles the clutch is not disengaged during upshifts and the inertia brake decelerates the inertia of both the engine and transmission input shaft. Downshifts are handled by shifting the gearbox to neutral and accelerating the gearbox input up to a speed matching the desired gear using the engine.

4.2.2.3.3.7 Manual Transmission

The results for Manual Transmission vehicles are calculated from the GEM AMT model. After simulation a 2 percent penalty is applied to non-idle test cycles to match the relative benefits observed in fleet data, as discussed in RIA Chapter 2.4.

4.2.2.3.4 Driveline

The driveline system contains all of the components that convert the torque at the transmission output to force at the wheels. This includes drive shafts as well as driven axles, consisting of a differential, brakes and tires.

4.2.2.3.4.1 Driveshaft

The driveshaft is a simple component for transferring torque while adding additional rotational inertia.

4.2.2.3.4.2 Final Drive

The final drive is modeled as a gear ratio change with power loss table provided in the optional axle input file. The input can be generated by following the test procedure 40 CFR 1036.560. If users do not provide the power loss table, a default table will be selected based on the vehicle category and axle ratio.

4.2.2.3.4.3 Brakes

The brake system on each axle applies a torque to the axle proportional to the brake pedal position from the driver model. The brake model is scaled to match the requirements of the vehicle.

4.2.2.3.4.4 Tires

The tire component model transfers the torques and rotational inertias from upstream components to a force and equivalent mass that is passed to the vehicle model. This conversion uses the loaded tire radius and adds the tire's rotational inertia. The force associated with the tire rolling resistance is also applied when the vehicle is moving. The magnitude of this force is determined by the coefficient of rolling resistance, vehicle static mass and current grade.

The new version of GEM will make tire size a manufacturer-specified input rather than use a predefined value as was done for Phase 1. Manufacturers will specify tire size in terms of tire revolutions per mile per SAE. Other than this, tires are being modeled the same as in Phase 1.

4.2.2.4 Vehicle

The vehicle system consists of the chassis, its mass and forces associated with aerodynamic drag, rolling resistance, and changes in road grade. The aerodynamic force is calculated from the air density, vehicle speed, coefficient of drag, and frontal area. The vehicle system also contains the vehicle speed integrator that computes acceleration from the input force and equivalent mass which is integrated to generate vehicle speed and distance traveled.

4.2.3 Capability, Features, and Computer Resources

GEM is a flexible simulation platform that can model a wide variety of vehicles with conventional powertrains from Class 2b to Class 8. The key to this flexibility is the component description files that can be modified or adjusted to accommodate vehicle-specific information. Parameters such as vehicle weight, engine fuel map, transmission gear ratios, tire radius, or axle ratio can all be changed as inputs by the user in this fashion. The Phase 2 GEM predefines all drive cycles (the Transient mode defined by the California Air Resources Board (CARB) in their Highway Heavy-Duty Diesel Transient (HHDDT) cycle, and EPA GEM highway cruise cycles at 65 mph and 55 mph, each with varying road grade). The agencies also pre-defined many key parameters, since those parameters are either hard to quantify due to lack of certified testing procedures or difficult to obtain due to proprietary barriers. One of the examples of this is the transmission shifting strategies. The transmission shifting strategies were developed as a result of substantial testing as discussed in the Southwest Research Institute Report[16], as well as confidential discussions with engine, chassis and component manufacturers.

During simulation the GEM tracks the status of many components and the status of all of the modeled losses. This information provides an energy audit to ensure the model conserves energy. The fuel consumed and vehicle speed traces are immediately available in the generated report, while the larger data set is available in a Matlab .mat file or a comma-separated values (CSV) file.

4.2.3.1 GEM Executable

The final rule requires that vehicle manufacturers use the Phase 2 GEM executable version, which does not require the use of Matlab or Simulink software, for demonstrating compliance with the Phase 2 CO_2 and fuel consumption standards. In this form, a precompiled executable format is used for certification. Its computational requirements are minimal. When using the minimum recommended 2 GHz processor and 4 GB of RAM, a single simulation should complete in 10 seconds and generate 100 MB output files. Inputs from the manufacturers are provided in a text file, and the results are available in a generated report.

4.2.3.2 GEM Matlab /Simulink Model

The Matlab/Simulink version of the GEM source code will be released for users that desire a more detailed look at the inner workings of the model. The system requirements for the Matlab /Simulink version of GEM include Matlab, Simulink and StateFlow software from Mathworks (version 2014a or later) and a compatible compiler.[17] The recommended hardware for the Matlab release of GEM is 2+ GHz processor and 4 GB of RAM. The output data from a GEM simulation into Matlab is approximately 500 MB, depending on the simulation configuration and outputs selected. Simulations inside Matlab /Simulink using the source code take approximately 2 to 3 minutes. Although the source code is available to users, all of the component initialization files, control strategies and the underlying Matlab /Simulink/StateFlow-based models may not be used for determining compliance. Only the executable version can be used when producing official HD vehicle certification results. Also, it should be pointed out that EPA will not provide any technical support for the use of the GEM source code because it is beyond the scope of the agency's responsibilities and resources.

4.2.4 Peer Review of Phase 2 GEM

Before proposal, Phase 2 GEM was the subject of peer review.[14] The peer review was conducted by an independent contractor and includes four reviewers. Additional details regarding the peer review and EPA's responses to the peer review comments can be found in the docket.[14]

The agencies also met with and received comments from the Engine Manufacturers Association, along with other industry stakeholders, during the development of Phase 2 GEM, which identified some areas of concern with GEM. In response, the agencies made significant improvements that are summarized in Chapter 4.2.1 above.

The agencies released two versions of GEM for public comment with the NPRM (GEM P2v1.0 and GEM P2v1.1). After making revisions in response to comments, the agencies released a few more versions for public comment with the NODA (GEM P2v2.1) GEM P2v2.2, GEM P2v2.3, and GEM P2v2.4.

4.3 Validation of Phase 2 GEM Simulations

This chapter presents the results of an engineering evaluation of the ability of the computer model in GEM to accurately simulate actual engine and vehicle performance. Note that this version differs from the compliance version in that it was possible to use actual values for vehicle parameters that are locked in the compliance version of GEM. For example, validations used actual vehicle curb weights. They also incorporated actual shift strategies where available. This is appropriate because the purpose of the validations was to evaluate the engineering basis of the model, rather than to evaluate whether the policy of locking certain parameters is appropriate.

4.3.1 Experimental Tests for GEM Validation

Working with Southwest Research Institute (SwRI), EPA has invested significantly in various truck tests in order to collect data to validate Phase 2 GEM. The technical research workshop held at SwRI, San Antonio, TX, December 10-11, 2014, details all of these tests[18]. The following truck tests were carried out by SwRI for the purpose of model validation:

- Class 6 Kenworth T270 vocational box truck with AT
- Class 6 Ford F-650 vocational tow truck with AT
- Class 8 Kenworth T700 line haul truck with AMT
- Class 8 Autocar refuse truck with AT

The key specifications for those trucks are listed in Table 4-1.

Table 4-1 Vehicle Specifications of Heavy-Duty Trucks Tested at Southwest Research Institute

Truck	2013 Kenworth T700	2012 Kenworth T270	2011 Ford F-650 Tow truck	2012 Autocar Refuse
Engine /Rated Power (hp)	Cummins ISX 455	Cummins ISB 240	Cummins ISB 270	Cummins ISL 345
Transmission	Eaton F016E310C-LAS	Allison 2100	Allison 2200 RDS	Allison 4500 Series

In order to fully validate the model, each truck was tested over six different driving cycles including regulatory cycles and non-regulatory cycles. They are the EPA GEM 55mph (with and without grade), EPA GEM 65mph (with and without grade), the transient portion of the CARB Heavy-Duty Diesel Truck (HDDT) cycle, the World Harmonized Vehicle Cycle (WHVC), the High-efficiency Truck Users Forum (HTUF) Class 6 Parcel Delivery Cycle, and the National Renewable Energy Laboratory (NREL) Combined International Local and Commuter Cycle (CILCC) cycle (which is a utility vehicle cycle). The inclusion of driving cycles in addition to those used for Phase 1 certification was done to expand the range of operation, and also to include cycles that are used in the Phase 2 certification process (e.g. CARB transient, and 55mph and 65mph cruise speed cycles). Some of the cycles are very aggressive (especially for Class 8 trucks), such as the CILCC and Parcel Delivery cycles, with many stops and rapid accelerations. EPA evaluated the results from these additional cycles to improve the modeling capability and its response to highly transient conditions, thus providing additional confidence in model fidelity. All trucks were tested on a chassis dynamometer. In addition, the engine and transmission from the F-650 tow truck were tested in a powertrain dynamometer cell. More information on the vehicle chassis and powertrain dynamometer setups and tests can found in the Southwest Research Institute Report[19].

Considering that procurement of trucks for model validations would be time consuming and expensive, EPA developed a comprehensive approach to quantify variants of vehicles in order to maximize testing efficiency. This was done by varying aerodynamic drag and tire rolling resistance, as well as using weights to simulate different trucks, affording coverage of a wide range of vehicles. For tractors, varying these parameters also reflects the effects of pulling different types of trailers, which would impact the combined drag, rolling resistance, and weight of the vehicle. In this sense, this simultaneously provides validation data for both tractors and trailers.

Three vehicles were selected for this portion of the test program and they are: the Kenworth T270 box truck, the Kenworth T700 truck with a 53 foot box trailer, and the F-650 tow truck. The first two trucks were tested on a chassis dynamometer, while the third one was tested on a powertrain system dynamometer. A total of six drive cycles were tested: EPA GEM 55 mph, EPA GEM 65 mph, CARB HHDDT, WHVC, NREL CILCC, and HTUF Parcel Delivery cycle. An additional set of six tests were run for each driving cycle listed above to evaluate the impact of various vehicle characteristics on CO_2 emissions and fuel efficiency. The characteristics of the six test modifications are listed below:

1. Adding 800 to 1,000 pounds to the vehicle's tare weight depending on the vehicle class

2. Adding 15 percent to the vehicle-specific constant value representing the vehicle's frictional load to simulate higher rolling resistance tires

3. Reducing the vehicle-specific constant value representing the vehicle's frictional load by 15 percent to simulate lower rolling resistance tires

4. Increasing the vehicle-specific coefficient representing aerodynamic effects by 15 percent to simulate a higher aerodynamic drag vehicle

5. Decreasing the vehicle-specific coefficient representing aerodynamic effects by 15 percent to simulate a lower aerodynamic drag vehicle

6. Running a new set of road load coefficients, to represent a vehicle configuration optimized for fuel efficiency for each vehicle that was tested, which consists of the lowest rolling resistance as well as the lowest aerodynamic drag coefficient

Three valid replicate tests were conducted for each vehicle and characteristic over each driving cycle. A valid replicate was defined as a successful test run in which all data was collected without regeneration of the diesel particulate filter. The following parameters were measured or recorded during all tests:

- Vehicle speed as a function of time

- Engine fuel rate as a function of time

- Engine speed as a function of time

- Gear number as a function of time
- Engine load (Nm) as a function of time
- Emissions (NO_X, HC, CO, CO_2, N_2O, CH_4) as a function of time in g/s
- Measured cycle fuel economy (MPG) and emissions (NO_X, HC, CO, CO_2, PM, N_2O, CH_4)
- Grade as function of time for the cycle with road grade if tested

In addition to all these tests mentioned above, two identical trucks have been used to validate GEM in a real-world driving route. The specification of these trucks are defined as follows.

- Kenworth T700 with 2012 Cummins ISX15
  - 450 hp @ 1800 RPM
  - 1550 lb-ft @ 1100 RPM (calibration verified with INSITE)
  - Engine family CCEXH0912XAP
  - Controlled parts list (CPL) 3719
  - Fuel rate code FR10993, Cal P/N CL10135.25
  - Eaton F016E310C-LAS UltraShift 10 speed automated manual
  - Axle ratio 3.36
  - Tire size 295/75R22.5
- Trailers ballasted for GCVW of approximately 61,000 lbs
- Test weight without aero = 60,440 lbs (27,415 lbs)
- Test weight with aero = 61,240 lbs (27,778 lbs)

4.3.2 Results of the GEM Validations

The validation process was comprehensive, featuring three levels of validations. The first level of the validation is the modeling using the exact same engine fuel maps and transmission shifting tables obtained from manufacturers when GEM is used to model these vehicles. This level of the comparisons between testing and simulations are the most critical among the three, because this level of validation can directly point out the fidelity or issues of the model. The second level is modeling of the vehicle with the agency's pre-defined shifting strategy, called auto-shift, when simulation results are compared to the testing results obtained only from powertrain tests.[15] The only difference between the first and second level validations is the shifting strategy. The third level of the validation is modeling of a real-world driving route with two well specified trucks, followed by relative comparisons between simulations and testing results.

4.3.2.1 Validations Using the Exact Engine and Transmission Information

This section describes the first level of validations. Taking into account all of the vehicles and test configurations mentioned above, more than 130 vehicle variants were tested, allowing GEM to be comprehensively validated against a very well-defined and robust set of test data. The results displayed in through Figure 4-3 through Figure 4-6 show the of comparison between the GEM simulations and testing data of the Class 8 Kenworth T700 truck, Class 6 Ford F-650 tow truck, Class 6 Kenworth T270 box truck, and Autocar refuse truck respectively. In all figures shown here for 55 and 65mph cycles, road grade is not included.

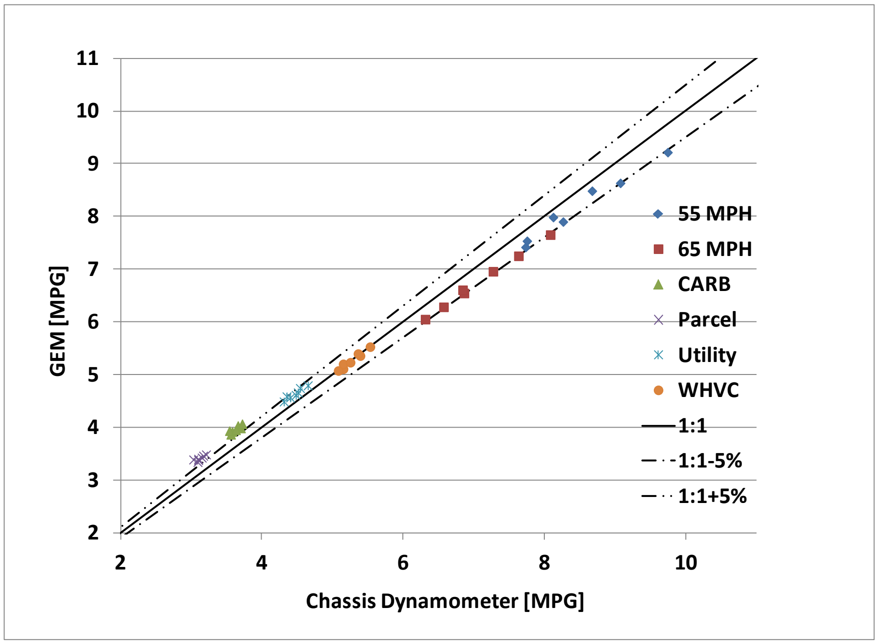

Figure 4-3 GEM Validation against Class 8 Kenworth T700 Truck Chassis Tests

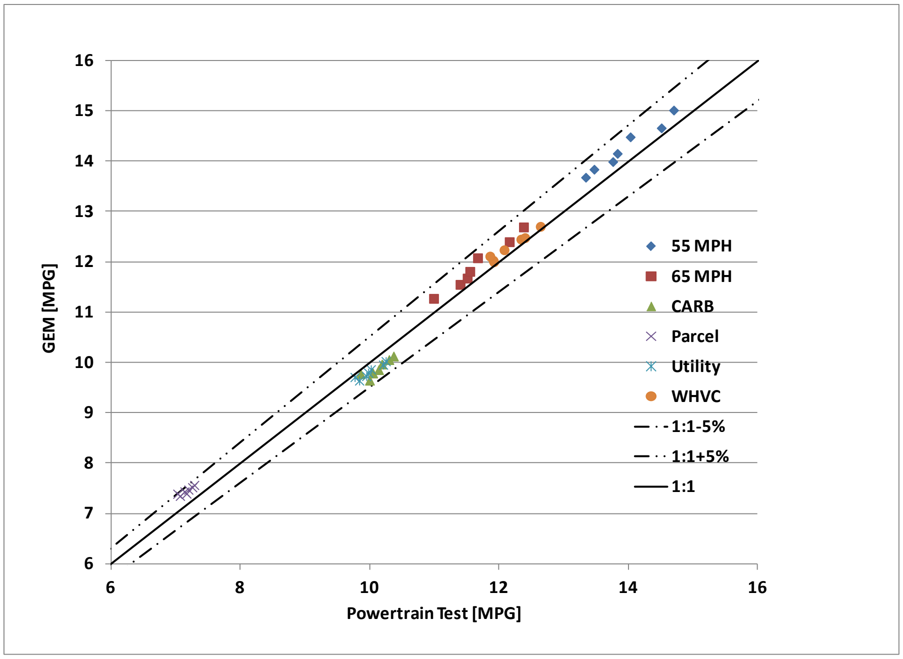

Figure 4-4 GEM Validation against Class 6 Ford F-650 Tow Truck Powertrain Tests

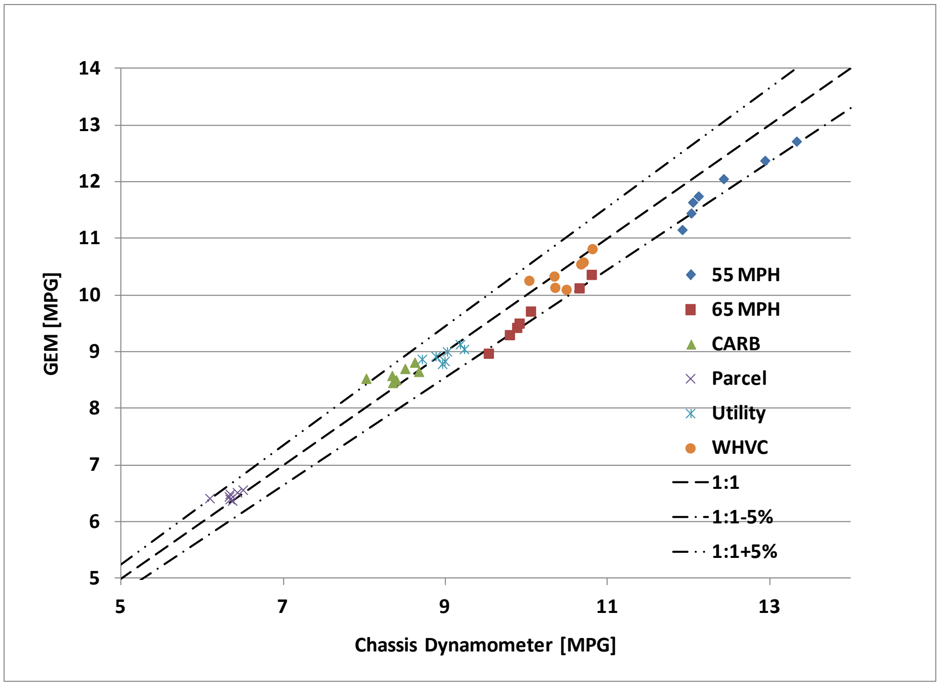

Figure 4-5 GEM Validation against Class 6 Kenworth T270 Box Truck Chassis Tests

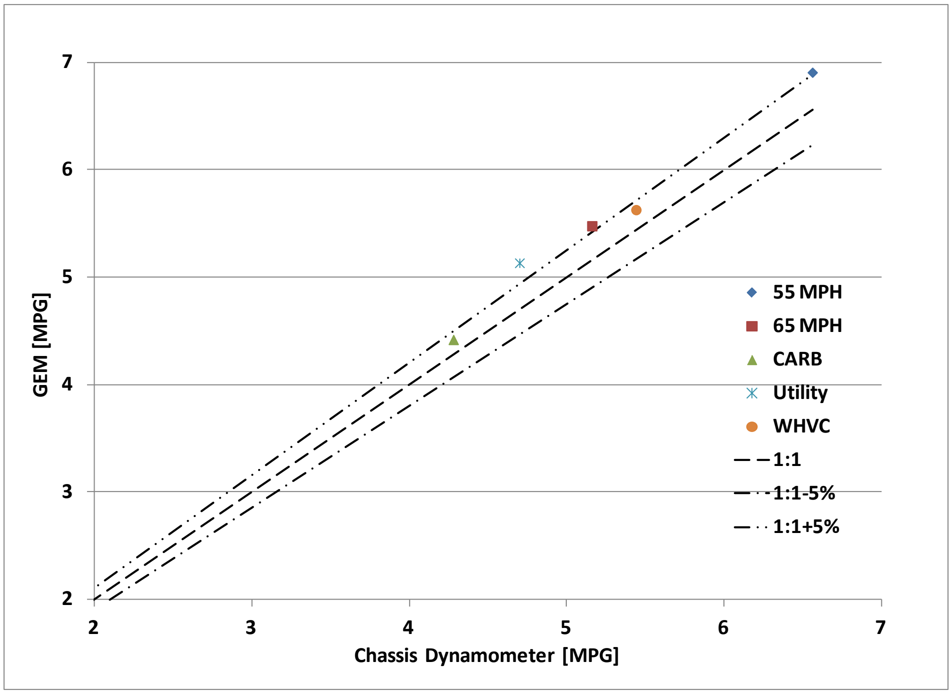

Figure 4-6 GEM Validation against Autocar Refuse Truck Chassis Tests

A review of the data indicates that there is good agreement between the GEM simulations and testing data obtained over the wide range of vehicles and conditions. In general, the accuracy of the model simulations against the testing data is very well controlled with an error of less than ±5 percent, although there are a few outliers of the transient simulation cases for Class 8 trucks due to the nature of the high variability of chassis dynamometer tests. The range of vehicles tested and simulated included vehicles that varied in terms of all of the regulatory inputs. Thus, the agencies believe that the accuracy of GEM is sufficient to simulate the benefits of the range technologies that form the basis of the standards.

Figure 4-7 shows the overall comparison between the simulation and test results when combining all of the testing and simulation into one figure. Overall, the simulation and test result correlate well.

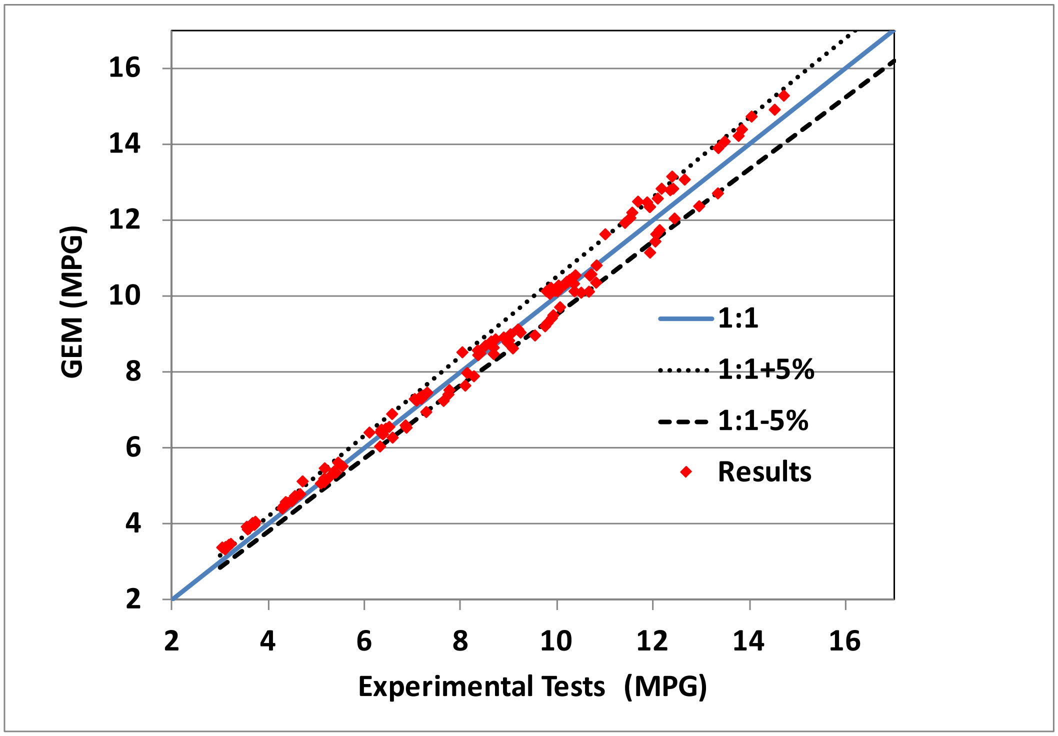

Figure 4-7 Comparison of Model Simulations and Chassis Test Results for the 130 Vehicle Test Configurations

While it is encouraging that GEM accurately simulates overall vehicle performance in an absolute sense, it is actually more important that GEM is accurate in relative comparisons. This is because the agencies used the same version of GEM to calculate the stringency of the standards as was used to evaluate baseline performance for this rulemaking. The ultimate purpose of this new version of GEM will be to evaluate *changes* or *additions* in technology, and compliance is demonstrated on a relative basis to the numerical standards that were also derived from GEM. The importance of relative comparisons can be further explained with the following simplified example.

Assume you have two simulation models: one that says a baseline vehicle with Bin 3 aerodynamics and a conventional automatic transmission would have CO_2 emissions of 90 g/ton-mile, and another that said the same vehicle would have emissions of 95 g/ton-mile. Assume also that there was a similar vehicle that was the basis of the new standards that had Bin 4 aerodynamics and a dual-clutch transmission. If both models simulated the second vehicle as being 10 g/ton-mile better than the baseline vehicle, then the models would work equally well for compliance as long as they were also used to set the standards. With the first model, we would set the standard at 80 g/ton-mile. And with the second, we would set the standard at 85 g/ton-mile. In both cases, manufacturers adding Bin 4 aerodynamics and dual-clutch transmissions would meet the standard. In other words, the two models would be equivalent in terms of measuring the effect of *the change* in technology on emissions, even though the absolute values differ.

As is shown below, GEM indeed performs better in this relative sense. The results from the T700 and T270 trucks, and powertrain tests for the F-650 tow truck shown in Figure 4-3 through Figure 4-5, can also be presented in a format to evaluate GEM's ability to measure the relative impact of a technology. Table 4-2 shows an example of relative comparisons to illustrate how the relative comparison is done with the T700 truck. For simplicity, only the results from the Class 8 T700 tractor on the 65mph cycle are shown in this table. The column labeled as Chassis Test Fuel Economy Result (MPG) shows the testing results, while the column with GEM Fuel Economy Result (MPG) shows the GEM simulation results. Each row represents a single change to the vehicle configuration, relative to the baseline case. The "Delta" in the last column is the difference between the impact of the vehicle configuration change as measured on the chassis dynamometer and simulated in GEM (which sometimes differs from the apparent delta due to rounding). For example, the row with the "+15 percent Crr" variable compares GEM results to chassis test results for a vehicle that is the same as the baseline vehicle except that it has tires with a coefficient of rolling resistance 15 percent higher than the baseline vehicle. For this example, chassis testing indicates the change in rolling resistance increases fuel consumption for this cycle by 3.9 percent, while GEM predicts it would increase by 4.9 percent, but the delta difference is only 1.0 percent as shown in the last column.

Table 4-2 Sample of Relative Comparisons for T700 Truck

Drive Cycle	Vehicle Attribute Variables	Chassis Test Fuel Economy Result (MPG)	GEM Fuel Economy Result (MPG)	Impact of Variable on Chassis Test Result	Impact of Variable on GEM Simulation Result	Delta
65 mph	Baseline	6.84	6.61	0.0%	0.0%	0.0%
65 mph	+907 kg	6.86	6.55	-0.3%	0.9%	-1.2%
65 mph	+15% Crr	6.57	6.28	3.9%	4.9%	-1.0%
65 mph	-15% Crr	7.27	6.96	-6.3%	-5.3%	-1.0%
65 mph	+15% Cd	6.31	6.05	7.7%	8.4%	-0.7%
65 mph	-15% Cd	7.63	7.25	-11.5%	-9.8%	-1.8%
65 mph	Optimized Package	8.08	7.65	-18.1%	-15.8%	-2.3%

The same methodology was applied to all other cases including three different trucks, and six driving cycles and six vehicle variables. The differences between the chassis test and GEM results from all of these comparisons are plotted in Figure 4-8.

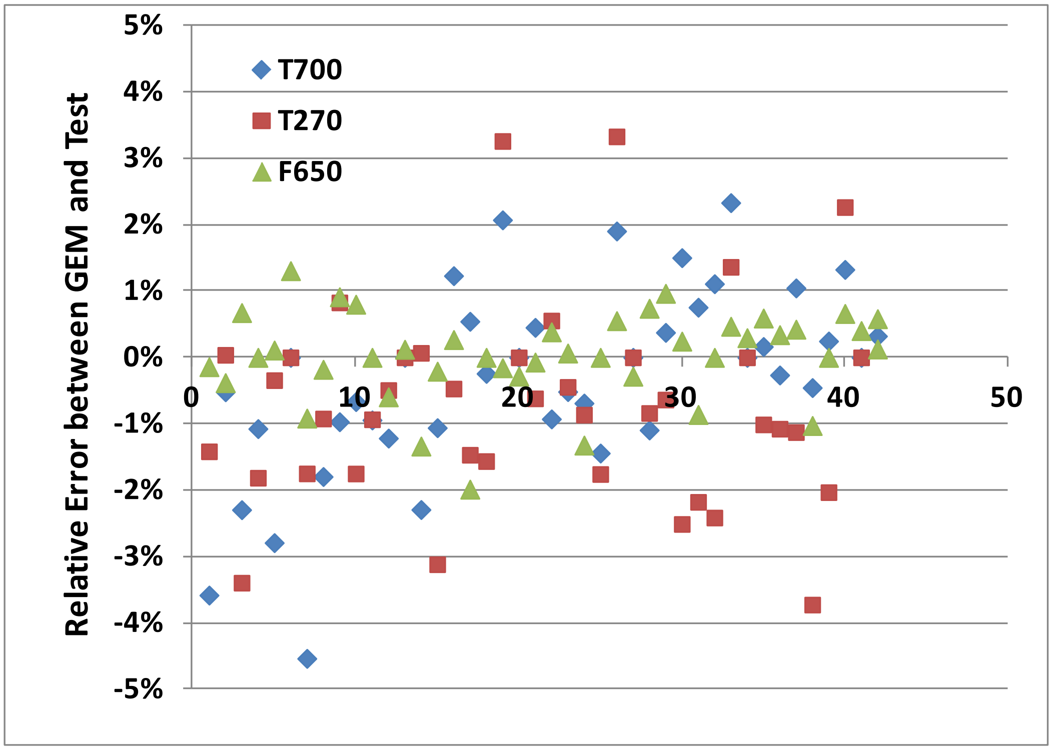

Figure 4-8 Relative Comparisons between Tests and GEM Results

In Figure 4-8, the horizontal axis represents the test number of each truck. It can be seen that the majority of cases have less than ±2-3 percent difference. Excellent correlation was obtained between the F-650 tow truck powertrain test data and GEM results, where all of the comparisons had an error less than ±2 percent. However, a few outliers with an error greater than 3 percent can be found in the Class 8 T700 and Class 6 T270 data. This is not unexpected since all the tests for both T700 and T270 trucks were conducted on the chassis dynamometer, while the tests for F-650 tow truck were conducted in the powertrain dynamometer cell.[20] The recent findings from the SwRI program sponsored by EPA show that chassis dynamometer tests have higher variability than powertrain tests, as discussed below.[21]

The driver behavior in the chassis dynamometer is one of the biggest contributors to the variability. This becomes even more of an issue when driving a very heavy vehicle like a Class 8 truck to follow a targeted vehicle speed trace in the chassis dynamometer cell, specifically for highly transient cycles such as CARB HHDDT, NREL CILCC, and HTUF Class 6 Parcel Delivery cycles. In contrast, a robot driver is used in the powertrain test for F-650 truck tests, thus removing this major source of variability. In addition, many other testing conditions, such as air temperature and coolant temperature, can be more stably controlled during powertrain than in chassis dynamometer tests. The findings also include many other sources of variability in the chassis dynamometer tests, such as tire temperature, thermal management during idle, and transmission oil temperature.[18,21] Because of the many uncertainties due to the variability of chassis dynamometer testing, it has been very challenging to match GEM results with chassis dynamometer test results in the same range of accuracy as the comparisons against the powertrain tests, specifically for those highly transient cycles. In some cases, it is hard to quantify which method, vehicle simulation or chassis dynamometer test, is more accurate.

Therefore, considering the favorable comparison between the powertrain tests and GEM simulation results, it is fair to say that the overall accuracy of the GEM to represent the relative changes in fuel economy of a real world vehicle should be in the range of ±2-3 percent.

Figure 4-7 and Figure 4-8, respectively, show the GEM accuracy against over 130 vehicle variants on an absolute and a relative basis. All are done in a total vehicle configuration, which includes all vehicle components, such as engine, transmission, and driveline. Since certification would be done in a total vehicle form for CO_2 emissions and fuel efficiency, these types of comparisons are the most important because they demonstrate that GEM is capable of capturing the impact on the total vehicle CO_2 emissions and fuel consumption due to technology improvement of individual components. In order to show the fidelity of GEM in modeling individual components in a more detailed level, the comparisons for the key components must be demonstrated as well. Displayed in Figure 4-9 through Figure 4-11 are the comparisons of engine speed, fuel rate, and transmission gear numbers as function of time over the CARB HHDDT cycle for Class 8 T700 truck.

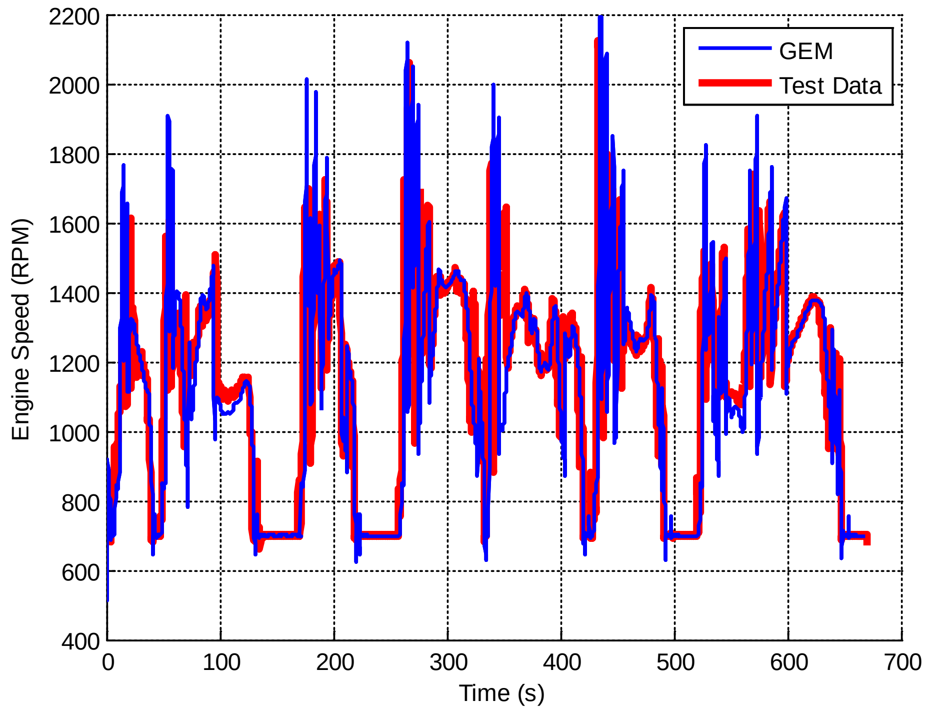

Figure 4-9 Engine Speed Comparisons over the WHVC for a Class 8 T700 Truck

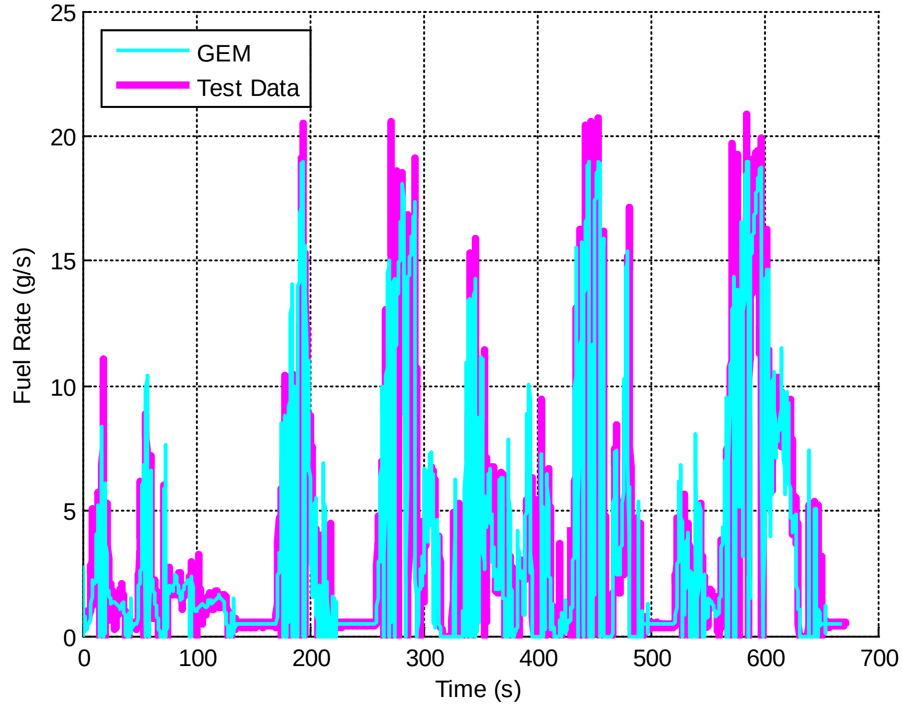

Figure 4-10 Engine Fuel Rate Comparisons Over the WHVC for a Class 8 T700 Truck

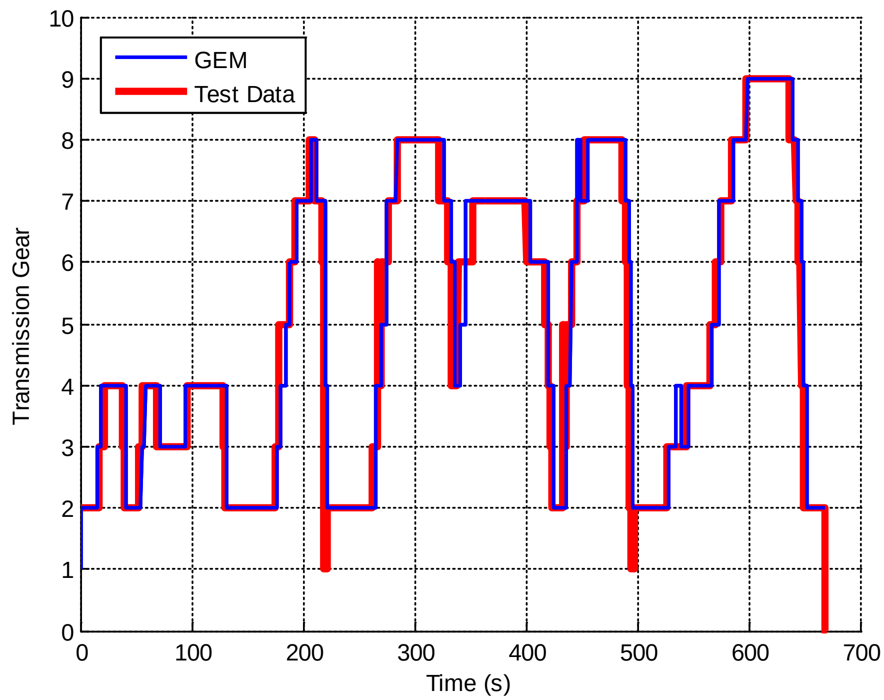

Figure 4-11 Transmission Gear Comparisons Over the WHVC for a Class 8 T700 Truck

As shown in Figure 4-9 through Figure 4-11, reasonably good comparisons between GEM simulations and tests are obtained. GEM basically can capture detailed behaviors of the engine and transmission. To further provide a more complete picture of the GEM validations, Figure 4-12 and Figure 4-13 show another set of examples for an F-650 tow truck. Shown in these two figures are the comparisons of engine speed and transmission output shaft torque over the World Harmonized Vehicle Cycle (WHVC) between powertrain dynamometer tests and GEM results. As can be seen from these two figures, reasonable comparisons are again obtained between GEM and actual test results.

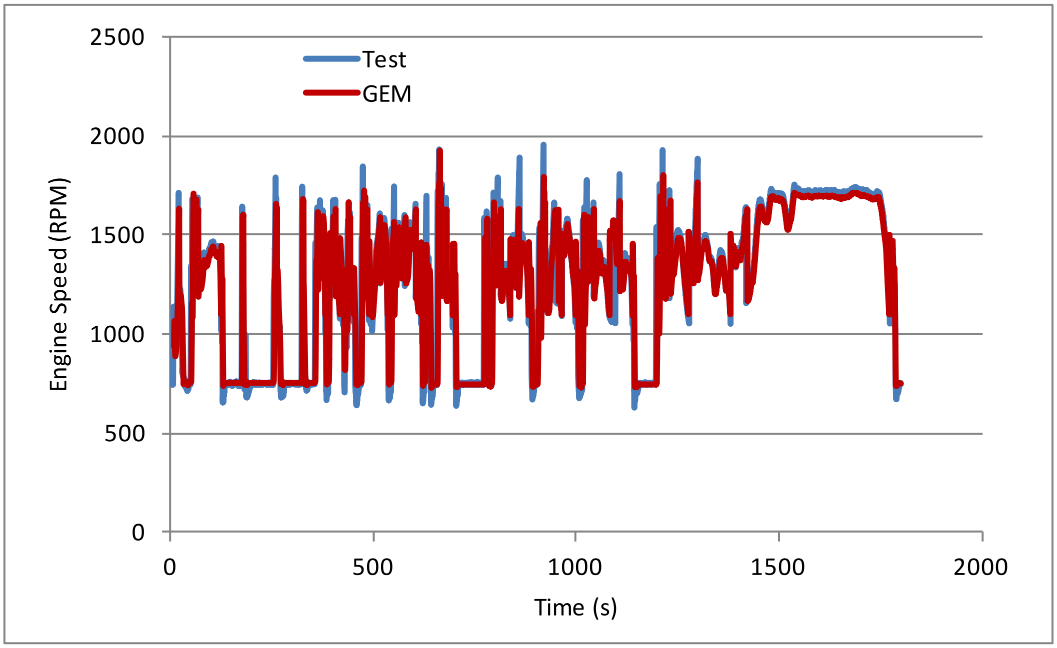

Figure 4-12 Engine Speed Comparisons Over the WHVC for an F-650 Tow Truck

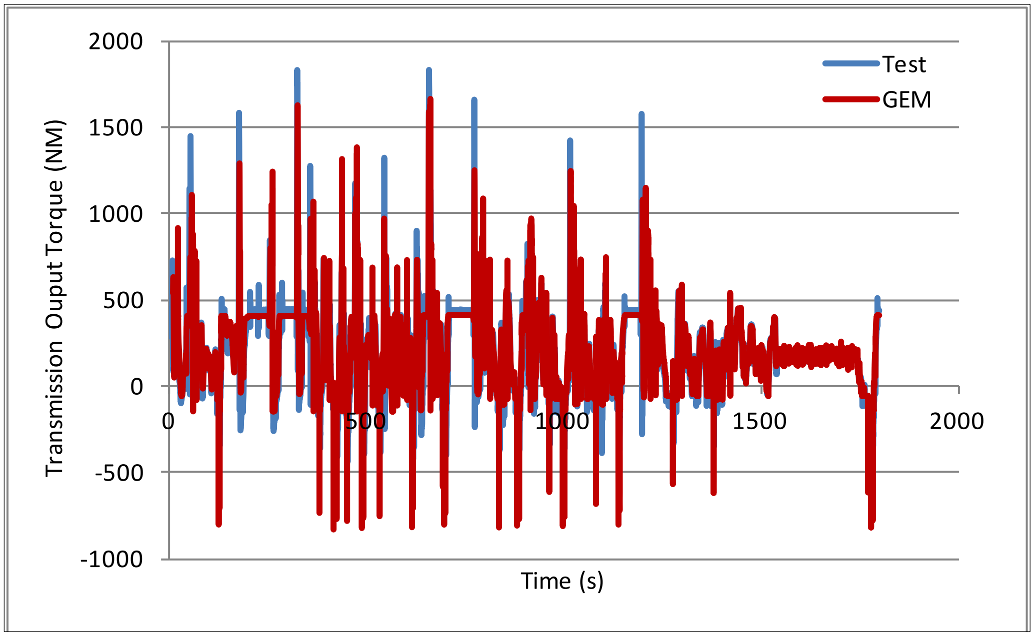

Figure 4-13 Transmission Output Torque Comparisons Over the WHVC for an F-650 Tow Truck

4.3.2.2 Validations Using Pre-default Shifting Strategy for All Transmissions

The second part of validations is to use the agency pre-defined shifting strategy for all transmissions[15] to conduct all simulations. Since the difference between the first level and second level validations is only in transmission shifting, it is recognized that the absolute comparisons would not be too good for certain conditions, specifically for transient cycles. For the cruise speed cycles, such as 55 and 65mph, the gear would stay on the top one or two gears. There is little or no shifting involved. As such, the comparisons between the shifting tables obtained from manufacturers and case with the agency's default shifting strategy should be about the same. Because of this reason, the second part of validations only focuses on the new data obtained from powertrain tests. No attempt was made to validate the model against chassis dynamometers. Display in Figure 4-14 is the comparisons between GEM with auto-shift and powertrain tests for ISB engine with Allison transmissions.

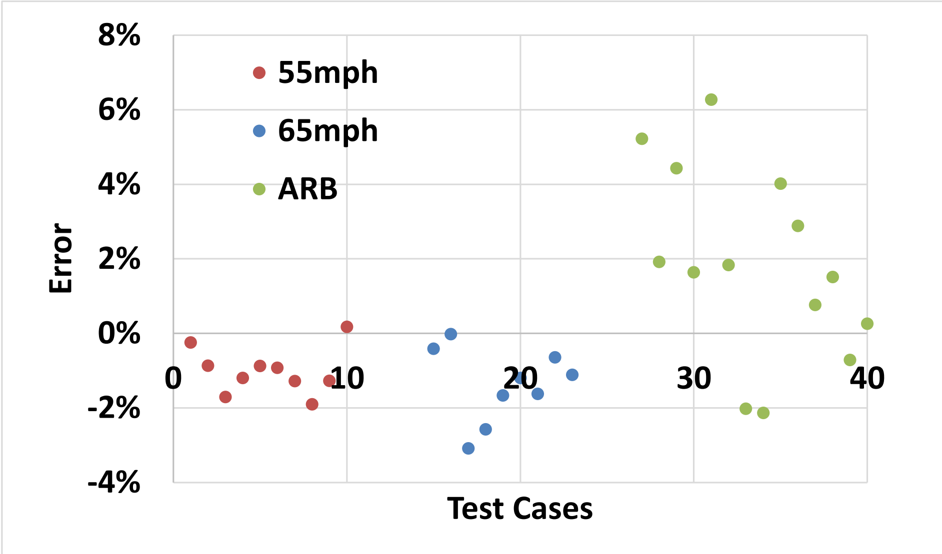

Figure 4-14 Comparisons between GEM with Auto-shift and Powertrain Dyno Tests

In 55 and 65 cruise speed cases, a road grade was included, and therefore, shifting in cruise speed cycle can happen depending on the combination of axle ratio, vehicle loads and many other conditions. As can be seen from this figure, cruise speed cycles are generally in good agreement with testing data in the range of 0-3 percent difference. However, the comparisons in the transient ARB cycle are not as good as cruise speed cycles. The main reasons can be attributed to the thermal management as well as to the different shifting strategy used in GEM. This happens for many of the ARB tests points. Since there is no mechanism in GEM with steady state fuel map to account for such transient behaviors, it is no surprise that GEM would not be able to predict the cycle accurately. That is one of the key reasons why the agencies introduce a new cycle average approach to replace the GEM simulation with steady state map, thus much more accurately accounting for the transient behavior. [24] More on this level of validations can be seen from the SwRI final report.[22]

4.3.2.3 Validations against Real-world Driving Route

The third part of validations is extremely challenging when GEM is used to simulate real-world driving routes. The most challenging parts of this validation are difficulty in obtaining the exact the same engine, transmission and vehicle input information for GEM, and measurement of the engine torque, the road grade, transmission gear number, and fueling over the entire road. Furthermore, the auto-shifting or the agency default's shifting is used for validations. Because of these challenges, it is impossible to compare GEM with absolute measurements of fueling. Only relative comparisons are meaningful. Detailed description of this part of the validations, including detailed routes, road grade, and complete vehicle specifications, can be seen from SwRI final report[22], and therefore only a brief summary is described here.

- The test procedure follows SAE J1321 "Type II." One truck is used as the controlled baseline, while the second one contains advanced technology packages, such as trailer aero treatment and lower rolling resistance tires. Difference of these two trucks in fueling by driving a pre-defined route is used to GEM validation. The route used for this purpose is part of Texas State Highway 130 from Seguin to Austin. The total distance used for GEM modeling is about 180 miles. Three repeat runs were carried out. The instruments used for these tests are listed below: 5 kN-m driveshaft torque meters

- High resolution GPS (10 meter resolution)
- CAN data from vehicle
  - Engine torque
  - Fuel flow
  - Engine RPM
  - Gear number
  - Vehicle speed
  - Regeneration status
  - Thermal management status
  - Accelerator pedal position
  - Brake pedal position
  - Air conditioning compressor on/off
  - Cruise control on/off

Table 4-3 shows one of three runs of the comparisons between GEM and testing results. The column “T393” is the control vehicle defined as the baseline following SAE J1321 “Type II,” while Column “T394” is the truck with advanced aero and tire on the second truck. The last column is the difference between these two trucks. Comparisons should focus on two rows of this table, which are GEM overall MPG and Actual overall MPG. Just as expected, the absolute comparisons between 7.41 and 7.63 MPG for the control vehicle and 8.08 and 7.85 MPG for the test vehicle are not too impressive, which is 7.7 percent difference shown in the row of Overall MPG% Difference. The reason is that it is virtually impossible to model the vehicle exactly because of the alignment of gear shifting, road grade and environmental conditions. In addition, during the simulations, it was found that the engine torque measured from the drive shaft torque meter is up to 200 NM higher than the peak torque curve of the engine fuel map used for GEM, suggesting that the engines in truck and the engine used in GEM are not exactly same. Furthermore, GEM didn’t use exact shifting table. Rather, the default shifting is used. However, the relative comparisons is in a good agreement between GEM and simulation (9.7 versus 10.2).

Table 4-3 GEM vs On-road Fuel Consumption Results

		Control Truck	Test Truck with Aero	Percent Change from Control due to Aero Package
GEM Predictions	Segment 1 Miles	19.89	19.85	
	Segment 1 Gal	2.74	2.49	
	Segment 1 MPG	7.27	7.97	9.7%
	Segment 2 Miles	56.65	56.56	
	Segment 2 Gal	7.36	6.69	
	Segment 2 MPG	7.69	8.45	9.9%
	Segment 3 Miles	29.81	29.77	
	Segment 3 Gal	4.05	3.70	
	Segment 3 MPG	7.35	8.05	9.5%
	Total Gals	14.15	12.88	
	Total Miles	106.35	106.18	
	GEM Overall MPG	7.51	8.25	9.7%
	GEM Total Fuel lbs	99.05	90.11	-9.0%
On-Road Results (Run 3)	Actual Total Fuel lbs	97.60	88.40	-9.4%
	Actual Gals	13.95	12.63	
	Actual Distance (miles)	106.37	106.21	
	Actual Overall MPG	7.63	8.41	10.2%

Again, more comprehensive discussions on this part can be seen the final report.[22]

4.4 EPA and NHTSA HD Vehicle Compliance Model

As described earlier, GEM is a computer model that simulates vehicle operation to predict CO_2 emissions and fuel consumption for a wide variety of heavy-duty vehicles. This section describes how that computer model is used as a compliance tool to evaluate vehicle performance relative to the applicable standards. The engineering evaluation of GEM discussed in Chapter 4.3 was not limited by computing time and presumes all inputs to be accurate. However, using GEM as a compliance tool requires some simplification of the model. It also requires the elimination of user inputs that cannot be verified by the agencies.

The Phase 2 GEM is EPA and NHTSA's vehicle compliance simulation model and is similar to Phase 1 GEM in many respects. However, it differs from the Phase 1 version in two major aspects. The first involves the significant improvements described in Chapter of 4.2.1. Second, Phase 2 GEM provides users the opportunity to enter additional vehicle and engine parameters for the actual vehicle being simulated. As noted above, Phase 1 GEM only allows a maximum of five user defined inputs for tractors. These are the aerodynamic drag coefficient, tire rolling resistance, vehicle speed limiter, weight reduction, and idle reduction. For vocational vehicles there is only one user defined input: tire rolling resistance. In contrast, the Phase 2 GEM allows the user to input many more engine and vehicle parameters, including most of those that have the greatest impact on emissions. In particular, it allows vehicle manufacturers to input their own engine fuel maps. Key driveline parameters, such as transmission gear number versus gear ratio, axle ratio, and tire rolling radius, are also part of the manufacturer inputs.

There are still some GEM input parameters that are pre-defined by the agencies. For some, such as shifting strategy, this is due to the fact that the parameters are hard to measure and quantify due to the lack of well-defined test procedures. For others, the manufacturers consider the parameter values to be proprietary and are reluctant to share the information with other parties. An example is the transmission gear shifting strategy table. The modeling parameters associated with torque converters for automatic transmission are also pre-defined by the agencies. The inertias of all rotational parts, vehicle weights and accessory power losses are also default parameters defined by the agencies. Finally, in order to have a consistent basis for the standards, the vehicle weights and payloads are predefined by vehicle class and duty cycle. In order to understand natures of those inputs, Table 4-4 lists three types of inputs used by GEM.

Table 4-4 GEM Inputs and Technology Improvement

GEM INPUTS	OEM INPUT	EPA DEFAULT	REQUIRED OEM INPUT
	No test required	with optional OEM input based on a test	Based on a test procedure
Engine Fuel map			Yes
Transmission loss map		Yes (40 CFR 1037.565)	
Axle power loss map		Yes (40 CFR 1037.560)	
Drive axle configuration	6x2, 6x4, 6x4D, 4x2		
Axle ratio	Input value		
CdA	Vocational: Input value based on directions in 40 CFR 1037.520		Tractors: Yes (40 CFR 1037.525)
Crr			Yes (40 CFR 1037.520)
Tire size (revs/mile)			Yes (40 CFR 1037.520)
Transmission Type	MT, AMT, AT,		
Weight adjustment	Input value based on directions in 40 CFR 1037.520		
Vehicle Speed Limiter (Tractor)	Input value based on directions in 40 CFR 1037.520		
Predictive Cruise Control (%)	Input value based on directions in 40 CFR 1037.520		
Accessory Load (%)	Input value based on directions in 40 CFR 1037.520		
Extended Idle Reduction (%)	Input value based on directions in 40 CFR 1037.520		
Tire Pressure System (%)	Input value based on directions in 40 CFR 1037.520		
Neutral Coast	Input value based on directions in 40 CFR 1037.520		
Neutral-Idle			Yes (40 CFR 1036.535(d))
Delta PTO (Vocational)		Yes, default is zero (40 CFR 1037.540)	

Automatic Engine Shutdown (Vocational)			Yes (40 CFR 1036.535(d))
Start-Stop (Vocational)			Yes (40 CFR 1036.535(d))

Table 4-8 and Table 4-9 list all of the GEM input parameters for tractors and Table 4-13 through Table 4-15 list the predefined parameters for vocational vehicles. These tables also include weighting factors for each driving cycle for the determination of composite CO_2 in g/ton-mile.

It is important to note that, for many of these parameters, publicly available information on the values for current and future vehicles is limited. Manufacturers have provided values to the agencies, but have generally identified them as confidential business information. Nevertheless, we have used this information to inform our estimation of appropriate default values.

4.4.1 GEM Input Values

4.4.1.1 Transmissions

One of the major changes in Phase 2 GEM is to allow manufacturers to enter their transmission gear ratio versus gear number. When entering this information, manufacturers also have an option to select the type of transmission, which is either manual, automated manual or automatic with a torque converter. Power loss associated with pumping and spin loss can either use the default values or use the one created by manufacturers.

One of the areas that required significant development work was the transmission shift strategy for use in the compliance tool. This was required because (as just noted) transmission suppliers have been reluctant to provide their shifting strategies to vehicle manufacturers for vehicle certification due to their concern over protecting intellectual property. The shifting strategy in the Phase 2 GEM includes the agencies' internally developed automatic shift algorithm.[15] The impact of the use of the agencies' default transmission shifting as opposed to using manufacturers' shifting strategies has been evaluated and the results are presented in Figure 4-14**,** shown above in Chapter 4.3.2.2. Phase 2 GEM includes three types of transmissions as discussed in Chapter 4.2.2.3.3. They are manual transmissions (MT), automated manual transmissions (AMT) and automatic transmissions (AT). Due to lack of test data for other types of transmissions, GEM was not able to be validated against these three cases:

1. Dual clutch transmission (DCT)
2. Dual clutch transmission with a torque converter
3. Allison TC-10 automatic transmission

The agencies will allow use of AMT to model case 1; use of AT to model case 2, and use of AT to model case 3. The manufacturers will still have the option to either use powertrain dynamometer tests to quantify the benefits of these or any other special transmissions, rather than use the GEM values. The detailed test procedure of the powertrain dynamometer tests are described in 40 CFR 1037.550. Alternatively, the manufacturers can conduct their own transmission tests on individual gears to get power loss table to replace the default ones used in GEM. The detailed test procedure on power loss measurement can be seen in 40 CFR 1037.565.

4.4.1.2 Axles

Axle ratios for all model sub-categories will be user defined. If users do not provide a power loss table, a power loss table generated in GEM will be used. 40 CFR 1037 covers the specific procedures to generate data for axle input file, including the axle power loss input. Four types of axles are uniquely modeled in GEM. They are 6x2, 6x4, 4x2 and 6x4D. 6x4D stands for an axle that can disengage one of the drive axles when certain conditions are met. If 6x4D is selected, GEM will model the axle as a 6x2 for the 55 and 65mph cruise cycles, and model the axle as a 6x4 for the transient cycle. However, only one drive axle ratio can be selected. The user must select the drive axle ratio that is expected to be used for the greatest driving distance. All other axles, such as 8x4, 8x6, 10x4, 10x6, 12x4, 14x4 or any other "non-conventional" axle configurations will not be modeled by GEM, rather they will be modeled as 6x4 axles. In addition to allowing manufactures to input axle losses into GEM, the default losses were also updated based on CBI from two major axle suppliers. Instead of the default efficiency taking the form of a fixed efficiency, the losses are modeled as power losses as function of wheel speed and wheel torque.

4.4.1.3 Weights

It is assumed that the vehicle unloaded weight will vary by vehicle subcategory. Taking tractors as an example, the total weight ranges from 65,500 to 70,500 lbs, while for Class 7 tractors weight ranges from 46,500 to 50,000 lbs. The payload capacity varies as shown in Table 4-7 through Table 4-15. The development of these weights is discussed in Chapter 3 of the RIA.

4.4.1.4 Inertia

All of the inertias for rotational parts, including engine, transmission and axle, are pre-defined based on a combination of the agencies' engineering judgment and confidential business information from OEMs. The default inertia values were used during GEM validation against respective trucks and they will be used as the default values for all of the vehicles certified using GEM. Thus, the vehicle OEM will not have flexibility to enter their own inertias.

4.4.1.5 Accessory Load

Based on additional data from manufacturers the agencies are finalizing different accessory loads from what was proposed. The breakdown in electrical and mechanical load are shown in Table 4-7 through Table 4-15, and are the default values used in vehicle certification. The change increased accessory power in all sectors, which increased CO_2 mass per ton-mile as shown in Table 4-5 and Table 4-6.

Table 4-5 Change in CO_2 Mass per Ton-Mile from Change in Accessory Load - Tractors

REGULATORY CLASS		% Change in CO_2 (g/ton-mi)
CLASS 8 COMBINATION	Sleeper Cab - High Roof	1.2%
	Sleeper Cab - Mid Roof	1.2%
	Sleeper Cab - Low Roof	1.2%
	Day Cab - High Roof	1.4%
	Day Cab - Mid Roof	1.4%
	Day Cab - Low Roof	1.5%
CLASS 7 COMBINATION	Day Cab - High Roof	1.7%
	Day Cab - Mid Roof	1.7%
	Day Cab - Low Roof	1.8%
HEAVY-HAUL COMBINATION	All Cabs – All Roofs	1.2%

Table 4-6 Change in CO_2 Mass per Ton-Mile from Change in Accessory Load – Vocational

REGULATORY CLASS		% Change in CO_2 (g/ton-mi)
HHD	Regional Duty Cycle	2.1%
	Multi-Purpose Duty Cycle	3.6%
	Urban Duty Cycle	4.0%
MHD	Regional Duty Cycle	1.7%
	Multi-Purpose Duty Cycle	3.1%
	Urban Duty Cycle	3.8%
LHD	Regional Duty Cycle	0.4%
	Multi-Purpose Duty Cycle	0.7%
	Urban Duty Cycle	0.8%
MHD - SI	Regional Duty Cycle	1.5%
	Multi-Purpose Duty Cycle	2.6%
	Urban Duty Cycle	3.0%
LHD - SI	Regional Duty Cycle	0.4%
	Multi-Purpose Duty Cycle	0.6%
	Urban Duty Cycle	0.7%

4.4.1.6 Tires

The tire revolutions per mile value is a user defined input; however, the agencies do provide default values for custom vocational sub-categories. Static loaded tire radius is used in

GEM for all simulations for every combination tractor and the default value can be overridden by the vehicle OEM.

Steer and drive axle tire coefficient of rolling resistance (Crr) values are provided by the user. On tractors the trailer tire Crr assumes a constant value for all trailer tires. This value was developed through tire testing performed by the SmartWay Transport Partnership.[23]

4.4.1.7 Idle Cycles and Modeling

GEM will model two additional idle-only cycles to determine both fuel consumption for use in the CO_2 emission calculation in 40 CFR 1037.510(b) when a vocational vehicle is idling, and to recognize technologies that either reduce the fuel consumption rate or shut the engine off (and restart) during short-term idle events or parked during the workday based on user inputs of which idle technologies are selected. GEM will determine a parked idle fuel rate and a driving idle fuel rate.

The parked idle fuel rate will use a 4-point idle fuel map to calculate CO_2 emissions and fuel consumption at parked idle conditions. If automatic engine shutdown is selected the calculated parked idle fuel rate will be reduced by 80 percent. The parked idle cycle is applicable for all weight classes of vocational vehicles (HHD, MHD and LHD, custom chassis) using the Regional, Multi-Purpose or Urban composite duty cycles.

For idle fueling during driving, the fueling is determine through the steady state engine fuel map at minimum and maximum idle speed and 0 Nm and 100N. , and then GEM will calculate reduced CO_2 and fueling for automatic transmission that feature neutral idle technology. Drive idle fuel consumption will be further reduced on vehicles with stop-start systems, based on an assumption that the effectiveness would represent a 90 percent reduction over this cycle. The drive idle cycle is applicable for all weight classes of vocational vehicles (HHD, MHD and LHD and custom chassis) using the Multi-Purpose or Urban composite duty cycles. The composite weighting factor of the drive idle cycle is zero for Regional vehicles. More information can be seen in Chapter 3.4.2.3 about the idle cycle. Chapter 4.5 discusses how these idle technologies are modeled as part of technology improvements that are recognized in GEM.

4.4.1.8 Cycle Average Test Procedure for Transient ARB

As described in Chapter 2, fuel consumption during transient engine operation typically is higher than during steady-state operation. The difference can vary significantly, but the trend is generally consistent. If the GEM simulation relies on steady-state fuel maps to predict emissions for all the cycles, including the transient cycle, the large error can be expected. The most significant difference between steady state and transient behavior is the smoke control during acceleration. Diesel engines must limit the fueling in order to prevent smoke during rapid acceleration. In contrast, there is no such issue during steady state mapping. Furthermore, all modern diesel engines use a fueling cut-off technique to shut off the fueling during deceleration based on a manufacturer-defined set of conditions. Thermal management is another major factor to that may create a difference between steady state and transient fueling. The aftertreatment system is very sensitive to exhaust temperature in order to maintain optimal performance of selective catalytic reduction devices. Post fueling must be injected into the exhaust stream once the exhaust temperature is below certain criteria, typically in the range of 200 degrees Celsius. In steady state fueling mapping, the engine always follows the defined testing procedure; thus, the engine runs hotter even at light loads than in a transient condition at the same speed and torque; thus, thermal management may not even kick in. Because of these differences, engine manufacturers typically include at least two distinguished engine calibrations into the engine control unit – one for typically on-highway operation, and the other for transient operation, such as urban and mountainous areas.

In view of these technical challenges, and in response to public comments (including those from a leading manufacturer of diesel engines), the agencies have adopted a test procedure called cycle average test procedure to account for this transient behavior (40 CFR 1036.540). The detailed analyses can be also seen in references [24] and [25] as well. Since these two notable publications, significant progress has been made, which covers a large number of confirmatory engine dynamometer tests. A wide range of industrial supporting activities, and significant refinement of numerical schemes for interpreting cycle average engine fuel map are also conducted. The engine dynamometer tests include Cummins' medium duty ISB engine, Navistar's heavy duty N13 engine, Volvo's heavy duty D13 engine, and Cummins' heavy-duty ISX engine. All testing results indicate that the new test procedure would work well for the transient ARB cycle. As for the cruise-cycles the procedure does generally work well especially with some recent improvements to the generic vehicle definitions. Therefore, we will optionally allow certification to be done with cycle average test procedure for these cruise speed cycles, primarily based on the following reasons. The first reason is that it will allow engine manufactures to provide engine fuel maps that don't reveal CBI. The second reason is that allowing the cycle average procedure for cruise cycles opens up the possibility for hybrids that are not integrated with a transmission to use the cycle average procedure instead of just the powertrain procedure. By allowing these hybrids to use the cycle average procedure we reduce the testing burned/cost for these systems. In order to ensure that manufacture using the cycle average procedure for cruise speed cycle can produce representative results, the test procedures are written in such a way that it allows EPA to use the steady-state mapping procedure during a confirmatory test for the cruise cycles.

For all 55 and 65mph cruise speed cycles, a simplified engine fuel map will be used in GEM by following the test procedure 40 CFR 1036.535, where only 80-90 testing points are required for the engine fuel mapping.

4.4.1.9 Tractor Tables

Table 4-7 through Table 4-12 display the predefined GEM parameters for the Phase 2 tractor compliance model. The predefined parameters were developed using the same methodology used in Phase 1.

Table 4-7 Class 8 Combination Tractor Sleeper Cab Predefined Modeling Parameters

REGULATORY CLASS	CLASS 8 COMBINATION	CLASS 8 COMBINATION	CLASS 8 COMBINATION
	Sleeper Cab - High Roof	Sleeper Cab - Mid Roof	Sleeper Cab - Low Roof
Total weight (kg)	31978	30277	30390
Number of Axles	5	5	5
Default Axle Configuration	6x4	6x4	6x4
Electrical Accessory Power (W)	1200	1200	1200
Mechanical Accessory Power (W)	2300	2300	2300
Environmental Air Temperature (°C)	25	25	25
Payload (tons)	19	19	19
Weight Reduction (lbs)	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons
Tire Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr
Drive Cycles & Weightings:			
CARB HHDDT	0.05	0.05	0.05
GEM 55 mph	0.09	0.09	0.09
GEM 65 mph	0.86	0.86	0.86
CdA value modeled in GEM is equal to the OEM input minus 0.3 m^2 to account for improved trailer aerodynamics beginning in 2027 MY for high roof tractors. See Section III.E.2.a of the Preamble.			

Table 4-8 Class 8 Combination Tractor Day Cab Predefined Modeling Parameters

REGULATORY SUBCATEGORY	CLASS 8 COMBINATION	CLASS 8 COMBINATION	CLASS 8 COMBINATION
	Day Cab - High Roof	Day Cab - Mid Roof	Day Cab - Low Roof
Total weight (kg)	31297	29529	29710
Number of Axles	5	5	5
Default Axle Configuration	6x4	6x4	6x4
Electrical Accessory Power (W)	1200	1200	1200
Mechanical Accessory Power (W)	2300	2300	2300
Environmental air temperature (°C)	25	25	25
Payload (tons)	19	19	19
Weight Reduction (lbs)	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons
Tire Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr
Drive Cycles & Weightings:			
CARB HHDDT	0.19	0.19	0.19
GEM 55 mph	0.17	0.17	0.17
GEM 65 mph	0.64	0.64	0.64
CdA value modeled in GEM is equal to the OEM input minus 0.3 m^2 to account for improved trailer aerodynamics beginning in 2027 MY for high roof tractors. See Section III.E.2.a of the Preamble.			

Table 4-9 Class 7 Combination Tractor Predefined Modeling Parameters

REGULATORY SUBCATEGORY	CLASS 7 COMBINATION	CLASS 7 COMBINATION	CLASS 7 COMBINATION
	Day Cab - High Roof	Day Cab - Mid Roof	Day Cab - Low Roof
Total weight (kg)	22679	20910	21091
Axle Base	4	4	4
Default Axle Configuration	4x2	4x2	4x2
Electrical Accessory Power (W)	1200	1200	1200
Mechanical Accessory Power (W)	2300	2300	2300
Environmental air temperature (°C)	25	25	25
Payload (tons)	12.5	12.5	12.5
Weight Reduction (lbs)	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons
Tire Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr
Drive Cycles & Weightings:			
CARB HHDDT	0.19	0.19	0.19
GEM 55 mph	0.17	0.17	0.17
GEM 65 mph	0.64	0.64	0.64
CdA value modeled in GEM is equal to the OEM input minus 0.3 m^2 to account for improved trailer aerodynamics beginning in 2027 MY for high roof tractors. See Section III.E.2.a of the Preamble.			

Table 4-10 Heavy-Haul Tractor Predefined Modeling Parameters[a]

REGULATORY SUBCATEGORY	HEAVY-HAUL COMBINATION
	All Cabs – All Roofs
Total weight (kg)	53750
Number of Axles	5
Default Axle Configuration	6x4
Electrical Accessory Power (W)	1200
Mechanical Accessory Power (W)	2300
Environmental air temperature (°C)	25
Payload (tons)	43
Weight Reduction (lbs)	Add 1/3*weight reduction to Payload tons
Tire Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr
Drive Cycles & Weightings:	
CARB HHDDT	0.19
GEM 55 mph	0.17
GEM 65 mph	0.64

Note:
[a] See 40 CFR 1037.106

Table 4-11 Optional Heavy Class 8 Combination Tractor Sleeper Cab Predefined Modeling Parameters[a]

REGULATORY CLASS	OPTIONAL HEAVY CLASS 8 COMBINATION	OPTIONAL HEAVY CLASS 8 COMBINATION	OPTIONAL HEAVY CLASS 8 COMBINATION
	Sleeper Cab - High Roof	Sleeper Cab - Mid Roof	Sleeper Cab - Low Roof
Total weight (kg)	53750	52049	52162
Number of Axles	5	5	5
Default Axle Configuration	6x4	6x4	6x4
Electrical Accessory Power (W)	1200	1200	1200
Mechanical Accessory Power (W)	2300	2300	2300
Environmental Air Temperature (°C)	25	25	25
Payload (tons)	43	43	43
Weight Reduction (lbs)	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons
Tire Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr
Drive Cycles & Weightings:			
CARB HHDDT	0.05	0.05	0.05
GEM 55 mph	0.09	0.09	0.09
GEM 65 mph	0.86	0.86	0.86
CdA value modeled in GEM is equal to the OEM input minus 0.3 m^2 to account for improved trailer aerodynamics. See Section III.E.2.a of the Preamble.			

Note:
[a] See 40 CFR 1037.670

Table 4-12 Optional Heavy Class 8 Combination Tractor Day Cab Predefined Modeling Parameters[a]

REGULATORY SUBCATEGORY	OPTIONAL HEAVY CLASS 8 COMBINATION	OPTIONAL HEAVY CLASS 8 COMBINATION	OPTIONAL HEAVY CLASS 8 COMBINATION
	Day Cab - High Roof	Day Cab - Mid Roof	Day Cab - Low Roof
Total weight (kg)	53069	51301	51482
Number of Axles	5	5	5
Default Axle Configuration	6x4	6x4	6x4
Electrical Accessory Power (W)	1200	1200	1200
Mechanical Accessory Power (W)	2300	2300	2300
Environmental air temperature (°C)	25	25	25
Payload (tons)	43	43	43
Weight Reduction (lbs)	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons	Add 1/3*weight reduction to Payload tons
Tire Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr
Drive Cycles & Weightings:			
CARB HHDDT	0.19	0.19	0.19
GEM 55 mph	0.17	0.17	0.17
GEM 65 mph	0.64	0.64	0.64
CdA value modeled in GEM is equal to the OEM input minus 0.3 m^2 to account for improved trailer aerodynamics beginning in 2027 MY for high roof tractors. See Section III.E.2.a of the Preamble.			

Note:
[a] See 40 CFR 1037.670

4.4.1.10 Vocational Tables

Table 4-13 through Table 4-15 display the predefined GEM parameters for use for the vocational vehicle compliance model. The optional custom chassis configurations use these parameters as well. Many of the parameters are based on the vehicles EPA selected to test at SwRI and are considered to reasonably represent the fleet in their respective categories. For example, the Kenworth T270 truck and Ford F-650 tow truck are used as vehicles to represent the MHD and LHD vocational vehicle fleet, while the Kenworth T700 and Autocar refuse trucks are used to represent the fleet of HHD vocational vehicles. With those vehicles as reference, it helps to determine the type of transmission and its gear ratio, tire diameters, and all accessory losses used for all vocational vehicles shown in these three tables. Tire radius and axle ratios were selected, using good engineering judgment and stakeholder input, to reflect reasonable final drive ratios to match with our modeled transmissions. With the exception of the HHD vehicles, the engine power rating is the same as in Phase 1. For the HHD subcategories, the agencies selected a mix of 15L 455-hp and 11L-350 hp engines because this is a more typical power rating for vehicles that are not long haul. The baseline engines are described in the RIA Chapter 2.9.1. Other parameters, such as the vehicle weight, payload, weight reduction, tire rolling resistance, frontal area, and axle base, etc. are defined in the RIA Chapter 2.9.2. The gear mechanical efficiency as well as axle mechanical efficiency is selected based on the inputs from stakeholders. The weighting of steer tire Crr and drive tire Crr is different than in Phase 1 to better reflect the weight distribution over the steer and drive axles. The assignment of 50 percent of reduced weight back to payload is not the same as for tractors. See the RIA Chapter 2.9 for details. Chapter 4.4.3 to 4.4.9 explain how these parameters are used in GEM.

The agencies are expanding the number of vocational subcategories from three (in Phase 1) to nine (in Phase 2). It can be seen from Table 4-13 through Table 4-15, the agencies will also add two idle cycles for vocational vehicles to the duty cycles used in Phase 1 certification.

Table 4-13 Vocational HHD Vehicle Predefined Modeling Parameters

REGULATORY SUBCATEGORY	HHD	HHD	HHD
	Regional Duty Cycle	Multi-Purpose Duty Cycle	Urban Duty Cycle
Total weight (kg)	19051	19051	19051
Number of Axles	3	3	3
Electrical Accessory Power (W)	1200	1200	1200
Mechanical Accessory Power (W)	2300	2300	2300
Environmental Air Temperature (°C)	25	25	25
C_dA (m^2)	6.86	6.86	6.86
Tire Crr	=0.7*Drive Crr + 0.3*Steer Crr	0.7*Drive Crr + 0.3*Steer Crr	=0.7*Drive Crr + 0.3*Steer Crr
Payload (tons)	7.50	7.50	7.50
Weight Reduction (lbs)	Add 0.5*weight reduction to Payload tons	Add 0.5*weight reduction to Payload tons	Add 0.5*weight reduction to Payload tons
Drive Cycles & Weightings:			
CARB HHDDT	0.20	0.54	0.90
GEM 55 mph	0.24	0.23	0.10
GEM 65 mph	0.56	0.23	0.00
Drive Idle cycle	0.00	0.17	0.15
Parked Idle Cycle	0.25	0.25	0.25

Table 4-14 Vocational MHD Vehicle Predefined Modeling Parameters

REGULATORY SUBCATEGORY	MHD	MHD	MHD
	Regional Duty Cycle	Multi-Purpose Duty Cycle	Urban Duty Cycle
Total weight (kg)	11408	11408	11408
Number of Axles	2	2	2
Electrical Accessory Power (W)	900	900	900
Mechanical Accessory Power (W)	1600	1600	1600
Environmental Air Temperature (°C)	25	25	25
C_dA (m^2)	5.40	5.40	5.40
Tire Crr	=0.7*Drive Crr + 0.3*Steer Crr	0.7*Drive Crr + 0.3*Steer Crr	=0.7*Drive Crr + 0.3*Steer Crr
Payload (tons)	5.60	5.60	5.60
Weight Reduction (lbs)	Add 0.5*weight reduction to Payload tons	Add 0.5*weight reduction to Payload tons	Add 0.5*weight reduction to Payload tons
Drive Cycles & Weightings:			
CARB HHDDT	0.20	0.54	0.92
GEM 55 mph	0.24	0.29	0.08
GEM 65 mph	0.56	0.17	0.00
Drive Idle cycle	0.00	0.17	0.15
Parked Idle cycle	0.25	0.25	0.25

Table 4-15 Vocational LHD Vehicle Predefined Modeling Parameters

REGULATORY SUBCATEGORY	LHD	LHD	LHD
	Regional Duty Cycle	Multi-Purpose Duty Cycle	Urban Duty Cycle
Total weight (kg)	7257	7257	7257
Number of Axles	2	2	2
Electrical Accessory Power (W)	500	500	500
Mechanical Accessory Power (W)	1000	1000	1000
Environmental Air Temperature (°C)	25	25	25
C_dA (m^2)	3.40	3.40	3.40
Tire Crr	=0.7*Drive Crr + 0.3*Steer Crr	0.7*Drive Crr + 0.3*Steer Crr	=0.7*Drive Crr + 0.3*Steer Crr
Payload (tons)	2.85	2.85	2.85
Weight Reduction (lbs)	Add 0.5*weight reduction to Payload tons	Add 0.5*weight reduction to Payload tons	Add 0.5*weight reduction to Payload tons
Drive Cycles & Weightings:			
CARB HHDDT	0.20	0.54	0.92
GEM 55 mph	0.24	0.29	0.08
GEM 65 mph	0.56	0.17	0.00
Drive Idle cycle	0.00	0.17	0.15
Parked Idle cycle	0.25	0.25	0.25

4.4.1.11 Trailer Tables

The agencies are adopting an equation-based compliance approach for box van manufacturers and they are not required to certify their trailers using GEM. However, the equations for each box van subcategory are based on the simulated trailers described in this section. The same four input parameters that would be applied in GEM for trailers are also applied in the GEM-based compliance equations. The following description of the GEM trailer model as it applies to box vans is included for informational purposes only. Note that non-box trailers do not use GEM or the GEM-based equation for compliance and a discussion of non-box trailers is not included here.

Trailers are simulated using the same GEM models as the tractor program. There are only minor differences between the trailer and tractor modeling parameters and inputs. Table 4-16 lists all of the predefined vehicle parameters of trailer baseline models. The predefined modeling parameters for the long box dry van subcategory are identical to the Class 8 high-roof sleeper cab tractor subcategory. The other trailer subcategories differ in tractor cab type, total weight, aerodynamic characteristics, number of axles, payload, and drive cycle. For example, the refrigerated vans include a refrigeration unit which adds weight. Short box vans are half the length, have a single axle, and are pulled by a day cab tractor which reduces total weight and the total payload carrying capacity. The drive cycle weightings are consistent with the tractor program. Long box vans are simulated as being pulled by sleeper cabs, and therefore have the long-haul drive cycle weightings. The short box trailers are pulled by Class 7 day cabs and have the short-haul weightings.

Similar to the tractor program, trailer manufacturers can provide aerodynamic drag, tire rolling resistance and weight reduction inputs to the model. The key differences between the trailer and tractor options are that aerodynamic drag is submitted as a *change* in drag (delta CdA) for trailers, which is compared to the baseline CdA values shown in Table 4-16 within GEM, and only adjustments to *trailer* tire rolling resistance are allowed. A list of weight reduction options is available in 40 CFR 1037.520 and manufacturers have the option to indicate that their trailers use Automatic Tire Inflation Systems (ATIS) or tire pressure monitoring systems (TPMS) for a predefined additional performance improvement. Additional information about each trailer subcategory is found in Chapter 2.10 of this RIA. A description of the GEM-based equation development is provided in Chapter 2.10.5.

Table 4-16 Predefined Modeling Parameters for Box Trailers

REGULATORY SUBCATEGORY	LONG BOX DRY VAN	LONG BOX REFRIGERATED VAN	SHORT BOX DRY VAN	SHORT BOX REFRIGERATED VAN
Tractor Type	C8 Sleeper Cab - High Roof		C7 Day Cab - High Roof	
Engine Fuel Map	MY 2018 15L - 455 HP		MY 2018 11L – 350 HP	
Total weight (kg)	31978	33778	18306	20106
Baseline CdA Values (m^2)	6.0	6.0	5.6	5.6
Total Number of Axles	5		3	
Payload (tons)	19		10	
Tractor Axle Configuration	6x4		4x2	
Electrical Accessory Power (W)	300			
Mechanical Accessory Power (W)	1000			
Steer Tire RR	6.54			
Drive Tire RR	6.92			
Tire Radius (m)	0.5			
Axle Drive Ratio	3.7			
Tire Crr	=0.425*Trailer Crr+0.425*Drive Crr+0.15*Steer Crr			
Weight Reduction (lbs)	Add 1/3*weight reduction to Payload tons			
Drive Cycles & Weightings:				
CARB HHDDT	0.05		0.19	
GEM 55 mph	0.09		0.17	
GEM 65 mph	0.86		0.64	

4.5 Technology Improvements that Are Recognized in GEM without Simulation

The development of GEM as a compliance tool has required the agencies to balance the need for simplicity against the rigor of the model. As part of that process, the agencies have identified several technologies and technological improvements that would be difficult to accurately simulate, but that should be recognized during certification. These are recognized in the Phase 2 GEM through post-simulation adjustments to the results. This is similar to what was done in Phase 1, where the GEM interface included pull-down menus for manufacturers to select these adjustments. For this reason, these adjustments have come to be known as pull-down technologies.

Phase 2 GEM will continue to recognize those technologies that would be difficult to model accurately. In addition to those recognized in Phase 1, the technology list is expanded to a much wider range as discussed in the next few paragraphs of this chapter. In contrast to Phase 1, Phase 2 GEM uses a different approach in recognizing these technologies. Predefined improvement values for each of these technologies, developed by the agencies after consulting various stakeholders and searching for literature values, are defined in 40 CFR 1037.520. The user is required to enter the predefined improvement value into the GEM input file in the corresponding technology column.

For some of these technologies, such as predictive cruise control and Automatic Tire Inflation Systems (ATIS), the actual benefit is dependent on how operators behave in the real world. For example, ATIS will be of very little benefit where a driver made sure on a daily basis that the tires were properly inflated, but will have large benefits where a driver never checked the tires. For other technologies, the benefits of the technology are small relative to the difficulty of rigorously simulating it. The agencies believe the technology improvement approach is an appropriate compromise that will achieve the regulatory goal of incentivizing the use of the technology.

In this approach, the GEM software will adjust the simulation results to decrease the g/ton-mile results that are output by the model. For example, with a technology that is assigned a 1 percent benefit, the official result for a vehicle that was simulated as having 500 g/ton-mile CO_2 emissions will be reported as having an emission rate of 495 g/ton-mile.

The technology improvement values used for tractors are shown in Table 4-17. These values represent the agencies' best judgment about the appropriate value for each of these technologies and are discussed in more detail in RIA Chapter 2.4. We are generally assigning minimum values to be conservative and not overestimate the actual in-use benefits. These values were developed based on all available information, including information from stakeholders.

Table 4-17 Tractor Technology Improvement Values

TECHNOLOGY IMPROVEMENT	CLASS 8 SLEEPER CABS	CLASS 8 DAY CABS	CLASS 7 DAY CABS	CLASS 8 HEAVY HAUL TRACTORS
Automated Manual, Automatic, and Dual Clutch Transmissions	2%	2%	2%	2%
Predictive Cruise control	2%	2%	2%	2%
High Efficiency Air Conditioning Compressor	0.5%	0.5%	0.5%	0.5%
Electric Accessories	1%	1%	1%	1%
Extended Idle Reduction	Values range between 1 - 6 %	N/A	N/A	N/A
Automatic Tire Inflation System (ATIS)	1.20%	1.20%	1.20%	1.20%
Tire Pressure Monitoring System	1%	1%	1%	1%
Neutral Coast	1%	1%	1%	1%
Neutral Idle	Emissions during idle cycle calculated using torque and speed values from fuel map with the transmission in drive and neutral, 10% and 90% of the cycle time, respectively[a]			

Note:
[a] See idle fuel consumption test procedure at 40 CFR 1036.535(d).

For vocational vehicles, the technology improvement values in Table 4-18 are being adopted.

Table 4-18 Vocational Vehicle Technology Improvement Values

TECHNOLOGY IMPROVEMENT	REGIONAL DUTY CYCLE	MULTI-PURPOSE DUTY CYCLE	URBAN DUTY CYCLE
PTO Delta Fuel (g/ton-mile)	Range 0 to 30; value obtained using separate test		
Automatic Tire Inflation System (ATIS)	1.2%	1.1%	1.1%
Tire Pressure Monitoring System	1.0%	0.9%	0.9%
Electric or high efficiency A/C compressor[a]	0.5% for HHD, 1.0% for MHD and LHD		
Electric Power Steering	0.5%	1.0%	1.0%
7-speed transmission for Custom Chassis School & Coach buses	1.7%	N/A	0.9%
Neutral Idle for Custom Chassis	Range depending on the default engine. Input is Yes or No.		
Stop-Start Idle Reduction for Custom Chassis			
Automatic Engine Shutdown for Custom Chassis			

Note:
[a] See instructions at 40 CFR 1037.520

For trailers, the following technologies in Table 4-19 will be considered.

Table 4-19 Trailer Technology Improvement Values

Technology Improvement	Effectiveness
Automatic Tire Inflation System (ATIS)	1.2%
Tire Pressure Monitoring System	1.0%

If a manufacturer believes that the CO_2 reduction benefits assigned by the agencies are an underestimate, they have the option to perform powertrain testing or request (and demonstrate) credit in the off-cycle technology process.

References

[1] National Academies of Science. "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles." 2010. Recommendation 8-4.
[2] Daimler Trucks North America Meeting Memo on GEM and Road grade, March 8, 2016, Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Phase 2, Proposed Rule, Docket ID No: EPA–HQ–OAR–2014–0827 and NHTSA–2014–0132.
[3] Allison Meeting Memo on GEM, June, 13 2016, Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Phase 2, Proposed Rule, Docket ID No: EPA–HQ–OAR–2014–0827 and NHTSA–2014–0132.
[4] EMA Meeting Memo on GEM, February 2, 16 2016, Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Phase 2, Proposed Rule, Docket ID No: EPA–HQ–OAR–2014–0827 and NHTSA–2014–0132.
[5] Ford Meeting Memo on GEM, June, 2 2016, Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Phase 2, Proposed Rule, Docket ID No: EPA–HQ–OAR–2014–0827 and NHTSA–2014–013280; Fed. Reg. 40137 (July 13, 2015).
[6] Dana Meeting Memo on GEM, June, 16 2016, Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Phase 2, Proposed Rule, Docket ID No: EPA–HQ–OAR–2014–0827 and NHTSA–2014–0132; 80 Fed. Reg. 40137 (July 13, 2015).
[7] See EPA's GEM web page at http://www3.epa.gov/otaq/climate/gem.htm.
[8] Navistar, Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Phase 2, Proposed Rule, Dockets ID No: EPA–HQ–OAR–2014–0827 and NHTSA–2014–0132;80 Fed. Reg. 40137 (July 13, 2015).
[9] Volvo Group, Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Phase 2, Proposed Rule, Dockets ID No: EPA–HQ–OAR–2014–0827 and NHTSA–2014–0132;80 Fed. Reg. 40137 (July 13, 2015).
[10] Paccar, Inc., Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles; Phase 2; Proposed Rule, 80 Fed. Reg. 40138 (July 13, 2015); Docket I.D. No.: EPA-HQ-OAR-2014-0827 and NHTSA-2014-0132; Fed. Reg. 40137 (July 13, 2015).
[11] Allison, Inc., Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles; Phase 2; Proposed Rule, 80 Fed. Reg. 40138 (July 13, 2015); Docket I.D. No.: EPA-HQ-OAR-2014-0827 and NHTSA-2014-0132; Fed. Reg. 40137 (July 13, 2015).
[12] Eaton Corporation., Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles; Phase 2; Proposed Rule, 80 Fed. Reg. 40138 (July 13, 2015); Docket I.D. No.: EPA-HQ-OAR-2014-0827 and NHTSA-2014-0132; Fed. Reg. 40137 (July 13, 2015).
[13] Daimler Trucks North America LLC, Detroit Diesel Corporation, And Mercedes-Benz USA, Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Phase 2, Proposed Rule, Docket ID No: EPA–HQ–OAR–2014–0827 and NHTSA–2014–0132; Fed. Reg. 40137 (July 13, 2015).
[14] "Peer Review of the Greenhouse gas Emissions Model (GEM) and EPA's Response to Comments," found in the docket of this rulemaking, EPA–420-R-15-009.
[15] K. Newman, J. Kargul, and D. Barba, "Development and Testing of an Automatic Transmission Shift Schedule Algorithm for Vehicle Simulation, "*SAE Int. J. Engines* 8(3):2015, doi:10.4271/2015-01-1142.
[16] Reinhart, T.E. (2015, June). Commercial Medium- and Heavy-Duty Truck Fuel Efficiency Technology Study – Report #1. (Report No. DOT HS 812 146). Washington, DC: National Highway Traffic Safety Administration.
[17] Matlab information (© 1994-2010 The MathWorks, Inc.) can be found at http://www.mathworks.com/products/matlab. Simulink information (© 1994-2010 The MathWorks, Inc.) can be found at http://www.mathworks.com/products/simulink. StateFlow information (© 1994-2010 The MathWorks, Inc.) can be found at http://www.mathworks.com/products/stateflow.
[18] US EPA, "Technical Research Workshop supporting EPA and NHTSA Phase 2 Standards for MD/HD Greenhouse Gas and Fuel Efficiency — December 10 and 11, 2014," http://www3.epa.gov/otaq/climate/regs-heavy-duty.htm.

[19] J. W. Anthony, J.V. Sarlashkar, A. Phan, C. E. Roberts, Jr., H. Zhang, J. Sanchez, M. Spears, A. Cullen, Powertrain test cell and its test procedure development for greenhouse gas emission measurements, ASME Int. J. , Vol. 4, Issue 3, 2015 (DOI: 10.1504/IJPT.2015.071729), 2015.
[20] SwRI, "GEM Validation," Technical Research Workshop supporting EPA and NHTSA Phase 2 Standards for MD/HD Greenhouse Gas and Fuel Efficiency — December 10 and 11, 2014, http://www3.epa.gov/otaq/climate/regs-heavy-duty.htm.
[21] J. Anthony, J. Sarlashkar, H. Zhang, J. Sanchez, M. Spears, A. Cullen, Chassis testing versus powertrain testing for heavy-duty vehicle greenhouse gas emission measurements, SAE 2014 Commercial Vehicle Engineering Congress, Oct. 7-9, 2014.
[22] Michael Ross, Validation Testing for Phase 2 Greenhouse Gas Test Procedures and the Greenhouse Gas Emission Model (GEM) for Medium and Heavy-Duty Engines and Powertrains, Final Report to EPA, Southwest Research Institute, June, 2016 , found in docket of this rulemaking, Phase 2 (Docket ID No. EPA–HQ–OAR–2014–0827.
[23] United States Environmental Protection Agency. SmartWay Transport Partnership July 2010 e-update accessed July 16, 2010, from http://www3.epa.gov/smartwaylogistics/newsroom/documents/e-update-july-10.pdf.
[24] H. Zhang, J, Sanchez, M, Spears, "Alternative Heavy-duty Engine Test Procedure for Full Vehicle Certification," SAE *Int. J. Commer. Veh.* 8(2): 2015, doi:10.4271/2015-01-2768.
[25] G. Salemme, E.D., D. Kieffer, M. Howenstein, M. Hunkler, and M. Narula, *An Engine and Powertrain Mapping Approach for Simulation of Vehicle CO2 Emissions.* SAE Int. J. Commer. Veh., October 2015. 8:: p. 440-450.

Chapter 5: Impacts on Emissions and Fuel Consumption

5.1 Executive Summary

Climate change is widely viewed as the most significant long-term threat to the global environment. According to the IPCC, it is extremely likely (>95 percent probability) that human influence was the dominant cause of the observed warming since the mid-20th century. The primary GHGs of concern are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons, and sulfur hexafluoride.[1] Mobile sources emitted 27 percent of all U.S. GHGs in 2013 when considering all upstream and downstream emissions, and the transportation-related GHGs alone have grown 16 percent between 1990 and 2013.[2] Mobile sources addressed in the recent endangerment finding under CAA section 202(a) – highway vehicles including passenger cars, light-duty trucks, heavy-duty trucks, buses, and motorcycles – accounted for almost 23 percent of all U.S. GHGs in 2013.[3] Heavy-duty vehicles emit CO_2, methane, nitrous oxide, and hydrofluorocarbons and are responsible for almost 24 percent of all mobile source GHGs (over 6 percent of all U.S. GHGs) and about 28 percent of CAA section 202(a) mobile source GHGs. For heavy-duty vehicles in 2013, CO_2 emissions represented roughly 96 percent of all GHG emissions (including HFCs).

This chapter provides the anticipated emissions impacts from the final standards. The reductions in emissions are expected for carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and hydrofluorocarbons (HFCs). In addition to reducing the emissions of greenhouse gases, this program will also affect the emissions of "criteria" air pollutants and their precursors, including carbon monoxide (CO), fine particulate matter ($PM_{2.5}$), oxides of sulfur (SO_X), volatile organic compounds (VOC) and oxides of nitrogen (NO_X), and several air toxics, such as benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein.

The final standards will affect both diesel- and gasoline-fueled heavy-duty vehicles, as well as those running on natural gases. The analyses account for both vehicle emissions ("downstream" emissions) and emissions from fuel production and distribution ("upstream" emissions). The agencies conducted two analyses by employing DOT's CAFE model and EPA's Motor Vehicle Emission Simulator (MOVES2014a)[4], relative to different reference cases (i.e., different baselines). The agencies used EPA's MOVES model to estimate fuel consumption and emissions impacts for tractor-trailers (including the engines which power the vehicle), and vocational vehicles (including the engine which powers the vehicle). For heavy-duty pickups and vans, the agencies performed separate analyses, which we refer to as "Method A" and "Method B," to estimate fuel consumption and emissions from these vehicles. See Section 5.3 for additional details. The changes in upstream emissions result from decreased fuel consumption. The emission factors from GREET[5] were used to estimate the changes in upstream emissions. In some cases, the GREET values were modified or updated by the agencies to be consistent with the EPA's National Emission Inventory (NEI) and emission factors from MOVES.

Table 5-1 through Table 5-3 summarize the impact of the program on GHG emissions from the heavy-duty sector in calendar years 2025, 2040 and 2050, using Method A and B, relative to two reference cases – flat (Alternative 1a) and dynamic (Alternative 1b). Table 5-4 through Table 5-6 summarize the projected fuel savings from the program in calendar years 2025, 2040 and 2050, using Method A and B, relative to the two reference cases.

Table 5-1 Annual Total GHG Emissions Impacts in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1b using Analysis Method A [a]

	CY2025		CY2040		CY2050	
	MMT CO_2eq	% Change	MMT CO_2eq	% Change	MMT CO_2eq	% Change
Downstream	-26.6	-4.9%	-103.3	-17.0%	-123.8	-18.0%
Upstream	-9.0	-4.9%	-35.5	-17.0%	-42.5	-19.0%
HFC	-0.1	-15.0%	-0.3	-13.0%	-0.3	-13.0%
Total	-35.7	-4.9%	-139.1	-17.0%	-166.6	-19.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-2 Annual Total GHG Emissions Impacts in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1a using Analysis Method A [a]

	CY2025		CY2040		CY2050	
	MMT CO_2eq	% Change	MMT CO_2eq	% Change	MMT CO_2eq	% Change
Downstream	-28.9	-5.3%	-114.1	-19.0%	-136.9	-20.0%
Upstream	-9.8	-5.3%	-39.3	-19.0%	-47.2	-20.0%
HFC	-0.1	-15.0%	-0.3	-13.0%	-0.3	-13.0%
Total	-38.8	-5.3%	-153.7	-19.0%	-184.4	-20.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-3 Annual Total GHG Emissions Impacts in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1a using Analysis Method B [a]

	CY2025		CY2040		CY2050	
	MMT CO_2eq	% Change	MMT CO_2eq	% Change	MMT CO_2eq	% Change
Downstream	-27.8	-4.6%	-124.3	-18.4%	-148.4	-20.0%
Upstream	-9.5	-4.7%	-42.2	-18.7%	-50.5	-20.3%
HFC[b]	-0.1	-15.0%	-0.3	-13.0%	-0.3	-13.0%
Total	-37.4	-4.7%	-166.8	-18.5%	-199.2	-20.1%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1
[b] HFC represents HFC emission reductions and percent change from the vocational vehicle category only.

Table 5-4 Annual Fuel Savings in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1b using Analysis Method A [a]

	CY2025		CY2040		CY2050	
	Billion Gallons	% Savings	Billion Gallons	% Savings	Billion Gallons	% Savings
Diesel	2.3	4.9%	9.2	17.8%	11.1	19.3%
Gasoline	0.4	5.0%	1.0	12.2%	1.2	12.8%
Total	2.7	4.9%	10.2	17.0%	12.3	18.5%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-5 Annual Fuel Savings in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1a using Analysis Method A [a]

	CY2025		CY2040		CY2050	
	Billion Gallons	% Savings	Billion Gallons	% Savings	Billion Gallons	% Savings
Diesel	2.4	5.2%	10.2	19.0%	12.3	21.0%
Gasoline	0.5	5.6%	1.2	13.0%	1.3	14.0%
Total	2.9	5.2%	11.4	18.0%	13.6	20.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-6 Annual Fuel Savings in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1a using Analysis Method B [a]

	CY2025		CY2040		CY2050	
	Billion Gallons	% Savings	Billion Gallons	% Savings	Billion Gallons	% Savings
Diesel	2.5	5.0%	10.8	19.4%	13.0	21.0%
Gasoline	0.3	2.8%	1.7	13.3%	1.9	14.4%
Total	2.8	4.6%	12.5	18.3%	14.9	19.9%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

The non-GHG impacts of the final program are largely driven by three factors. The largest contributor is from the projected increased use of auxiliary power units (APUs), which provide power, heat and cooling for trucks during extended engine idling. Note that since the proposal, the assumptions of APU usage were changed in the final rulemaking (see Section III.D.1.a of the Preamble) and EPA is adopting Phase 1 and Phase 2 requirements to control $PM_{2.5}$ emissions from APUs installed in new tractors (see Section III.C.3 of the Preamble). Reduced emissions from upstream fuel production and distribution also contribute significantly to the emissions benefits. Emissions of certain pollutants, such as NO_X and $PM_{2.5}$ are further reduced through improved engine efficiency, aerodynamics and tire rolling resistance and absolute changes in average total running weight of the vehicles. To a smaller extent, a rebound of vehicle miles traveled (VMT) will increase the emissions of all pollutants proportional to the VMT rebound amount. The emissions impacts of non-GHGs on both downstream and upstream from the heavy-duty sector in calendar years 2025, 2040 and 2050 are summarized in Table 5-7 through Table 5-9, using Method A and B, relative to the two reference cases.

Table 5-7 Annual Total Impacts (Upstream and Downstream) of Criteria Pollutants and Air Toxics from Heavy-Duty Sector in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1b using Analysis Method A [a]

POLLUTANT	CY2025		CY2040		CY2050	
	US Short Tons	% Change	US Short Tons	% Change	US Short Tons	% Change
1,3-Butadiene	0.3	0.1%	0.1	0.1%	-0.4	-0.3%
Acetaldehyde	-4	-0.1%	-30	-1.3%	-35	-1.4%
Acrolein	-0.2	0%	-2	-0.7%	-3	-0.9%
Benzene	-25	-1.2%	-101	-6.3%	-118	-6.7%
CO	-12,830	-0.9%	-49,416	-3.7%	-59,724	-4.0%
Formaldehyde	-39	-0.5%	-167	-2.7%	-205	-2.9%
NO_X	-21,337	-2.0%	-89,218	-11.0%	-108,157	-12.0%
$PM_{2.5}$	-1,033	-2.0%	-4,213	-10.0%	-5,071	-11.0%
SO_X	-6,005	-4.9%	-23,401	-17.0%	-28,047	-19.0%
VOC	-5,188	-2.7%	-18,293	-11.0%	-21,513	-12.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-8 Annual Total Impacts (Upstream and Downstream) of Criteria Pollutants and Air Toxics from Heavy-Duty Sector in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1a using Analysis Method A [a]

POLLUTANT	CY2025		CY2040		CY2050	
	US Short Tons	% Change	US Short Tons	% Change	US Short Tons	% Change
1,3-Butadiene	0.2	0.1%	-0.2	-0.1%	-1	-0.5%
Acetaldehyde	-5	-0.2%	-29	-1.3%	-35	-1.4%
Acrolein	-0.2	0%	-2	-0.7%	-3	-1.0%
Benzene	-27	-1.4%	-110	-6.8%	-129	-7.2%
CO	-13,086	-0.9%	-50,800	-3.8%	-61,438	-4.1%
Formaldehyde	-40	-0.5%	-170	-2.7%	-207	-2.9%
NO_X	-23,492	-2.2%	-100,407	-12.0%	-121,985	-14.0%
$PM_{2.5}$	-1,143	-2.2%	-4,731	-12.0%	-5,707	-13.0%
SO_X	-6,568	-5.3%	-25,902	-19.0%	-31,096	-20.0%
VOC	-5,641	-3.0%	-19,954	-12.0%	-23,502	-13.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-9 Annual Total Impacts (Upstream and Downstream) of Criteria Pollutants and Air Toxics from Heavy-Duty Sector in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1a using Analysis Method B [a]

POLLUTANT	CY2025		CY2040		CY2050	
	US Short Tons	% Change	US Short Tons	% Change	US Short Tons	% Change
1,3-Butadiene	-2	-0.5%	-8	-3.7%	-9	-4.1%
Acetaldehyde	-10	-0.3%	-53	-2.0%	-61	-2.1%
Acrolein	-1	-0.1%	-4	-1.3%	-5	-1.3%
Benzene	-35	-1.1%	-165	-6.8%	-192	-7.5%
CO	-13,254	-0.6%	-52,594	-3.3%	-63,869	-3.8%
Formaldehyde	-40	-0.5%	-187	-2.7%	-227	-2.9%
NO_X	-22,710	-1.9%	-101,961	-12.1%	-123,824	-13.3%
SO_X	-1,110	-1.9%	-5,081	-11.1%	-6,100	-12.1%
$PM_{2.5}$	-6,080	-4.8%	-26,933	-18.9%	-32,282	-20.5%
VOC	-5,305	-2.2%	-25,070	-11.9%	-29,253	-13.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

5.2 Introduction

5.2.1 Downstream (Tailpipe) Emissions

As described in more detail in this chapter, the downstream reductions in emissions due to the final program will be achieved through improvements in engine efficiency, road load reduction, and projected increase in idle reduction technologies (for additional details, see Chapter 5.3.2.3.1). Absolute reductions in tailpipe emissions are projected to grow over time as the fleet turns over to vehicles affected by the final standards, meaning that the emissions benefits of the program will continue to grow as older vehicles in the fleet are replaced by newer vehicles that emit less CO_2.

The effect of the regulations on the timing of fleet turnover and total VMT can have an impact on downstream GHG and other emissions, as discussed in Section IX of the Preamble. If the regulations spur firms to increase their purchase of new vehicles before efficiency standards are in place ("pre-buy") or to delay their purchases once the standards are in place then there will be a delay in achieving the full GHG and other emission reductions from improved fuel economy across the fleet. If the lower per-mile costs associated with higher fuel economy lead to an increase in VMT (the "rebound effect"), then the total emission reductions will also be reduced. Chapter 8 of the RIA provides more detail on how the rebound effect was calculated in the agencies' analysis. The analysis discussed in this chapter incorporates the rebound effect into the estimates. However, the impacts of any delayed fleet turnover are not estimated.

5.2.2 Upstream Emissions

In addition to downstream emission reductions, reductions are expected in the emissions associated with the processes involved in getting fuel to the pump, including the extraction and transportation of crude oil, the production and distribution of finished gasoline and diesel, and the production and transportation of renewable fuels. Changes are anticipated in upstream emissions due to the expected reduction in the overall volume of gasoline and diesel consumed. Less fuel consumed means less fuel transported, less fuel refined, and less crude oil extracted and transported to refineries. Thus, there will be reductions in the emissions associated with each of these steps in the fuel production and distribution processes. In addition, any changes in downstream reductions associated with changes in fleet turnover, and VMT are reflected in a corresponding change in upstream emissions associated with fuel processing and distribution.

The agencies recognize that the standards could lower the world price of oil (the "monopsony" effect, further discussed in Chapter 8 of the RIA). Lowering oil prices could lead to an uptick in oil consumption globally, resulting in a corresponding increase in GHG emissions in other countries. This global increase in emissions will slightly offset some of the emission reductions achieved domestically as a result of the regulation. EPA does not provide quantitative estimates of the impact of the final program on global petroleum consumption and GHG emissions in this RIA.

5.2.3 Global Warming Potentials

Throughout this document, in order to refer to the four inventoried greenhouse gases on an equivalent basis, Global Warming Potentials (GWPs) are used. In simple terms, GWPs provide a common basis with which to combine several gases with different heat trapping abilities into a single inventory (Table 5-10). When expressed in CO_2eq terms, each gas is weighted by its heat trapping ability relative to that of CO_2. The GWPs used in this analysis are consistent with the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) on a 100-year timescale.[6]

Table 5-10 Global Warming Potentials of GHGs

GAS	GLOBAL WARMING POTENTIAL (CO_2EQ)
CO_2	1
CH_4	25
N_2O	298
HFC134a	1,430

5.3 Program Analysis and Modeling Methods

5.3.1 Models Used

Different tools exist for estimating potential fuel consumption and emissions impacts associated with fuel efficiency and GHG emissions standards. One such tool is EPA's official mobile source emissions inventory model named Motor Vehicle Emissions Simulator (MOVES).[4] The agencies used a revised version of the official public model, MOVES2014a, to quantify the impacts of these standards on GHG emissions, fuel consumption, as well as criteria pollutants and air toxics emissions.

Since the notice of proposed rulemaking, MOVES has undergone a series of updates in response to the public comments on the proposal: (1) the projections of vehicle sales, populations, and activity in the version used for the final rulemaking were updated to incorporate the latest projections from the U.S. Department of Energy's Annual Energy Outlook 2015 report[7]; (2) the extended idle and APU emission rates in MOVES were updated based on the analyses of latest test programs that reflect the current prevalence of clean idle certified engines; and (3) the baseline adoption rates of idle reduction technology were reassessed and projected to be lower than what was assumed in the proposal, as described in Section III.D.1.a of the Preamble. In addition, changes to APU emissions rates for $PM_{2.5}$ were implemented in MOVES reflecting the fact that EPA is adopting requirements to control $PM_{2.5}$ emissions from APUs, as discussed in Section III.C.3 of the Preamble. Finally, methodological improvements were made in classifying vehicle types and in forecasting vehicle populations and activity. The aforementioned updates above, along with other changes, are documented in the memorandum to the docket.[8]

The agencies ran MOVES with user input databases that reflected the projected technological improvements resulting from the final rules, such as the improvements in engine and vehicle efficiency, aerodynamic drag, and tire rolling resistance. The changes made to the default MOVES database are described below in Chapter 5.3.2. All the input data, MOVES runspec files, and the scripts used for the analysis, as well as the version of MOVES used to generate the emissions inventories, can be found in the docket.[9]

Another such tool is DOT's CAFE model. For this analysis, the model was reconfigured to use the work based attribute metric of "work factor" established in the Phase 1 rule for heavy-duty pickups and vans, instead of the light-duty "footprint" attribute metric. The CAFE model takes user-specified inputs on, among other things, vehicles that will be produced in a given model year, technologies available to improve fuel efficiency on those vehicles, potential regulatory standards that will drive improvements in fuel efficiency, and economic assumptions. The CAFE model takes every vehicle in each manufacturer's fleet and decides what technologies to add to those vehicles in order to allow each manufacturer to comply with the standards in the most cost-effective way and uses a representation of the HD pickup and van fleet that captures heterogeneity at the manufacturer, model year, and powertrain (and other technology) level. Based on the resulting improved vehicle fleet, the CAFE model then calculates total fuel consumption and GHG, criteria, and toxics emissions impacts based on those inputs, along with economic costs and benefits. The CAFE model is discussed in greater detail in Chapter 10 of the RIA.

For this rulemaking, the agencies conducted two analyses by employing DOT's CAFE model and EPA's MOVES model. These models were used to project the impacts resulting from the standards on fuel consumption, GHG emissions, as well as criteria pollutants and air toxics emissions. As described in Chapter 5.3.2, the agencies used EPA's MOVES model to estimate fuel consumption and emissions impacts for tractor-trailers (including the engines which power the vehicle), and vocational vehicles (including the engine which powers the vehicle). For heavy-duty pickups and vans, the agencies performed separate analyses, referred to as "Method

A" and "Method B," to estimate fuel consumption and emissions from these vehicles. For these methods, the agencies analyzed the impact of the final rules, relative to two different reference cases – flat and dynamic. The flat baseline projects very little improvement in new vehicles in the absence of new Phase 2 standards. In contrast, the dynamic baseline projects more significant improvements in vehicle fuel efficiency. The agencies considered both reference cases. The results for all of the regulatory alternatives relative to both reference cases, derived via the same methodologies discussed in this Chapter, are presented in Chapter 11 of the RIA.

For brevity, a subset of these analyses are presented in this section, and the reader is referred to both Chapter 11 of the RIA and NHTSA's FEIS Chapters 3, 4 and 5 for complete sets of these analyses. In this Chapter, Method A is presented for the final standards, relative to both the dynamic baseline (Alternative 1b) and the flat baseline (Alternative 1a). Method B is presented for the final standards, relative only to the flat baseline.

Because reducing fuel consumption also affects emissions that occur as a result of fuel production and distribution (including renewable fuels), the agencies also calculated those "upstream" changes using the "downstream" fuel consumption reductions predicted by the MOVES model for vocational vehicles and tractor-trailers. As described earlier, for HD pickups and vans, separate analyses of estimating the emissions from upstream processes were conducted using the fuel consumption estimates from DOT's CAFE model (Method A) and EPA's MOVES model (Method B), relative to the two reference cases. Method A used a modified version of the CAFE model to estimate vehicular fuel consumption and emissions impacts for HD pickups and vans and to calculate upstream impacts. For vocational vehicles and combination tractor-trailers, both Method A and Method B estimated the projected corresponding changes in upstream emissions using the same tools originally created for the Renewable Fuel Standard 2 (RFS2) rulemaking analysis,[10] used in the LD GHG rulemakings,[11] HD GHG Phase 1,[12] and updated for the current analysis. The estimate of emissions associated with production and distribution of gasoline and diesel from crude oil is based on emission factors in the "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation" model (GREET) developed by DOE's Argonne National Lab. In some cases, the GREET values were modified or updated by the agencies to be consistent with the National Emission Inventory (NEI) and emission factors from MOVES. Method B used the same tool described above to estimate the upstream impacts for HD pickups and vans.

Updates and enhancements to the GREET model assumptions include updated crude oil and gasoline transport emission factors that account for recent EPA emission standards and modeling, such as accounting for impacts of fuel requirements on vapor emissions from storage and transport. In addition, GREET does not include air toxics. Thus, emission factors for the following air toxics were added: benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. These upstream toxics emission factors were calculated from the 2005 National Emissions Inventory (NEI), a risk and technology review for petroleum refineries, speciated emission profiles in EPA's SPECIATE database, or the Mobile Source Air Toxics rulemaking (MSAT) inventory for benzene; these pollutant tons were divided by refinery energy use or gasoline distribution quantities published by the DOE Energy Information Administration (EIA) to get emission factors in terms of grams per million BTU of finished gasoline and diesel. These updates are consistent with those used for the upstream analysis included in the LD GHG rulemaking and HD GHG Phase 1. The actual calculation of the emission inventory impacts of the decreased gasoline and diesel production is done in EPA's tool for upstream emission impacts.[13]

5.3.2 Calculation of Downstream Emissions

5.3.2.1 Model inputs and Assumptions for the Flat Reference Case

The flat reference case (identified as Alternative 1a in Section X of the Preamble and Chapter 11 of the RIA), a "no action" alternative, functions as one the baselines against which the impacts of the standards can be evaluated. The MOVES2014a default road load parameters and energy rates were used for the vocational vehicles and HD pickups and vans for this alternative because we assumed no market-driven improvements in fuel efficiency. The tractor-trailer road load parameters were changed from the MOVES2014a default values to account for projected improvements in the efficiency of the box trailers pulled by combination tractors due to increased penetration of aerodynamic technologies and low rolling resistance tires attributed to both EPA's SmartWay Transport Partnership and California Air Resources Board's Tractor-Trailer Greenhouse Gas regulation, as described in Section IV of the Preamble. We maintained the same road load inputs for tractor-trailers for 2018 and beyond.

The flat reference case assumed the growth in vehicle populations and miles traveled based on the relative annual VMT growth from AEO2015 Final Release for model years 2014 and later.[7] In the proposal, the agencies assumed the baseline APU adoption rate of 30 percent. However, based on the comments received from the proposed rulemaking, the flat reference case assumes that 9 percent of all combination long-haul tractors model year 2010 and later use an APU during extended idling (see Section III.D.1.a of the Preamble).

5.3.2.2 Model inputs and Assumptions for the Dynamic Reference Case

The dynamic reference case (identified as Alternative 1b in Section X of the Preamble and Chapter 11 of the RIA), also includes the impact of Phase 1 and generally assumes that fuel efficiency and GHG emission standards are not improved beyond the required 2018 model year levels. However, for this case, the agencies assume market forces will lead to additional fuel efficiency improvements for tractors and trailers. These additional assumed improvements are described in Section X of the Preamble. No additional fuel efficiency improvements due to market forces were assumed for vocational vehicles. For HD pickups and vans, the agencies applied the CAFE model using the input assumption that manufacturers having achieved compliance with Phase 1 standards will continue to apply technologies for which increased purchase costs will be "paid back" through corresponding fuel savings within the first six months of vehicle operation. The agencies conducted the MOVES analysis of this case in the same manner as for the flat reference case.

5.3.2.3 Model Inputs and Assumptions for the Control Case

The control case (identified as Alternative 3 in Chapter 11 of the RIA) represents the agencies' fuel efficiency and GHG standards for HD engines, HD pickup trucks and vans, Class 2b through Class 8 vocational vehicles, Class 7 and 8 combination tractors, and trailers. To account for improvements of engine and vehicle efficiency in vocational vehicles and combination tractor-trailers, EPA developed additional user input data for MOVES runs in estimating the control case inventories.

The agencies used the percent reduction in aerodynamic drag and tire rolling resistance coefficients and absolute changes in average total running weight (gross combined weight) expected from the final rules to develop the road load inputs for the control case. For running emissions, the key concept underlying the definition of operating mode in MOVES is scaled tractive power (STP), vehicle speed and vehicle acceleration.[14] STP represents the vehicle's tractive power scaled by a constant factor. It is calculated using mass of the vehicle and road load factors that include tire rolling resistance, aerodynamic drag, and friction losses in the drivetrain. STP is estimated using the equation below:

$$STP_t = \frac{Av_t + Bv_t^2 + Cv_t^3 + mv_t a_t}{f_{scale}}$$

Equation 5-1

Where:

A = the rolling resistance coefficient [kW·sec/m],
B = the rotational resistance coefficient [kW·sec^2/m^2],
C = the aerodynamic drag coefficient [kW·sec^3/m^3],
m = mass of individual vehicle [metric ton],
f_{scale} = fixed mass factor,
v_t = instantaneous vehicle velocity at time t [m/s],
a_t = instantaneous vehicle acceleration [m/s^2]

The improvements in road load factors will reduce the tractive power exerted by a vehicle to move itself and its cargo. The emissions from heavy-duty trucks are a function of STP as determined from a variety of data sources. Thus, a reduction in road load factors are expected to result in reduced GHG and non-GHG emissions. The improvements in tire rolling resistance, aerodynamic drag, and absolute changes in average vehicle weight expected from the technologies which could be used to meet the standards were modified in the "sourceusetypephysics" table.[A]

For vocational vehicles and tractor-trailers, the agencies developed energy inputs for the control case runs using the percent reduction in CO_2 emissions expected from the powertrain and other vehicle technologies not accounted for in the aerodynamic drag and tire rolling resistance improvements in the final rules. In contrast, for HD pickup trucks and vans, the standards were evaluated only in terms of the total vehicle reductions in fuel use and CO_2 emissions, since nearly all of these vehicles would be certified on a chassis dynamometer. Finally, EPA assumed increased penetration of idle reduction technology during extended idling, based on the expectation that manufacturers will use APUs and other idle reduction technologies to meet the

[A] Class 2b and 3 trucks do not use the STP metric and are regulated based on chassis testing (gram per mile basis) rather than engine testing (gram per brake horsepower-hour basis), therefore road load reductions are not expected to result in reduced non-GHG emissions.

vehicle GHG standard for combination long-haul tractors, as discussed in Section III.D of the Preamble.

5.3.2.3.1 Emission Rate and Road Load Inputs

Both the stringency and the form of the fuel consumption and CO_2 emission standards vary by vehicle category. Accordingly, the modeling of the standards in MOVES varies by the vehicle category. For the vocational vehicles and combination tractor-trailers, EPA has analyzed the impacts of the standards by evaluating the technologies applied to the energy rates as well as to the road load inputs. However, the impacts on the HD pickup trucks and vans were estimated only in terms of reduction in energy rates.

5.3.2.3.1.1 Tractor-Trailers

Similar to the approach used in the HD Phase 1 analysis, EPA aggregated the nine tractor subcategories into the two MOVES combination tractor-trailer categories – short-haul and long-haul. The agencies used sales distribution data from the HD Phase 1 analysis and determined the long-haul reductions in energy rates and road load factors, based on a sales mix assumption of 80 percent high roof, 15 percent mid roof, and 5 percent low roof sleeper cabs. The short-haul combination tractors were evaluated using a day cab sales distribution assumption of 7 percent Class 7 low roof, 10 percent Class 7 high roof, 40 percent Class 8 low roof, 35 percent Class 8 high roof, and 8 percent vocational tractors, based on the information used in the HD Phase 1 analysis. The details of the analyses aggregating the tractor subcategories into MOVES categories using the sales mix assumption described above can be found in the docket.[15]

The trailer category encompasses many types of trailers. As with the tractor category, EPA aggregated the trailer subcategories into two MOVES combination tractor-trailer categories. EPA used a combination of ACT Research's 2013 factory shipment data[16] for trailer distribution by type and "primary trip length" information from the U.S. Census' 2002 Vehicle Inventory and Use Survey[17] to distribute each trailer type into long- and short-haul categories. EPA applied the trailer market percentages as shown in Table 5-11 to determine the trailer impact on the MOVES long- and short-haul combination tractor-trailer categories.

Table 5-11 Aggregation of Trailer Types into MOVES Combination Tractor-Trailer Categories

TRAILER TYPE	Combination Long-Haul Tractor-Trailers	Combination Short-Haul Tractor-Trailers
Long Dry Van	51.6%	15.6%
Short Dry Van	20.6%	27.9%
Long Refrigerated Van	21.2%	2.5%
Short Refrigerated Van	6.6%	3.9%
Container Chassis	0.0%	8.4%
Flatbed	0.0%	8.4%
Tank	0.0%	8.3%
Excluded Trailers	0.0%	25.0%

Table 5-12 describes the improvements in the energy rate expected from the heavy-duty engine, transmission, and driveline technologies which will be applied to meet the tractor standards. The percentage reductions from the reference case were applied to the default MOVES energy rates in the appropriate source bins by modifying MOVES "emissionrateadjustment" table.

Table 5-12 Estimated Reductions in Energy Rates for the Final Standards for Tractor-Trailers

VEHICLE TYPE	FUEL	MODEL YEARS	REDUCTION FROM FLAT BASELINE
Long-haul Tractor-Trailers	Diesel	2018-2020	1.0%
		2021-2023	7.9%
		2024-2026	12.4%
		2027+	16.3%
Short-haul Tractor-Trailers[B]	Diesel	2018-2020	0.6%
		2021-2023	7.4%
		2024-2026	11.9%
		2027+	15.0%

Table 5-13 contains the improvements in tire rolling resistance, coefficient of drag, and weight reductions expected from the technologies which could be used to meet the Phase 2 standards for combination tractor-trailers. The percentage reductions in tire rolling resistance and drag coefficients and the absolute changes in average vehicle weight were modified in the "sourceusetypephysics" table.

Table 5-13 Estimated Reductions in Road Load Factors for the Final Standards for Tractor-Trailers

VEHICLE TYPE	MODEL YEARS	REDUCTION IN TIRE ROLLING RESISTANCE COEFFICIENT	REDUCTION IN AERODYNAMIC DRAG COEFFICIENT	WEIGHT REDUCTION (LB)[a]
Combination Long-haul Tractor-Trailers	2018-2020	6.1%	5.6%	-140
	2021-2023	13.3%	12.5%	-199
	2024-2026	16.3%	19.3%	-294
	2027+	18.0%	28.2%	-360
Combination Short-haul Tractor-Trailers[C]	2018-2020	5.2%	0.9%	-23
	2021-2023	11.9%	4.0%	-43
	2024-2026	14.1%	6.2%	-43
	2027+	15.9%	8.8%	-43

Note:
[a] Negative weight reductions reflect an expected weight increase as a byproduct of aerodynamic improvements and other improvements to the vehicle.

[B] Vocational and heavy-haul tractors are included in the short-haul tractor segment.
[C] Vocational and heavy-haul tractors are included in the short-haul tractor segment.

In addition, the projected use of auxiliary power units (APUs) during extended idling, shown below in Table 5-14, was included in the modeling for the long-haul combination tractor-trailers by modifying the "hotellingactivitydistribution" table in MOVES.

Table 5-14 Assumed APU Use during Extended Idling for Combination Long-haul Tractor-Trailers [a]

VEHICLE TYPE	MODEL YEARS	DIESEL APU PENETRATION	BATTERY APU PENETRATION
Combination Long-Haul Trucks	2010-2020	9%	0%
	2021-2023	30%	10%
	2024-2026	40%	10%
	2027+	40%	15%

Note:
[a] Other idle reduction technologies (such as automatic engine shutdown, fuel operated heaters, and stop-start systems) were modeled as part of the energy rates.

5.3.2.3.1.2 Vocational Vehicles

Similar to the approach for tractor-trailers, EPA aggregated the nine vocational vehicle subcategories into each of the seven MOVES vehicle types.[D] The energy rate inputs were derived by applying the anticipated levels of engine, axle, transmission, and idle reduction technologies across the weight classes and vehicle types. Each of these technology packages is described in Chapter 2 of the RIA. The differences between gasoline and diesel vocational vehicles in energy rate reduction from the reference cases, shown in Table 5-15, are due to the differences in anticipated engine-level technology packages, as described in Chapter 2 of the RIA.

The percentage reductions from the reference case were applied to the default MOVES energy rates in the appropriate source bins by modifying MOVES "emissionrateadjustment" table.

[D] Seven MOVES vehicle types for vocational vehicles are intercity bus, transit bus, school bus, refuse truck, single-unit short-haul truck, single-unit long-haul truck, and motor home.

Table 5-15 Estimated Reductions in Energy Rates for the Final Standards for Vocational Vehicles

VEHICLE TYPE	FUEL	MODEL YEARS	REDUCTION FROM FLAT BASELINE
Single-Frame Vocational[E]	Diesel & CNG	2021-2023	7.8%
		2024-2026	12.3%
		2027+	16.0%
	Gasoline	2021-2023	6.9%
		2024-2026	9.8%
		2027+	13.3%
Urban Buses	Diesel & CNG	2021-2023	7.0%
		2024-2026	11.8%
		2027+	14.4%

The agencies used MOVES population data for new vehicles expected to be sold in 2018 for each weight class, as well as assumptions about their distribution among the three new vocational vehicle duty cycles. This population allocation is shown in Table 5-16.

Table 5-16 Vocational Vehicle Types and Population Allocation

VEHICLE TYPE	REGIONAL	MULTI-PURPOSE	URBAN
Short Haul Straight Truck	20%	28%	52%
Long Haul Straight Truck, Motor Home, Intercity Bus	100%	0%	0%
School Bus	0%	10%	90%
Transit Bus	0%	0%	100%
Refuse	0%	10%	90%
All Class 4-5	15%	10%	19%
All Class 6-7	11%	7%	19%
All Class 8	5%	4%	10%

Using these population distribution estimates and the technology application rates described in Chapter 2 of the RIA, EPA derived the levels of improvements in tire rolling resistance and weight reduction.

Table 5-17 contains the improvements in tire rolling resistance, and weight reductions expected from the technologies which will be used to meet the standards for vocational vehicles. No reduction in aerodynamic drag coefficient was modeled for vocational vehicles because the final standards for vocational vehicles do not assume any aerodynamic improvements (see

[E] Vocational vehicles modeled in MOVES include heavy heavy-duty, medium heavy-duty, and light heavy-duty vehicles. However, for light heavy-duty vocational vehicles, class 2b and 3 vehicles are not included in the inventories for the vocational sector. Instead, all vehicles with GVWR less than 14,000 lbs were modeled using the energy rate reductions described below for HD pickup trucks and vans. In practice, many manufacturers of these vehicles choose to average the lightest vocational vehicles into chassis-certified families (i.e., heavy-duty pickups and vans).

Section V.C.1.c.i of the Preamble). The percentage reductions in tire rolling resistance and the absolute changes in average vehicle weight were modified in the "sourceusetypephysics" table in MOVES. The analyses used to develop the MOVES inputs for vocational vehicles, described above, can be found in the docket.[18]

Table 5-17 Estimated Reductions in Road Load Factors for the Final Standards for Vocational Vehicles

VEHICLE TYPE	MODEL YEARS	REDUCTION IN TIRE ROLLING RESISTANCE COEFFICIENT	WEIGHT REDUCTION (LB)
Intercity Buses	2021-2023	18.2%	0
	2024-2026	20.8%	0
	2027+	24.7%	0
Transit Buses	2021-2023	0%	0
	2024-2026	0%	0
	2027+	12.1%	0
School Buses	2021-2023	10.1%	0
	2024-2026	14.9%	0
	2027+	19.7%	0
Refuse Trucks	2021-2023	0%	0
	2024-2026	0%	0
	2027+	12.1%	0
Single Unit Short-haul Trucks	2021-2023	6.4%	4.4
	2024-2026	6.4%	10.4
	2027+	10.2%	16.5
Single Unit Long-haul Trucks	2021-2023	8.4%	7.9
	2024-2026	13.3%	23.6
	2027+	13.3%	39.4
Motor Homes	2021-2023	20.8%	0
	2024-2026	20.8%	0
	2027+	24.7%	0

5.3.2.3.1.3 Heavy-Duty Pickup Trucks and Vans

As explained above, the agencies used both DOT's CAFE model and EPA's MOVES model, using analytical Method A and B, respectively, to project fuel consumption, GHG and non-GHG emissions impacts resulting from the standards for HD pickups and vans, including downstream vehicular emissions as well as emissions from upstream processes related to fuel production, distribution, and delivery.

5.3.2.3.1.3.1 Method A for HD Pickups and Vans

For Method A, NHTSA used the CAFE model which applies fuel properties (density and carbon content) to estimated fuel consumption in order to calculate vehicular CO_2 emissions, applies per-mile emission factors from MOVES to estimated VMT (for each regulatory alternative, adjusted to account for the rebound effect) in order to calculate vehicular CH_4 and N_2O emissions (as well, as discussed below, of non-GHG pollutants), and applies per-gallon upstream emission factors from GREET in order to calculate upstream GHG (and non-GHG) emissions.

As discussed above in Section VI, the standards for HD pickups and vans increase in stringency by 2.5 percent annually during model years 2021-2027. The standards define targets specific to each vehicle model, but no vehicle is required to meet its target; instead, the production-weighted averages of the vehicle-specific targets define average fuel consumption and CO_2 emission rates that a given manufacturer's overall fleet of produced vehicles is required to achieve. The standards are specified separately for gasoline and diesel vehicles, and vary with work factor. Both the NPRM and today's analysis assume that some application of mass reduction could enable increased work factor in cases where manufacturers increase a vehicle's rated payload and/or towing capacity, but there are other ways manufacturers may change work factor which the analysis does not capture. Average required levels will depend on the future mix of vehicles and the work factors of the vehicles produced for sale in the U.S. Since these can only be estimated at this time, average required and achieved fuel consumption and CO_2 emission rates are subject to uncertainty. Between the NPRM and the issuance of today's final rules, NHTSA updated the market forecast (and other inputs) used to analyze HD pickup and van standards, and doing so leads to different estimates of required and achieved fuel consumption and CO_2 emission rates (as well as different estimates of impacts, costs, and benefits).

The following four tables present stringency increases and estimated required and achieved fuel consumption and CO_2 emission rates for the two No Action Alternatives (Alternative 1a and 1b) and the standards defining the Preferred Alternative. Stringency increases are shown relative to standards applicable in model year 2018 (and through model year 2020). As mathematical functions, the standards themselves are not subject to uncertainty. By 2027, they are 16.2 percent more stringent (i.e., lower) than those applicable during 2018-2020. NHTSA estimates that, by model 2027, these standards could reduce average required fuel consumption and CO_2 emission rates to about 4.88 gallons/100 miles and about 4 grams/mile, respectively. NHTSA further estimates that average achieved fuel consumption and CO_2 emission rates could correspondingly be reduced to about the same levels. If, as represented by Alternative 1b, manufacturers will, even absent today's standards, voluntarily make improvements that pay back within six months, these model year 2027 levels are about 12 percent lower than the agencies' estimate could be achieved under the Phase 1 standards defining the No Action Alternative. If, as represented by Alternative 1a, manufacturers will, absent today's standards, only apply technology as required to achieve compliance, these model year 2027 levels are about 13 percent lower than the agencies' estimate could be achieved under the Phase 1 standards. As indicated below, NHTSA's estimate that these improvements in fuel consumption and CO_2 emission rates will build from model year to model year, beginning as soon as model year 2017 (insofar as manufacturers may make anticipatory improvements if warranted given planned product cadence).

The NPRM analysis suggested that both the achieved and required fuel consumption and CO_2 reductions would be larger than the current Method A analysis suggests. The NPRM suggested that achieved reductions would be 13.5 and 15 percent, for the dynamic and flat baselines, respectively. The change in the standards and fuel consumption reductions can be attributed to the projected increased work factor of the 2015 fleet relative to the 2014 fleet.

Section VI discusses in more detail the changes in the distribution of work factor for key market players from the MY2014 to the MY2015 fleet.

Table 5-18 Stringency of HD Pickup and Van Standards, Estimated Average Required and Achieved Fuel Consumption Rates for Method A, Relative to Alternative 1b [a]

MODEL YEAR	STRINGENCY (VS. 2018)	AVE. REQUIRED FUEL CONS. (GAL./100 MI.)			AVE. ACHIEVED FUEL CONS. (GAL./100 MI.)		
		No	Final	Reduction	No	Final	Reduction
2016	MYs 2016-2020 Subject to Phase 1 Standards	6.32	6.32	0.0%	6.14	6.14	0.0%
2017		6.16	6.16	0.0%	6.02	5.89	2.2%
2018		5.83	5.83	0.0%	5.97	5.78	3.2%
2019		5.81	5.81	0.0%	5.77	5.47	5.3%
2020		5.80	5.80	0.0%	5.75	5.46	5.1%
2021	2.5%	5.79	5.65	2.4%	5.68	5.28	7.2%
2022	4.9%	5.80	5.52	4.8%	5.64	5.22	7.5%
2023	7.3%	5.80	5.38	7.2%	5.64	5.21	7.6%
2024	9.6%	5.80	5.25	9.5%	5.65	5.22	7.6%
2025	11.9%	5.81	5.12	11.8%	5.65	5.14	9.1%
2026	14.1%	5.81	5.01	13.7%	5.65	5.02	11.1%
2027	16.2%	5.80	4.88	15.8%	5.57	4.92	11.7%
2028*	16.2%	5.81	4.91	15.5%	5.57	4.89	12.2%
2029*	16.2%	5.81	4.91	15.6%	5.57	4.88	12.4%
2030*	16.2%	5.81	4.91	15.6%	5.57	4.88	12.4%

Notes:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.
* Absent further action, standards assumed to continue unchanged after model year 2027.

Table 5-19 Stringency of HD Pickup and Van Standards, Estimated Average Required and Achieved CO_2 Emission Rates for Method A, Relative to Alternative 1b [a]

MODEL YEAR	STRINGENCY (VS. 2018)	AVE. REQUIRED CO_2 RATE (G./MI.)			AVE. ACHIEVED CO_2 RATE (G./MI.)		
		No	Final	Reduction	No Action	Final	Reduction
2016	MYs 2016-2020 Subject to Phase 1 Standards	597	597	0.0%	578	578	0.0%
2017		582	582	0.0%	567	554	2.2%
2018		550	550	0.0%	562	544	3.2%
2019		548	548	0.0%	543	514	5.3%
2020		547	547	0.0%	541	513	5.1%
2021	2.5%	545	532	2.4%	534	496	7.1%
2022	4.9%	546	519	4.9%	530	491	7.4%
2023	7.3%	545	506	7.2%	529	490	7.5%
2024	9.6%	547	494	9.5%	531	491	7.5%
2025	11.9%	547	483	11.7%	530	483	9.0%
2026	14.1%	547	472	13.7%	530	472	11.0%
2027	16.2%	546	460	15.8%	523	462	11.5%
2028*	16.2%	547	462	15.5%	523	460	12.0%
2029*	16.2%	547	462	15.5%	524	460	12.2%
2030*	16.2%	547	462	15.5%	524	460	12.2%

Notes:

[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.

* Absent further action, standards assumed to continue unchanged after model year 2027.

Table 5-20 Stringency of HD Pickup and Van Standards, Estimated Average Required and Achieved Fuel Consumption Rates for Method A, Relative to Alternative 1a [a]

MODEL YEAR	STRINGENCY (VS. 2018)	AVE. REQUIRED FUEL CONS. (GAL./100 MI.)			AVE. ACHIEVED FUEL CONS. (GAL./100 MI.)		
		No Action	Final	Reduction	No Action	Final	Reduction
2016	MYs 2016-2020 Subject to Phase 1 Standards	6.32	6.32	0.0%	6.14	6.14	0.0%
2017		6.16	6.16	0.0%	6.00	5.85	2.4%
2018		5.83	5.83	0.0%	5.94	5.75	3.2%
2019		5.81	5.81	0.0%	5.74	5.43	5.4%
2020		5.80	5.80	0.0%	5.73	5.43	5.2%
2021	2.5%	5.79	5.65	2.4%	5.70	5.27	7.5%
2022	4.9%	5.80	5.52	4.8%	5.69	5.23	8.2%
2023	7.3%	5.80	5.38	7.2%	5.69	5.22	8.3%
2024	9.6%	5.80	5.25	9.5%	5.70	5.22	8.3%
2025	11.9%	5.81	5.13	11.8%	5.70	5.13	10.0%
2026	14.1%	5.81	5.02	13.6%	5.70	5.03	11.9%
2027	16.2%	5.80	4.89	15.8%	5.64	4.92	12.8%
2028*	16.2%	5.81	4.91	15.4%	5.64	4.89	13.3%
2029*	16.2%	5.81	4.91	15.5%	5.64	4.89	13.4%
2030*	16.2%	5.81	4.91	15.5%	5.64	4.89	13.4%

Notes:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.
* Absent further action, standards assumed to continue unchanged after model year 2027.
** Increased work factor for some vehicles produces a slight increase in average required fuel consumption.

Table 5-21 Stringency of HD Pickup and Van Standards, Estimated Average Required and Achieved CO_2 Emission Rates for Method A, Relative to Alternative 1a [a]

MODEL YEAR	STRINGENCY (VS. 2018)	AVE. REQUIRED CO_2 RATE (G./MI.)			AVE. ACHIEVED CO_2 RATE (G./MI.)		
		No Action	Final	Reduction	No Action	Final	Reduction
2016	MYs 2016-2020 Subject to Phase 1 Standards	597	597	0.0%	578	578	0.0%
2017		582	582	0.0%	564	551	2.3%
2018		550	550	0.0%	559	541	3.2%
2019		548	548	0.0%	540	511	5.4%
2020		547	547	0.0%	538	510	5.2%
2021	2.5%	545	532	2.4%	535	495	7.4%
2022	4.9%	546	519	4.8%	534	491	8.0%
2023	7.3%	545	506	7.2%	533	490	8.2%
2024	9.6%	547	494	9.5%	535	491	8.2%
2025	11.9%	547	483	11.7%	535	483	9.8%
2026	14.1%	547	472	13.6%	535	473	11.7%
F 2027	16.2%	546	460	15.8%	529	462	12.6%
2028*	16.2%	547	462	15.5%	530	460	13.1%
2029*	16.2%	547	462	15.5%	530	460	13.2%
2030*	16.2%	547	462	15.5%	530	460	13.2%

Notes:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.
* Absent further action, standards assumed to continue unchanged after model year 2027.
** Increased work factor for some vehicles produces a slight increase in the average required CO_2 emission rate.

While the above tables show NHTSA's estimates of average fuel consumption and CO_2 emission rates manufacturers of pickups and vans might achieve under today's standards, total U.S. fuel consumption and GHG emissions from HD pickups and vans will also depend on how many of these vehicles are produced, and how they are operated over their useful lives. Relevant to estimating these outcomes, the CAFE model applies vintage-specific estimates of vehicle survival and mileage accumulation, and adjusts the latter to account for the rebound effect. This impact of the rebound effect is specific to each model year (and, underlying, to each vehicle model in each model year), varying with changes in achieved fuel consumption rates. These details of the model are further discussed in Chapter 10 of this RIA and Section VI of the Preamble.

For Method B, MOVES model was used to estimate fuel consumption and GHG emissions for HD pickups and vans. MOVES evaluated the standards for HD pickup trucks and vans in terms of grams of CO_2 per mile or gallons of fuel per 100 miles. Since nearly all HD pickup trucks and vans are certified on a chassis dynamometer, the CO_2 reductions for these vehicles were not represented as engine and road load reduction components, but rather as total vehicle CO_2 reductions. The stringency increases relative to the Phase 1 standards for HD pickup trucks and vans (Table 5-23) were modified in the "emissionrateadjustment" table in MOVES.

Table 5-22 Estimated Total Vehicle CO_2 Reductions for the Final Standards and In-Use Emissions for HD Pickup Trucks and Vans in Method B [a]

VEHICLE TYPE	FUEL	MODEL YEAR	CO_2 REDUCTION FROM FLAT BASELINE
HD Pickup Trucks and Vans	Gasoline and Diesel	2021	2.50%
		2022	4.94%
		2023	7.31%
		2024	9.63%
		2025	11.89%
		2026	14.09%
		2027+	16.24%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

5.3.2.3.2 VMT Inputs

The "HPMSVtype" table in MOVES was modified to reflect the VMT rebound (VMT rebound is described in more detail in Chapter 8.3 of the RIA). This table includes VMT values for all calendar years. For the control case, the absolute VMT for vocational vehicle and combination tractor-trailer were increased from the reference cases by 0.30 percent, and 0.75 percent, respectively, to reflect the VMT rebound.[19] Since VMT is applied by calendar year and not by model year, post-processing of the results were performed to ensure that only the model years affected by the program experienced VMT rebound – the results from the reference cases were used in the control case inventories for model years not affected by the final rules.

For HD pickups and vans, Method A used the CAFE model, which simulates VMT in a dynamic fashion that responds to changes in vehicle fuel economy and fuel prices and adjusts the marginal VMT of each vehicle model, at every age (so in each calendar year). In general, the more stringent alternatives considered lead to larger improvements in fuel economy and, thus, a greater number of vehicle miles traveled as a result of the rebound effect. In the CAFE model, the rebound effect represents a symmetric driver of changes to VMT; if the per-mile price of driving declines relative to today (either from improvements in vehicle fuel economy or declines in fuel prices), VMT increases by the amount of the rebound effect, conversely, if the per-mile price of driving increases relative to today (due to increases in the price of fuel), VMT will decline by the amount of the rebound effect. In Method B, the VMT rebound effect was modeled using the MOVES model, which assumed an increase in VMT from the reference levels of 1.08 percent.[19]

5.3.3 Calculation of Upstream Emissions

The term "upstream emissions" refers to air pollutant emissions generated from all crude oil extraction, transport, refining, and finished fuel transport, storage, and distribution; this includes all stages prior to the final filling of vehicle fuel tanks at retail service stations. Additionally, it includes the production of renewable fuels and transportation of such fuel, either separately or mixed with conventional fuels.

As described in Chapter 5.3.1, the decreased volumes of the crude based fuels and the various crude production and transport emission factors from GREET were used to estimate the net impact of fuel use changes on upstream emissions. The analysis for this final rulemaking assumes that all changes in volumes of fuel used affect only gasoline and diesel, with no effects on use of ethanol, biodiesel or other renewable fuels. The production and transport of these renewable fuels, although unchanged in volume for this analysis, are still accounted for in the total inventory in this rulemaking. Although impacts to agriculture related to renewable fuels and the associated transport of these feedstocks were originally included in the RFS2 rulemaking, the effects to these sectors from the regulations will be minimal and they have therefore been excluded from this analysis.

The agencies recognize the unique GHG emission characteristics associated with biofuels, and specifically that in the context of biofuels, "upstream emissions" include not only GHG emissions, but also any net biological sequestration that takes place. When considered on a lifecycle basis (including both tailpipe and upstream emissions), the net GHG emission impact of individual biofuels can vary significantly from both petroleum-based fuels and from one biofuel to another. EPA's Renewable Fuel Standard (RFS) program, as modified by EISA, examined these differences in lifecycle emissions in detail. For example, EPA found that with respect to aggregate lifecycle emissions including non-tailpipe GHG emissions (such as feedstock growth, transportation, fuel production, and land use), lifecycle GHG emissions in 2022 for biodiesel from soy, using certain advanced production technologies, are about 50 percent less than diesel from petroleum.

Non-GHG fuel production and distribution emission impacts of the program were estimated in conjunction with the development of lifecycle GHG emission impacts, and the GHG emission inventories discussed above. The basic calculation is a function of fuel volumes in the analysis year and the emission factors associated with each process or sub-process. It relies partially on the GREET model, but takes advantage of additional information and models to significantly strengthen and expand on the GREET analysis, as discussed in Chapter 5.3.1. The details of the assumptions, data sources, and calculations that were used to estimate the emission impacts presented here can be found in the docket memo, "Calculation of Upstream Emissions for the GHG Vehicle Rule," initially created for use in the LD GHG rulemaking.[20] The agencies note that to the extent future policy decisions involve upstream emissions, the agencies will need to consider the unique emission characteristics associated with biofuels. More broadly, the agencies recognize that biofuels, including biodiesel, will play an important role in reducing the nation's dependence on foreign oil, thereby increasing domestic energy security. The volumes of renewable fuels are defined by the RFS2 standards as well as the Annual RFS rulemakings, and are projected using AEO2015. The volumes of renewable fuel for these standards remain in place regardless of overall volume of fuel affected by this rulemaking. Therefore, we have assumed that the effect of the Phase 2 standards on biofuels agriculture and transportation of raw agricultural goods will be minimal and excluded it from this analysis.

As described earlier, the agencies estimated the impact of the final rules on upstream using the downstream fuel consumption reductions predicted by MOVES for vocational vehicles and tractor-trailers. For HD pickups and vans, separate analyses of estimating the emissions from upstream processes were conducted using the fuel consumption estimates from DOT's CAFE model and EPA's MOVES model, using Method A and B, respectively.

5.3.4 Calculation of HFC Emissions[F]

EPA is adopting new air conditioning (A/C) leakage standards for vocational vehicles to reduce HFC emissions. The Vintaging Model, developed by EPA Office of Atmospheric programs, produces HFC inventories for several categories of stationary and mobiles sources. However, it does not include air conditioning systems in medium and heavy-duty trucks within its inventory calculations. For this final rulemaking, we conducted an analysis based on the inputs to the Vintaging Model and the inputs to the MOVES analysis discussed in Chapter 5.3.2 above.

The general equation for calculating HFC emissions follows:

$$\text{HFC emissions}_{\text{Year x}} = \text{A/C Systems}_{\text{Year x}} \text{ Average Charge Size x HFC loss rate}$$

We determined the number of functioning A/C systems in each year based on the projected sales of vehicles, the fraction of vehicles with A/C systems, and the average lifetime of an A/C system. Sales were drawn from the MOVES analysis and we assumed that every vehicle had a functioning A/C system when sold. The Vintaging Model assumes that all light-duty passenger vehicle A/C systems (in the U.S.) last exactly 12 years.[G] In the absence of other information, we assumed that heavy-duty vehicles A/C systems last for the same period of time as light-duty vehicles. Light, medium and heavy-duty vehicles use largely the same components in their air conditioning systems (sometimes from the same suppliers), which will indicate similar periods of durability.

The charge size was determined using the Minnesota refrigerant leakage database.[21] EPA sorted the data based on A/C charge size and evaluated only the largest 25 percent of A/C systems to be more representative of HD systems. The average charge size is 1,025 grams of refrigerant.

Due to the similarity in system design, we assumed that the light-duty vehicle emission rate in the Vintaging Model was applicable to the current analysis, as shown in Table 5-23. The Vintaging Model assumes that losses occur from three events: leak, service, and disposal. Although vehicle A/C systems are serviced during discrete events and not usually every year, emissions from those events are averaged over the lifetime of the A/C system in the Vintaging model. Leak and service emissions are considered "annual losses" and are applied every year;

[F] The U.S. has submitted a proposal to the Montreal Protocol which, if adopted, would phase-down production and consumption of HFCs.
[G] This is in agreement with the IPCC report IPCC/TEAP 2005 *Safeguarding the Ozone Layer and the Global Climate System – Issues Related to Hydrofluorocarbons and Perfluorocarbons,* which indicates lifetimes (worldwide) of 9 to 12 years.

disposal is considered an "end of life loss" and is applied only once for each vintage of vehicles.[H]

Table 5-23 Annual In-use Vehicle HFC134a Emission Rate from Vintaging Model

KIND OF LOSS	LOSS FRACTION
Leakage	8%
Maintenance /Servicing	10%
End of Life	43%

The Vintaging Model assumes that charge loss is replaced every year; i.e., assuming an 18 percent rate of charge loss, a vehicle with a charge of 1,000 grams will lose a constant rate of 180 grams per year. While this loss rate is not representative of any single given vehicle, it is assumed accurate for the fleet as a whole. Other emissions, such as fugitive emissions at a production facility, leaks from cylinders in storage, etc., are not explicitly modeled, but such emissions are accounted for within the average annual loss rate.

EPA's analysis of the Minnesota database of MY 2010 vehicles suggests that many of the modeled vehicles likely contain some of the technology required to meet the leakage standard, and as a consequence are leaking less. We assume that these improvements are independent of EPA regulation, rather than a preemptive response to regulation. Consequently, this rulemaking does not take credit for these emission reductions. EPA also reviewed a study conducted by the Eastern Research Group (ERG) of R134a leaks in heavy-duty vehicles to California Air Resources Board.[22] The study included a total of 70 medium- and heavy-duty vehicles and off-road equipment, of which 18 of the samples were HD tractors ranging between 1990 and 2008 model years. The mobile air conditioning capacity in the tractors ranged between 1,080 grams to 1,950 grams. The study measured HFC leakage during sample times which ranged between 0.3 and 0.6 years. ERG then calculated an annualized in-use leakage rate with an assumed linear projection of measured leak rates to annual leak rates, which may be an over-estimate. The annualize leakage rate for tractors ranged between nearly 0 to nearly 1.5 grams leakage per gram of MAC capacity. These leakage rates did not include other leakage sources such as maintenance or end of life recovery. ERG found that the average of all MD and HD trucks and equipment which were 2006 MY or newer had an average leakage of 103 grams of R134a per year. Based on these results, the agency believes that our estimates for HFC reductions may understate the benefits of the program. The agency will continue to analyze this and other studies that may be conducted in the future.

Based on the Minnesota database, we determined that it is possible to reduce the HFC emissions from these vehicles on average by 13 percent. EPA calculated this based on the assumption that vehicles currently in the fleet which meet the MY 2021 standard will not make any additional improvements to reduce leakage. We also assumed that the systems which currently have leakage rates above the standard will reduce their leakage to the level of the standard. We then applied the 13 percent reduction to the baseline 18 percent leakage rate to

[H] The U.S. EPA has reclamation requirements for refrigerants in place under Title VI of the Clean Air Act.

develop a 15.6 percent leakage rate for MY 2021 and later vehicles to determine the reduction in emission rate which should be credited to this rulemaking.[I]

We calculated our emission reductions based on the difference between the baseline case of 2010 vehicle technology (discussed above) and the control scenario where the loss prevention technology has been applied to 100 percent of the new vocational vehicles starting in 2021 model year, as will be required by the standards.

Total HFC reductions are 179 metric tons over the MY 2021 baseline A/C system in 2040 and 220 metric tons in 2050. This is equivalent to a reduction of 256,061 metric tons of CO_2eq emissions in 2040; and 314,930 metric tons CO_2eq in 2050.[J]

5.3.5 Development of Onroad Emission Inventories for Air Quality Modeling

This section summarizes the onroad emission inventories that were used to create emissions inputs to the air quality modeling described in Chapter 6.2 of the RIA. Details on the development of emission inventories for sectors other than onroad, as well as additional information on the methodologies for producing onroad inventories for air quality modeling, are provided in the Emission Inventories for Air Quality Modeling Technical Support Document, which can be found in the docket for this rulemaking.[23]

The emission inventories for air quality modeling requires estimating the inventories for the entire U.S. by 12 km grid cell and hour of the day for each day of the year, involving a methodology with much greater detail than the national emission inventories discussed above. In addition to the methodological differences, due to the long lead time needed to do the air quality runs, differences exist in the modeling tools and inputs used for the national inventories and air quality modeling, and in essence, they are separate analyses.

Because using this modeling methodology with added precision is time-consuming and resource-intensive, the inventories for air quality modeling were developed using an earlier version of MOVES[K] than what was used for the national inventories. The series of updates in MOVES that were implemented since the NPRM, described in Chapter 5.3.1 of the RIA, were not included in the air quality modeling version of MOVES. Additional details on the differences between the two versions are documented in the memorandum to the docket.[8] The MOVES model used to generate the inventories for air quality modeling can also be found in the docket.[9]

Furthermore, the model inputs used to generate the inventories for air quality modeling differ from the ones for national inventories. Because the development of air quality inventories had to be started prior to receiving the comments from the proposal, the flat baseline (Alternative

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[I] Using 18 percent as the base emission rate may overstate the net emission reductions. However, numbers from the ERG Report to CARB studying the leakage rate of heavy-duty vehicles are actually much larger (range of near 0 to 150 percent annually), and this places an 18 percent annual loss rate well within the literature. However, (a) the net impact is very small, (b) these numbers have significant uncertainty, and (c) it is unclear what the appropriate modification would be.

[J] Using a Global Warming Potential of 1,430 for HFC-134a.

[K] A revised version of MOVES2014 was used to develop the inventories for air quality modeling (MOVES20150507 code and MOVESDB20150515).

1a) for the air quality inventories assumed the APU adoption rate of 30 percent, instead of the 9 percent assumed in the national inventories based on public comments. For modeling of the Phase 2 standards, we used the projected technological improvements, such as the improvements in engine and vehicle efficiency, aerodynamic drag, and tire rolling resistance, from the proposal (Alternative 3). Also, the inventories for air quality modeling assumed higher projected use of APUs to meet the Phase 2 standards than the national inventories (Figure 5-4). Lastly, the additional $PM_{2.5}$ control on APUs being required in the final rules was not modeled in the air quality inventories. Chapter 5.5.2.3 of this RIA presents the differences between the air quality and final national inventories.

The onroad mobile source emission inventories were generated for two calendar years, 2011 and 2040, using Method B.[L] The emission inventories for 2011 were developed to provide a base year for forecasting future air quality. Calendar year 2040 was run for both the flat baseline (Alternative 1a)[M] and the preferred alternative (Alternative 3) from the proposal. The meteorological data used to develop and temporally allocate emissions for both 2011 and 2040 were consistent with the 2011 data used for the air quality modeling. In addition, the inventories for air quality modeling accounted for the county-specific information on vehicle populations, VMT, age distributions, and inspection-maintenance programs, as well as the anti-idling mandates, such as the one in California.

5.4 Greenhouse Gas Emission and Fuel Consumption Impacts

The following subsections summarize two slightly different analyses of the annual GHG emissions and fuel consumption reductions expected from the final standards, as well as the reductions in GHG emissions and fuel consumption expected over the lifetime of each heavy-duty vehicle category. Chapter 5.4.1 shows the impacts of the final rules on fuel consumption and GHG emissions using the MOVES model for tractor-trailers and vocational vehicles, and the DOT's CAFE model for HD pickups and vans (Method A), relative to two different reference cases – flat and dynamic. Chapter 5.4.2 shows the impacts of the final standards, relative to the flat reference case only, using the MOVES model for all heavy-duty vehicle categories.

5.4.1 Impacts of the Final Rules using Analysis Method A

5.4.1.1 Calendar Year Analysis

5.4.1.1.1 Downstream Impacts

As described in Section VII.A of the FRM Preamble, for the analysis using Method A, NHTSA used MOVES to estimate downstream GHG inventories from the final rules for vocational vehicles and tractor-trailers. For HD pickups and vans, DOT's CAFE model was used.

The following two tables summarize NHTSA's estimates of HD pickup and van fuel consumption and GHG emissions under the current standards defining the No-Action and final

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[L] For an explanation of analytical Methods A and B, please see Section I.D of the Preamble.

[M] For an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1 of the Preamble.

program, respectively, using Method A. Table 5-24 shows results assuming manufacturers will voluntarily make improvements that pay back within six months (i.e., Alternative 1b). Table 5-25 shows results assuming manufacturers will only make improvements as needed to achieve compliance with standards (i.e., Alternative 1a). While underlying calculations are all performed for each calendar year during each vehicle's useful life, presentation of outcomes on a model year basis aligns more clearly with consideration of cost impacts in each model year, and with consideration of standards specified on a model year basis. In addition, Method A analyzes manufacturers' potential responses to HD pickup and van standards on a model year basis through 2030, and any longer-term costs presented in today's notice represent extrapolation of these results absent any underlying analysis of longer-term technology prospects and manufacturers' longer-term product offerings.

Table 5-24 Estimated Fuel Consumption and GHG Emissions over Useful Life of HD Pickups and Vans Produced in Each Model Year for Method A, Relative to Alternative 1b [a]

MODEL YEAR	FUEL CONSUMPTION (B. GAL.) OVER FLEET'S USEFUL LIFE			GHG EMISSIONS (MMT CO_2EQ) OVER FLEET'S USEFUL LIFE		
	No Action	Final	Reduction	No Action	Final	Reduction
2016	10.4	10.4	0.0%	127	127	0.0%
2017	10.4	10.2	2.0%	127	124	2.0%
2018	10.5	10.2	2.9%	127	124	2.9%
2019	10.1	9.60	4.8%	123	117	4.8%
2020	10.1	9.60	4.6%	123	117	4.6%
2021	9.82	9.17	6.6%	120	112	6.5%
2022	9.67	9.01	6.9%	118	110	6.8%
2023	9.64	8.97	7.0%	117	109	6.9%
2024	9.67	9.00	7.0%	118	110	6.9%
2025	9.79	8.98	8.3%	119	109	8.2%
2026	9.91	8.90	10.2%	121	109	10.1%
2027	9.89	8.84	10.7%	120	108	10.5%
2028	10.0	8.89	11.1%	122	108	10.9%
2029	10.1	8.97	11.2%	123	109	11.1%
2030	10.1	8.94	11.2%	123	109	11.1%

Note:

[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.

Table 5-25 Estimated Fuel Consumption and GHG Emissions over Useful Life of HD Pickups and Vans Produced in Each Model Year for Method A, Relative to Alternative 1a [a]

MODEL YEAR	FUEL CONSUMPTION (B. GAL.) OVER FLEET'S USEFUL LIFE			GHG EMISSIONS (MMT CO_2EQ) OVER FLEET'S USEFUL LIFE		
	No Action	Final	Reduction	No Action	Final	Reduction
2016	10.43	10.43	0.0%	122	122	0.0%
2017	10.37	10.15	2.2%	122	119	2.2%
2018	10.41	10.10	3.0%	122	118	3.1%
2019	10.04	9.55	4.9%	118	112	5.1%
2020	10.03	9.56	4.7%	118	112	4.9%
2021	9.84	9.16	6.9%	115	107	7.1%
2022	9.74	9.01	7.5%	114	105	7.7%
2023	9.71	8.97	7.6%	114	105	7.8%
2024	9.75	9.00	7.6%	114	105	7.8%
2025	9.88	8.97	9.1%	116	105	9.3%
2026	10.00	8.92	10.8%	117	104	11.1%
2027	10.01	8.84	11.7%	117	103	11.9%
2028	10.12	8.89	12.1%	119	104	12.4%
2029	10.22	8.98	12.1%	120	105	12.4%
2030	10.18	8.95	12.2%	119	105	12.4%

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.

To more clearly communicate these trends visually, the following two charts present the above results graphically for Method A, relative to Alternative 1b. As shown, fuel consumption and GHG emissions follow parallel though not precisely identical paths. Though not presented, the charts for Alternative 1a will appear sufficiently similar that differences between Alternative 1a and Alternative 1b remain best communicated by comparing values in the above tables.

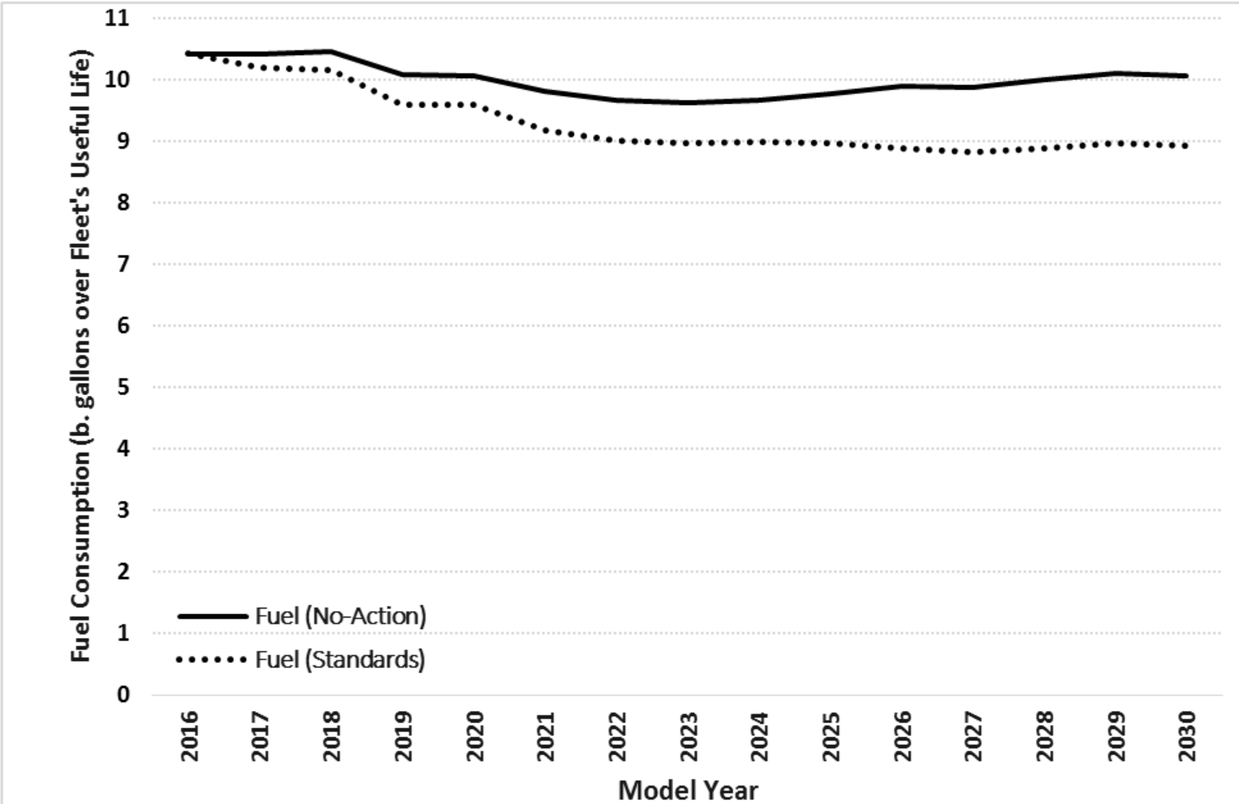

Figure 5-1 Fuel Consumption (b. gal.) over Useful Life of HD Pickups and Vans Produced in Each Model Year for Method A

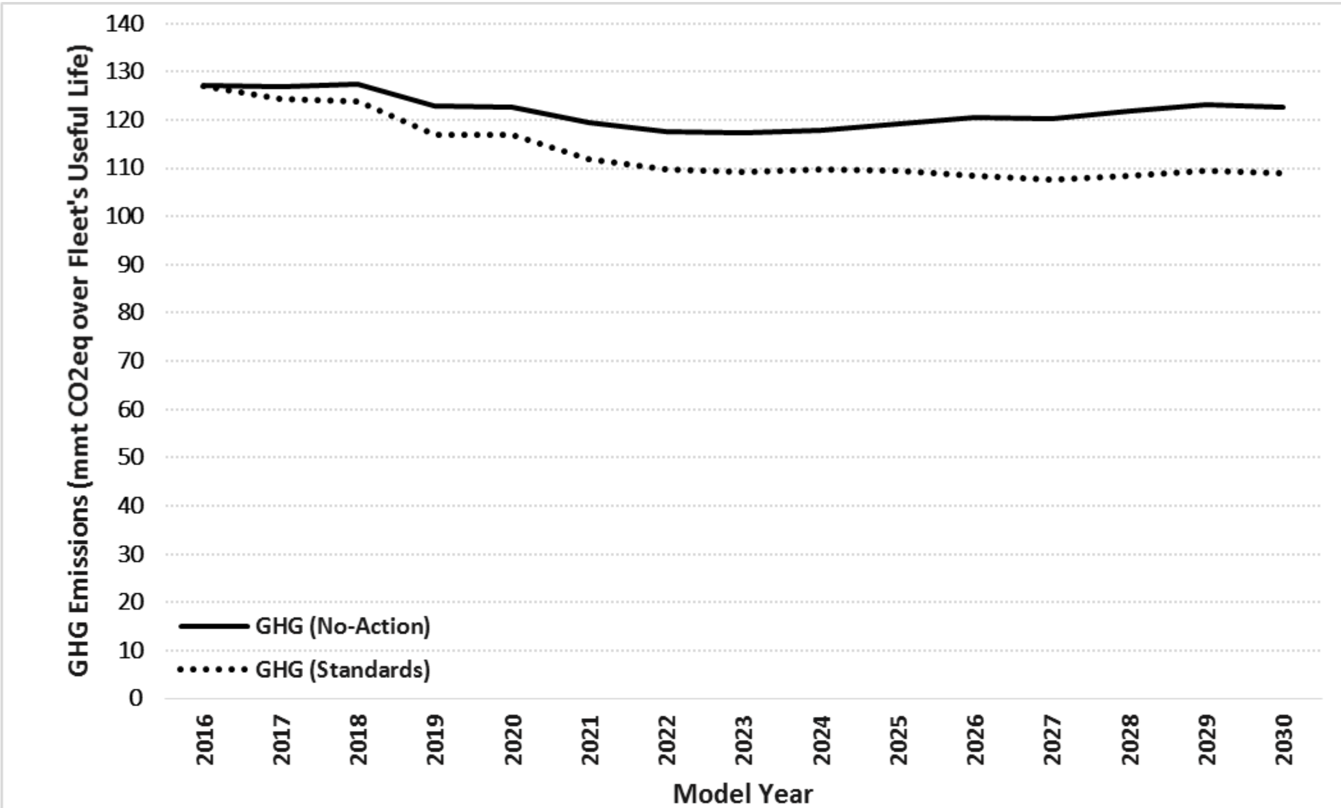

Figure 5-2 GHG Emissions (MMT CO_2eq) over Useful Life of HD Pickups and Vans Produced in Each Model Year for Method A

Table 5-26 Annual Downstream GHG Emissions Impacts in Calendar Years 2025, 2040 and 2050 by Heavy-Duty Vehicle Category – Final Program vs. Alt 1b using Analysis Method A [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)	TOTAL DOWNSTREAM	
					MMT CO_2EQ	% CHANGE
2025	HD Pickups and Vans	-4.3	0.0005	0.001	-4.3	-4.8%
	Vocational	-4.3	0.0001	0	-4.3	-4.1%
	Tractor-Trailers	-17.9	-0.005	0.0006	-17.9	-5.1%
	Total	-26.5	-0.004	0.002	-26.6	-4.9%
2040	HD Pickups and Vans	-9.7	0.002	0.005	-9.7	-10.0%
	Vocational	-18.1	0	0.0003	-18.1	-15.0%
	Tractor-Trailers	-75.5	-0.02	0.001	-75.5	-19.0%
	Total	-103.3	-0.02	0.006	-103.3	-17.0%
2050	HD Pickups and Vans	-10.7	0.002	0.006	-10.7	-11.0%
	Vocational	-21.2	0	0.0003	-21.2	-16.0%
	Tractor-Trailers	-91.9	-0.03	0.001	-91.9	-21.0%
	Total	-123.8	-0.03	0.007	-123.8	-18.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-27 Annual Downstream GHG Emissions Impacts in Calendar Years 2025, 2040 and 2050 by Heavy-Duty Vehicle Category – Final Program vs. Alt 1a using Analysis Method A [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)	TOTAL DOWNSTREAM	
					MMT CO_2EQ	% CHANGE
2025	HD Pickups and Vans	-4.7	0.0005	0.002	-4.7	-5.2%
	Vocational	-4.3	0.0001	0.0001	-4.3	-4.1%
	Tractor-Trailers	-19.9	-0.006	0.0006	-19.9	-5.7%
	Total	-28.9	-0.005	0.003	-28.9	-5.3%
2040	HD Pickups and Vans	-10.6	0.002	0.005	-10.6	-11.2%
	Vocational	-18.1	0	0.0003	-18.1	-14.9%
	Tractor-Trailers	-85.4	-0.02	0.001	-85.4	-21.3%
	Total	-114.1	-0.02	0.006	-114.1	-18.5%
2050	HD Pickups and Vans	-11.7	0.002	0.006	-11.7	-11.7%
	Vocational	-21.2	-0.0001	0.0003	-21.2	-16.1%
	Tractor-Trailers	-104.0	-0.03	0.001	-104.0	-23.0%
	Total	-136.9	-0.03	0.007	-136.9	-20.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-28 Annual Fuel Savings in Calendar Years 2025, 2040 and 2050 by Heavy-Duty Vehicle Category – Final Program vs. Alt 1b using Analysis Method A [a]

CY	VEHICLE CATEGORY	DIESEL		GASOLINE	
		BILLION GALLONS	% SAVINGS	BILLION GALLONS	% SAVINGS
2025	HD Pickups and Vans	0.2	4.0%	0.3	5.5%
	Vocational	0.3	4.1%	0.1	3.8%
	Tractor-Trailers	1.8	5.4%	0	0%
	Total	2.3	4.9%	0.4	5.0%
2040	HD Pickups and Vans	0.3	8.3%	0.7	12.0%
	Vocational	1.5	15.0%	0.3	13.0%
	Tractor-Trailers	7.4	19.0%	0	0%
	Total	9.2	17.8%	1.0	12.2%
2050	HD Pickups and Vans	0.4	8.7%	0.8	13.0%
	Vocational	1.7	17.0%	0.4	13.0%
	Tractor-Trailers	9.0	21.0%	0	0%
	Total	11.1	19.3%	1.2	12.8%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-29 Annual Fuel Savings in Calendar Years 2025, 2040 and 2050 by Heavy-Duty Vehicle Category – Final Program vs. Alt 1a using Analysis Method A [a]

CY	VEHICLE CATEGORY	DIESEL		GASOLINE	
		BILLION GALLONS	% SAVINGS	BILLION GALLONS	% SAVINGS
2025	HD Pickups and Vans	0.2	3.8%	0.4	6.2%
	Vocational	0.3	4.1%	0.1	3.8%
	Tractor-Trailers	1.9	5.7%	0	0%
	Total	2.4	5.2%	0.5	5.5%
2040	HD Pickups and Vans	0.3	8.6%	0.8	13.0%
	Vocational	1.5	15.5%	0.4	12.8%
	Tractor-Trailers	8.4	21.3%	0	0%
	Total	10.2	19.0%	1.2	13.0%
2050	HD Pickups and Vans	0.4	9.0%	0.9	14.0%
	Vocational	1.7	16.7%	0.4	13.5%
	Tractor-Trailers	10.2	23.0%	0	0%
	Total	12.3	21.0%	1.3	14.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

5.4.1.1.1 Upstream Impacts

Table 5-30 Annual Upstream GHG Emissions Impacts in Calendar Years 2025, 2040 and 2050 by Heavy-Duty Vehicle Category – Final Program vs. Alt 1b using Analysis Method A [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)	TOTAL UPSTREAM	
					MMT CO_2EQ	% CHANGE
2025	HD Pickups and Vans	-1.1	-0.2	-0.04	-1.3	-4.8%
	Vocational	-1.3	-0.1	-0.006	-1.4	-4.1%
	Tractor-Trailers	-5.7	-0.6	-0.03	-6.3	-5.1%
	Total	-8.1	-0.9	-0.08	-9.0	-4.9%
2040	HD Pickups and Vans	-2.4	-0.4	-0.1	-2.9	-10.0%
	Vocational	-5.4	-0.6	-0.03	-6.0	-15.0%
	Tractor-Trailers	-24.0	-2.4	-0.1	-26.5	-19.0%
	Total	-31.8	-3.4	-0.2	-35.5	-17.0%
2050	HD Pickups and Vans	-2.6	-0.5	-0.1	-3.2	-11.0%
	Vocational	-6.3	-0.7	-0.03	-7.0	-16.0%
	Tractor-Trailers	-29.2	-3.0	-0.1	-32.3	-21.0%
	Total	-38.1	-4.2	-0.2	-42.5	-19.0%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-31 Annual Upstream GHG Emissions Impacts in Calendar Years 2025, 2040 and 2050 by Heavy-Duty Vehicle Category – Final Program vs. Alt 1a using Analysis Method A [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)	TOTAL UPSTREAM	
					MMT CO_2EQ	% CHANGE
2025	HD Pickups and Vans	-1.1	-0.2	-0.05	-1.4	-5.2%
	Vocational	-1.3	-0.1	-0.01	-1.4	-4.1%
	Tractor-Trailers	-6.3	-0.6	-0.03	-7.0	-5.7%
	Total	-8.7	-0.9	-0.09	-9.8	-5.3%
2040	HD Pickups and Vans	-2.6	-0.5	-0.1	-3.2	-11.0%
	Vocational	-5.4	-0.6	-0.03	-6.0	-15.1%
	Tractor-Trailers	-27.2	-2.8	-0.1	-30.1	-21.3%
	Total	-35.2	-3.9	-0.2	-39.3	-19.0%
2050	HD Pickups and Vans	-2.8	-0.5	-0.1	-3.5	-12.0%
	Vocational	-6.3	-0.7	-0.03	-7.0	-16.3%
	Tractor-Trailers	-33.1	-3.4	-0.2	-36.7	-23.0%
	Total	-42.2	-4.6	-0.3	-47.2	-20.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

5.4.1.1.1 HFC Impacts

The projected HFC emission reductions due to the A/C leakage standards are estimated to be 86,735 metric tons of CO_2eq in 2025, 256,061 metric tons of CO_2eq in 2040, and 314,930 metric tons CO_2eq in 2050.

5.4.1.1.2 Total (Downstream + Upstream + HFC) Impacts

Table 5-32 Annual Total GHG Emissions Impacts in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1b using Analysis Method A [a]

	CY2025		CY2040		CY2050	
	MMT CO_2eq	% Change	MMT CO_2eq	% Change	MMT CO_2eq	% Change
Downstream	-26.6	-4.9%	-103.3	-17.0%	-123.8	-18.0%
Upstream	-9.0	-4.9%	-35.5	-17.0%	-42.5	-19.0%
HFC	-0.1	-15.0%	-0.3	-13.0%	-0.3	-13.0%
Total	-35.7	-4.9%	-139.1	-17.0%	-166.6	-19.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-33 Annual Total GHG Emissions Impacts in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1a using Analysis Method A [a]

	CY2025		CY2040		CY2050	
	MMT CO_2eq	% Change	MMT CO_2eq	% Change	MMT CO_2eq	% Change
Downstream	-28.9	-5.3%	-114.1	-19.0%	-136.9	-20.0%
Upstream	-9.8	-5.3%	-39.3	-19.0%	-47.2	-20.0%
HFC	-0.1	-15.0%	-0.3	-13.0%	-0.3	-13.0%
Total	-38.8	-5.3%	-153.7	-19.0%	-184.4	-20.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

5.4.1.1 Model Year Lifetime Analysis

Table 5-34 Lifetime GHG Reductions and Fuel Savings by Heavy-Duty Vehicle Category – Summary for Model Years 2018-2029 using Analysis Method A [a]

	FINAL PROGRAM (ALTERNATIVE 3)	
NO-ACTION ALTERNATIVE (BASELINE)	1b (Dynamic)	1a (Flat)
Fuel Savings (Billion Gallons)	71.1	77.7
HD Pickups and Vans	9.0	9.8
Vocational	12.4	12.3
Tractor/Trailers	49.7	55.6
Total GHG Reductions (MMT CO_2eq)	958	1,049
HD Pickups and Vans	111	120
Vocational	162	162
Tractor/Trailers	685	767

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.

5.4.2 Impacts of the Final Rules using Analysis Method B

5.4.2.1 Calendar Year Analysis

5.4.2.1.1 Downstream Impacts

After all the MOVES runs and post-processing were completed, the flat reference (Alternative 1a) and control case (Alternative 3) inventories were totaled for all heavy-duty vehicle types and emission processes to estimate total downstream GHG and fuel consumption impacts of the program.

The fuel savings from the final rules were calculated from the estimates of total energy consumption from MOVES using the fuel heating values assumed in the Renewable Fuels Standard rulemaking[N] and in MOVES.[O]

Table 5-35 summarizes these downstream GHG impacts in calendar years 2025, 2040, and 2050, relative to Alternative 1a, for the final program. Table 5-36 shows the estimated fuel savings from the final program in 2025, 2040, and 2050, relative to Alternative 1a. The reductions in CO_2 emissions result from all heavy-duty vehicle categories (including the engines associated with tractor-trailer combinations and vocational vehicles) due to engine and vehicle improvements. N_2O emissions show a very slight increase because of a rebound in vehicle miles traveled (VMT). However, since N_2O is produced as a byproduct of fuel combustion, the increase in N_2O emissions is expected to be more than offset by the improvements in fuel efficiency from the final rules.[P] The methane emissions decrease primarily due to differences in hydrocarbon emission characteristics between on-road diesel engines and APUs. The amount of methane emitted as a fraction of total hydrocarbons is expected to be less for APUs than for diesel engines. Overall, downstream GHG emissions will be reduced significantly. In addition, substantial fuel savings will be achieved from improved fuel efficiency. All emissions impacts reflect the heavy-duty sector only, and do not include emissions from light-duty vehicles or any other vehicle sector.

[N] Renewable Fuels Standards assumptions of 115,000 BTU/gallon gasoline (E0) and 76,330 BTU/gallon ethanol (E100) were weighted 90 percent and 10 percent, respectively, for E10 and 85 percent and 15 percent, respectively, for E15 and converted to kJ at 1.055 kJ/BTU. The conversion factors are 117,245 kJ/gallon for gasoline blended with ten percent ethanol (E10) and 115,205 kJ/gallon for gasoline blended with fifteen percent ethanol (E15).

[O] The conversion factor for diesel is 138,451 kJ/gallon. See MOVES2004 Energy and Emission Inputs. EPA420-P-05-003, March 2005. http://www3.epa.gov/otaq/models/ngm/420p05003.pdf.

[P] MOVES is not capable of modeling the changes in exhaust N_2O emissions from the improvements in fuel efficiency. Due to this limitation, a conservative approach was taken to only model the VMT rebounds in estimating the emissions impact on N_2O from the final rules, resulting in a slight increase in downstream N_2O inventory.

Table 5-35 Annual Downstream GHG Emissions Impacts in Calendar Years 2025, 2040 and 2050 by Heavy-Duty Vehicle Category – Final Program vs. Alt 1a using Analysis Method B [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)	TOTAL DOWNSTREAM	
					MMT CO_2EQ	% CHANGE
2025	HD Pickups and Vans	-3.6	0.0004	0.001	-3.6	-2.5%
	Vocational	-4.3	0.0001	0.0001	-4.3	-4.1%
	Tractor-Trailers	-19.9	-0.006	0.0006	-19.9	-5.7%
	Total	-27.8	-0.005	0.002	-27.8	-4.6%
2040	HD Pickups and Vans	-20.9	0.001	0.002	-20.8	-13.6%
	Vocational	-18.1	0	0.0003	-18.1	-14.9%
	Tractor-Trailers	-85.4	-0.02	0.001	-85.4	-21.3%
	Total	-124.3	-0.02	0.004	-124.3	-18.4%
2050	HD Pickups and Vans	-23.2	0.001	0.003	-23.2	-14.8%
	Vocational	-21.2	-0.0001	0.0003	-21.2	-16.0%
	Tractor-Trailers	-104.0	-0.03	0.001	-104.0	-23.0%
	Total	-148.4	-0.03	0.004	-148.4	-20.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-36 Annual Fuel Savings in Calendar Years 2025, 2040 and 2050 by Heavy-Duty Vehicle Category – Final Program vs. Alt 1a using Analysis Method B [a]

CY	VEHICLE CATEGORY	DIESEL		GASOLINE	
		BILLION GALLONS	% SAVINGS	BILLION GALLONS	% SAVINGS
2025	HD Pickups and Vans	0.2	2.6%	0.2	2.5%
	Vocational	0.3	4.1%	0.1	3.8%
	Tractor-Trailers	1.9	5.7%	0	0%
	Total	2.5	5.0%	0.3	2.8%
2040	HD Pickups and Vans	0.9	13.9%	1.3	13.5%
	Vocational	1.5	15.5%	0.4	12.8%
	Tractor-Trailers	8.4	21.3%	0	0%
	Total	10.8	19.4%	1.7	13.3%
2050	HD Pickups and Vans	1.1	15.0%	1.5	14.7%
	Vocational	1.7	16.7%	0.4	13.5%
	Tractor-Trailers	10.2	23.0%	0	0%
	Total	13.0	21.0%	1.9	14.4%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

5.4.2.1.2 Upstream Impacts

The upstream GHG impacts of final program associated with the production and distribution of gasoline and diesel from crude oil, relative to Alternative 1a, are summarized in Table 5-37, for calendar years 2025, 2040, and 2050. These estimates show impacts for domestic emission reductions only. Additionally, since this rulemaking is not expected to impact biofuel volumes mandated by the Annual Renewable Fuel Standards (RFS) regulations, the impacts on upstream emissions from changes in biofuel feedstock (i.e., agricultural sources such as fertilizer, fugitive dust, and livestock) are not included. In other words, we attribute decreased fuel consumption from this program to petroleum-based fuels only, while assuming no net effect on volumes of renewable fuels. We used this approach because annual renewable fuel volumes are mandated independently from this rulemaking under RFS. As a consequence, it is not possible to conclude whether the decreasing petroleum consumption projected here would increase the fraction of the U.S. fuel supply that is made up by renewable fuels (if RFS volumes remained constant), or whether future renewable fuel volume mandates would decrease in proportion to the decreased petroleum consumption projected here.

As background, EPA sets annual renewable fuel volume mandates through a separate RFS notice-and-comment rulemaking process, and the final volumes are based on EIA projections, EPA's own market assessment, and information obtained from the RFS notice and comment process. Also, RFS standards are nested within each other, which means that a fuel with a higher GHG reduction threshold can be used to meet the standards for a lower GHG reduction threshold. This creates additional uncertainty in projecting this rule's net effect on future annual RFS standards.

In conclusion, the impacts of this rulemaking on annual renewable fuel volume mandates are difficult to project at the present time. However, since it is not centrally relevant to the analysis for this rulemaking, we have not included any impacts on renewable fuel volumes in this analysis. The reductions in upstream GHGs are proportional to the amount of fuel saved.

Table 5-37 Annual Upstream GHG Emissions Impacts in Calendar Years 2025, 2040 and 2050 by Heavy-Duty Vehicle Category – Final Program vs. Alt 1a using Analysis Method B [a]

CY	VEHICLE CATEGORY	CO_2 (MMT)	CH_4 (MMT CO_2EQ)	N_2O (MMT CO_2EQ)	TOTAL UPSTREAM	
					MMT CO_2EQ	% CHANGE
2025	HD Pickups and Vans	-1.0	-0.1	-0.01	-1.1	-2.6%
	Vocational	-1.3	-0.1	-0.01	-1.4	-4.1%
	Tractor-Trailers	-6.3	-0.6	-0.03	-7.0	-5.7%
	Total	-8.6	-0.9	-0.04	-9.5	-4.7%
2040	HD Pickups and Vans	-5.4	-0.7	-0.03	-6.1	-13.7%
	Vocational	-5.4	-0.6	-0.03	-6.0	-15.1%
	Tractor-Trailers	-27.2	-2.8	-0.1	-30.1	-21.3%
	Total	-38.0	-4.0	-0.2	-42.2	-18.7%
2050	HD Pickups and Vans	-6.1	-0.8	-0.03	-6.8	-14.9%
	Vocational	-6.3	-0.7	-0.03	-7.0	-16.3%
	Tractor-Trailers	-33.1	-3.4	-0.2	-36.7	-23.0%
	Total	-45.5	-4.8	-0.2	-50.5	-20.3%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

5.4.2.1.3 HFC Impacts

Based on projected HFC emission reductions due to the AC leakage standards, EPA estimates the HFC reductions to be 86,735 metric tons of CO_2eq in 2025, 256,061 metric tons of CO_2eq in 2040, and 314,930 metric tons CO_2eq in 2050.

5.4.2.1.4 Total (Downstream + Upstream + HFC) Impacts

The combined annual GHG emissions reductions of final program from downstream, upstream, and HFC, relative to Alternative 1a, are summarized in Table 5-38 for calendar years 2025, 2040 and 2050.

Table 5-38 Annual Total GHG Emissions Impacts in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1a using Analysis Method B [a]

	CY2025		CY2040		CY2050	
	MMT CO_2eq	% Change	MMT CO_2eq	% Change	MMT CO_2eq	% Change
Downstream	-27.8	-4.6%	-124.3	-18.4%	-148.4	-20.0%
Upstream	-9.5	-4.7%	-42.2	-18.7%	-50.5	-20.3%
HFC[b]	-0.1	-15.0%	-0.3	-13.0%	-0.3	-13.0%
Total	-37.4	-4.7%	-166.8	-18.5%	-199.2	-20.1%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] HFC represents HFC emission reductions and percent change from the vocational vehicle category only.

Figure 5-3 graphically illustrates the total annual GHG trends for both Phase 1 and Phase 2 rules, using Method B, for calendar years from 2016 to 2050. The flat baseline from Phase 2 rule is assumed to be equivalent to the Phase 1 program.

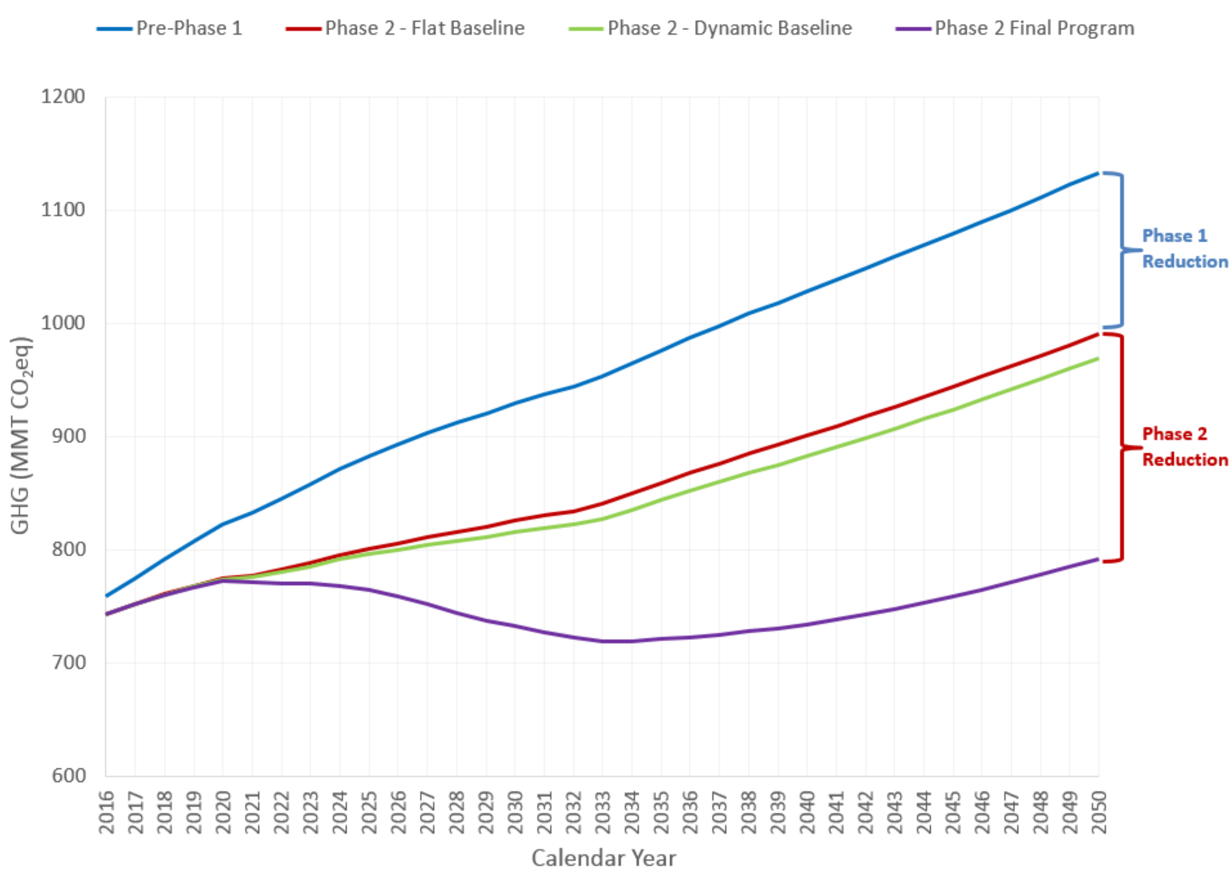

Figure 5-3 Total Annual GHG Trends for Phase 1 and Phase 2 Rule, using Analysis Method B

5.4.2.2 Model Year Lifetime Analysis

In addition to the annual GHG emissions and fuel consumption reductions expected from the final rules, we estimated the combined (downstream and upstream) GHG and fuel consumption impacts over the model year lifetimes of the impacted vehicles sold in the regulatory timeframe. In contrast to the calendar year analysis, the model year lifetime analyses show the impacts of the program on each of these model year fleets over the course of their lifetimes. Table 5-39 shows the fleet-wide GHG reductions and fuel savings from the final rules through the lifetime[Q] of heavy-duty vehicles, relative to Alternative 1a.

Table 5-39 Lifetime GHG Reductions and Fuel Savings by Heavy-Duty Vehicle Category – Summary for Model Years 2018-2029 using Analysis Method B [a]

	FINAL PROGRAM (ALTERNATIVE 3)
NO-ACTION ALTERNATIVE (BASELINE)	1a (Flat)
Fuel Savings (Billion Gallons)	82.2
HD Pickups and Vans	14.3
Vocational	12.3
Tractor/Trailers	55.6
Total GHG Reductions (MMT CO_2eq)	1,097.6
HD Pickups and Vans	169.2
Vocational	161.6
Tractor/Trailers	766.7

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.

Furthermore, the combined lifetime GHG reductions and fuel savings of Phase 1 and Phase 2 programs are presented in Table 5-40. To be consistent with the emissions modeling done for this program, the lifetime GHG reductions and fuel savings from Phase 1 were estimated using the same modeling tools used in the Phase 2 final rulemaking.

[Q] A lifetime of 30 years is assumed in MOVES.

Table 5-40 Combined Lifetime GHG Reductions and Fuel Savings of Phase 1 and Phase 2 Program using Analysis Method B [a]

	TOTAL GHG REDUCTIONS (MMT CO_2EQ)	FUEL SAVINGS (BILLION GALLONS)
Phase 1		
MY 2014-2018	338	26
MY 2019-2029	1,081	84
Phase 2		
MY 2018-2029	1,098	82
Combined Total	2,517	192

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.

5.5 Non-Greenhouse Gas Emission Impacts

The medium- and heavy-duty vehicle standards will influence the emissions of criteria air pollutants and several air toxics. Similar to Chapter 5.4, the following subsections summarize two slightly different analyses of the annual non-GHG emissions reductions expected from the standards. Chapter 5.5.1 shows the impacts of the final rules on non-GHG emissions using the analytical Method A, relative to two different reference cases – flat and dynamic. Chapter 5.5.2 shows the impacts of the standards, relative to the flat reference case only, using the MOVES model for all heavy-duty vehicle categories.

5.5.1 Impacts of the Final Rules using Analysis Method A

5.5.1.1 Calendar Year Analysis

5.5.1.1.1 Downstream Impacts

Table 5-41 Annual Downstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1b using Analysis Method A [a]

POLLUTANT	CY2025		CY2040		CY2050	
	US Short Tons	% Change	US Short Tons	% Change	US Short Tons	% Change
1,3-Butadiene	1	0.5%	4	3.6%	4	3.4%
Acetaldehyde	-1	0%	-16	-0.7%	-19	-0.8%
Acrolein	0.2	0%	-0.3	-0.1%	-1	-0.4%
Benzene	-2	-0.1%	-13	-1.2%	-13	-1.1%
CO	-9,045	-0.6%	-34,702	-2.8%	-42,095	-3.0%
Formaldehyde	-21	-0.3%	-96	-1.6%	-119	-1.8%
NO_X	-12,082	-1.3%	-53,254	-9.1%	-65,068	-9.9%
$PM_{2.5}$	-58	-0.2%	-363	-2.0%	-453	-2.2%
SO_X	-201	-4.1%	-851	-16.0%	-1,028	-17.0%
VOC	-769	-0.8%	-3,436	-5.3%	-4,128	-5.8%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-42 Annual Downstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1a using Analysis Method A [a]

POLLUTANT	CY2025		CY2040		CY2050	
	US Short Tons	% Change	US Short Tons	% Change	US Short Tons	% Change
1,3-Butadiene	1	0.5%	4	3.7%	4	3.5%
Acetaldehyde	-1	0%	-14	-0.7%	-18	-0.8%
Acrolein	0.2	0%	-0.3	-0.1%	-1	-0.4%
Benzene	-2	-0.2%	-13	-1.2%	-14	-1.2%
CO	-8,944	-0.6%	-34,502	-2.8%	-41,880	-3.0%
Formaldehyde	-20	-0.3%	-91	-1.6%	-113	-1.7%
NO_X	-13,368	-1.5%	-60,594	-10.2%	-74,206	-11.0%
$PM_{2.5}$	-78	-0.2%	-473	-2.6%	-591	-2.9%
SO_X	-219	-4.5%	-941	-17.0%	-1,138	-19.0%
VOC	-831	-0.8%	-3,736	-5.8%	-4,499	-6.3%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

5.5.1.1.2 Upstream Impacts

Table 5-43 Annual Upstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1b using Analysis Method A [a]

POLLUTANT	CY2025		CY2040		CY2050	
	US Short Tons	% Change	US Short Tons	% Change	US Short Tons	% Change
1,3-Butadiene	-1	-4.9%	-4	-18.0%	-5	-19.0%
Acetaldehyde	-3	-4.4%	-14	-15.0%	-16	-16.0%
Acrolein	-0.4	-4.6%	-2	-16.0%	-2	-17.0%
Benzene	-23	-4.8%	-88	-16.0%	-105	-18.0%
CO	-3,785	-4.9%	-14,714	-17.0%	-17,629	-19.0%
Formaldehyde	-18	-4.9%	-71	-17.0%	-86	-19.0%
NO_X	-9,255	-4.9%	-35,964	-17.0%	-43,089	-19.0%
$PM_{2.5}$	-975	-4.9%	-3,850	-18.0%	-4,618	-19.0%
SO_X	-5,804	-4.9%	-22,550	-17.0%	-27,019	-19.0%
VOC	-4,419	-4.8%	-14,857	-15.0%	-17,385	-16.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-44 Annual Upstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1a using Analysis Method A [a]

POLLUTANT	CY2025		CY2040		CY2050	
	US Short Tons	% Change	US Short Tons	% Change	US Short Tons	% Change
1,3-Butadiene	-1	-5.3%	-4	-20.0%	-5	-21.0%
Acetaldehyde	-4	-4.6%	-15	-16.0%	-17	-17.0%
Acrolein	-0.4	-4.9%	-2	-17.0%	-2	-18.0%
Benzene	-25	-5.1%	-96	-18.0%	-115	-19.0%
CO	-4,142	-5.4%	-16,298	-19.0%	-19,558	-20.0%
Formaldehyde	-20	-5.3%	-79	-19.0%	-95	-20.0%
NO_X	-10,124	-5.4%	-39,813	-19.0%	-47,779	-20.0%
$PM_{2.5}$	-1,065	-5.3%	-4,258	-19.0%	-5,117	-21.0%
SO_X	-6,349	-5.4%	-24,961	-19.0%	-29,958	-20.0%
VOC	-4,810	-5.2%	-16,218	-16.0%	-19,004	-17.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

5.5.1.1.3 Total Impacts

Table 5-45 Annual Total Impacts (Upstream and Downstream) of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1b using Analysis Method A [a]

POLLUTANT	CY2025		CY2040		CY2050	
	US Short Tons	% Change	US Short Tons	% Change	US Short Tons	% Change
1,3-Butadiene	0.3	0.1%	0.1	0.1%	-0.4	-0.3%
Acetaldehyde	-4	-0.1%	-30	-1.3%	-35	-1.4%
Acrolein	-0.2	0%	-2	-0.7%	-3	-0.9%
Benzene	-25	-1.2%	-101	-6.3%	-118	-6.7%
CO	-12,830	-0.9%	-49,416	-3.7%	-59,724	-4.0%
Formaldehyde	-39	-0.5%	-167	-2.7%	-205	-2.9%
NO_X	-21,337	-2.0%	-89,218	-11.0%	-108,157	-12.0%
$PM_{2.5}$	-1,033	-2.0%	-4,213	-10.0%	-5,071	-11.0%
SO_X	-6,005	-4.9%	-23,401	-17.0%	-28,047	-19.0%
VOC	-5,188	-2.7%	-18,293	-11.0%	-21,513	-12.0%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 5-46 Annual Total Impacts (Upstream and Downstream) of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1a using Analysis Method A [a]

POLLUTANT	CY2025		CY2040		CY2050	
	US Short Tons	% Change	US Short Tons	% Change	US Short Tons	% Change
1,3-Butadiene	0.2	0.1%	-0.2	-0.1%	-1.0	-0.5%
Acetaldehyde	-5	-0.2%	-29	-1.3%	-35	-1.4%
Acrolein	-0.2	0%	-2	-0.7%	-3	-1.0%
Benzene	-27	-1.4%	-109	-6.8%	-129	-7.2%
CO	-13,086	-0.9%	-50,800	-3.8%	-61,438	-4.1%
Formaldehyde	-40	-0.5%	-170	-2.7%	-208	-2.9%
NO_X	-23,492	-2.2%	-100,407	-12.0%	-121,985	-14.0%
$PM_{2.5}$	-1,143	-2.2%	-4,731	-12.0%	-5,708	-13.0%
SO_X	-6,568	-5.3%	-25,902	-19.0%	-31,096	-20.0%
VOC	-5,641	-3.0%	-19,954	-12.0%	-23,503	-13.0%

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

5.5.1.2 Model Year Lifetime Analysis

Table 5-47 Lifetime Non-GHG Reductions by Heavy-Duty Vehicle Category – Summary for Model Years 2018-2029 using Analysis Method A (US Short Tons) [a]

	FINAL PROGRAM (ALTERNATIVE 3)	
NO-ACTION ALTERNATIVE (BASELINE)	1b (Dynamic)	1a (Flat)
NO_X	492,070	545,780
HD Pickups and Vans	23,702	26,297
Vocational	42,621	42,621
Tractor/Trailers	425,747	477,021
$PM_{2.5}$	27,605	30,594
HD Pickups and Vans	2,164	2,385
Vocational	4,436	4,436
Tractor/Trailers	21,005	23,773
SO_X	157,579	172,952
HD Pickups and Vans	17,477	19,214
Vocational	25,082	25,082
Tractor/Trailers	115,020	128,656

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.

5.5.2 Impacts of the Final Rules using Analysis Method B

5.5.2.1 Calendar Year Analysis

5.5.2.1.1 Downstream Impacts

After all the MOVES runs[R] and post-processing were completed, the flat reference (Alternative 1a) and control case (Alternative 3) inventories were aggregated for all vehicle types and emission processes to estimate the total downstream non-GHG impacts of the program. Table 5-48 summarizes these downstream non-GHG impacts of final program for calendar years 2025, 2040 and 2050, relative to Alternative 1a. The results are shown both in changes in absolute tons and in percent reductions from the flat reference to alternatives for the heavy-duty sector.

The agencies expect the Phase 2 program to impact the downstream emissions of non-GHG pollutants. These pollutants include oxides of nitrogen (NO_X), oxides of sulfur (SO_X), volatile organic compounds (VOC), carbon monoxide (CO), fine particulate matter ($PM_{2.5}$), and

[R] For non-GHGs, MOVES was run only for January and July and the annual emissions were extrapolated by scaling up each month by a factor of 5.88 for all pollutants except particulate matter (PM). For PM, to offset the disproportionate effect of the cold temperature on January results, a scaling factor of 4.3 was applied to January and 7.5 to July; these factors were determined based on analysis of annual PM emissions during modeling for the RFS2 rule. Note that for GHGs, MOVES was run for all months.

air toxics. The agencies expect reductions in downstream emissions of NO_X, $PM_{2.5}$, VOC, SO_X, CO, and air toxics. Much of these estimated net reductions are a result of the agencies' anticipation of increased use of auxiliary power units (APUs) in combination tractors during extended idling; APUs emit these pollutants at a lower rate than on-road engines during extended idle operation, with the exception of $PM_{2.5}$. As discussed in Section III.C.3, EPA is adopting Phase 1 and Phase 2 requirements to control $PM_{2.5}$ emissions from APUs installed in new tractors and therefore, eliminate the unintended consequence of increases in $PM_{2.5}$ emissions from increased APU use.

The downstream emission reductions of non-GHG pollutants estimated in the final rulemaking are significantly less than what was estimated for the proposal, mainly because of the changes in projected use of auxiliary power units (APUs) during extended idling. The idle reduction adoption rates were reassessed and projected to be lower (Table 5-14) than what was assumed in the proposal, as described in Section III.D.1.a of the Preamble. Lower penetration of APUs assumed in the final program results in lower downstream reductions of criteria pollutants and air toxics, compared to the proposal.

Furthermore, in response to the public comments received on the proposal, the MOVES emission rates for extended idle were lowered significantly for criteria pollutants based on the analyses of the latest test programs that reflect the current prevalence of clean idle certified engines.[24] For example, the extended idle rate for NO_X was changed from 203 g/hr to 42.6 g/hr for model year 2013 and later. This change resulted in smaller differences between emission rates for extended idle and APUs for all criteria pollutants. Therefore, the emissions benefits of using APUs during extended idle, instead of the main engine, are lower for non-GHGs in the final rulemaking than the proposal.

Additional reductions in tailpipe emissions of NO_X and CO and refueling emissions of VOC will be achieved through improvements in engine efficiency and reduced road load (improved aerodynamics and tire rolling resistance), which reduces the amount of work required to travel a given distance and increases fuel economy.

For vehicle types not affected by road load improvements, such as HD pickups and vans[S], non-GHG emissions will increase very slightly due to VMT rebound. In addition, brake wear and tire wear emissions of $PM_{2.5}$ will also increase very slightly due to VMT rebound. The agencies estimate that downstream emissions of SO_X will be reduced, because they are roughly proportional to fuel consumption.

[S] HD pickups and vans are subject to gram per mile (distance) emissions standards, as opposed to larger heavy-duty vehicles which are certified to a gram per brake horsepower (work) standard.

Table 5-48 Annual Downstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1a using Analysis Method B [a]

POLLUTANT	CY2025		CY2040		CY2050	
	US Short Tons	% Change	US Short Tons	% Change	US Short Tons	% Change
1,3-Butadiene	-1	-0.2%	-3	-1.5%	-3	-1.8%
Acetaldehyde	-3	-0.1%	-18	-0.8%	-23	-0.9%
Acrolein	-0.1	0%	-1	-0.3%	-1	-0.4%
Benzene	-5	-0.2%	-22	-1.4%	-26	-1.6%
CO	-9,445	-0.4%	-35,710	-2.4%	-43,642	-2.7%
Formaldehyde	-20	-0.2%	-97	-1.5%	-120	-1.7%
NO_X	-13,396	-1.4%	-60,681	-9.7%	-74,362	-10.8%
$PM_{2.5}$	-73	-0.2%	-462	-2.2%	-580	-2.5%
SO_X	-252	-4.7%	-1,122	-18.5%	-1,341	-20.1%
VOC	-1,071	-0.8%	-5,060	-5.9%	-6,013	-6.6%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

As noted above, EPA is adopting Phase 1 and Phase 2 requirements to control $PM_{2.5}$ emissions from APUs installed in new tractors. In the NPRM, an unintended increase in downstream $PM_{2.5}$ emissions was projected because engines powering APUs are currently required to meet less stringent PM standards (40 CFR 1039.101) than on-road engines (40 CFR 86.007-11) and because the increase in emissions from APUs more than offset the reduced tailpipe emissions from improved engine efficiency and road load. However, with the new requirements for APUs, the final program is projected to lead to reduced downstream $PM_{2.5}$ emissions of 462 tons in 2040 and 580 tons in 2050 (Table 5-48). As shown in Table 5-49, the net reductions in national $PM_{2.5}$ emissions with further PM control on APUs are 927 tons and 1,114 tons in 2040 and 2050, respectively. For additional details on EPA's PM emission standards for APUs, see Section III.C.3 of the Preamble. The development of APU emission rates with PM control is documented in the memorandum to the docket.[25]

Table 5-49 Projected Impact on $PM_{2.5}$ Emissions of Further $PM_{2.5}$ Control on APUs using Analysis Method B[a]

CY	BASELINE NATIONAL HEAVY-DUTY VEHICLE $PM_{2.5}$ EMISSIONS (TONS)	FINAL HD PHASE 2 PROGRAM NATIONAL $PM_{2.5}$ EMISSIONS WITHOUT FURTHER PM CONTROL (TONS)	FINAL HD PHASE 2 PROGRAM NATIONAL $PM_{2.5}$ EMISSIONS WITH FURTHER PM CONTROL (TONS)	NET IMPACT ON NATIONAL $PM_{2.5}$ EMISSION WITH FURTHER PM CONTROL ON APUS (TONS)
2040	20,939	21,403	20,476	-927
2050	22,995	23,529	22,416	-1,114

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

It is worth noting that the emission reductions shown in Table 5-48 are not incremental to the emissions reductions projected in the Phase 1 rulemaking. This is because the agencies have revised their assumptions about the adoption rate of APUs. This final rule assumes that without the Phase 2 program (i.e., in the Phase 2 baselines), the APU adoption rate will be 9 percent for model years 2010 and later, which is lower than the value used in both the Phase 1 control case and Phase 2 proposal. This decision was based on the agencies' assessment of how the current level of automatic engine shutdown and idle reduction technologies are used by the tractor manufacturers to comply with the 2014 model year CO_2 and fuel consumption standards. To date, the manufacturers are meeting the 2014 model year standards without the use of this technology. Compared to Phase 1, the final program projects lower and much delayed penetration of APUs (including both diesel- and battery-powered) and other idle reduction technologies starting in model year 2021 (Figure 5-4).

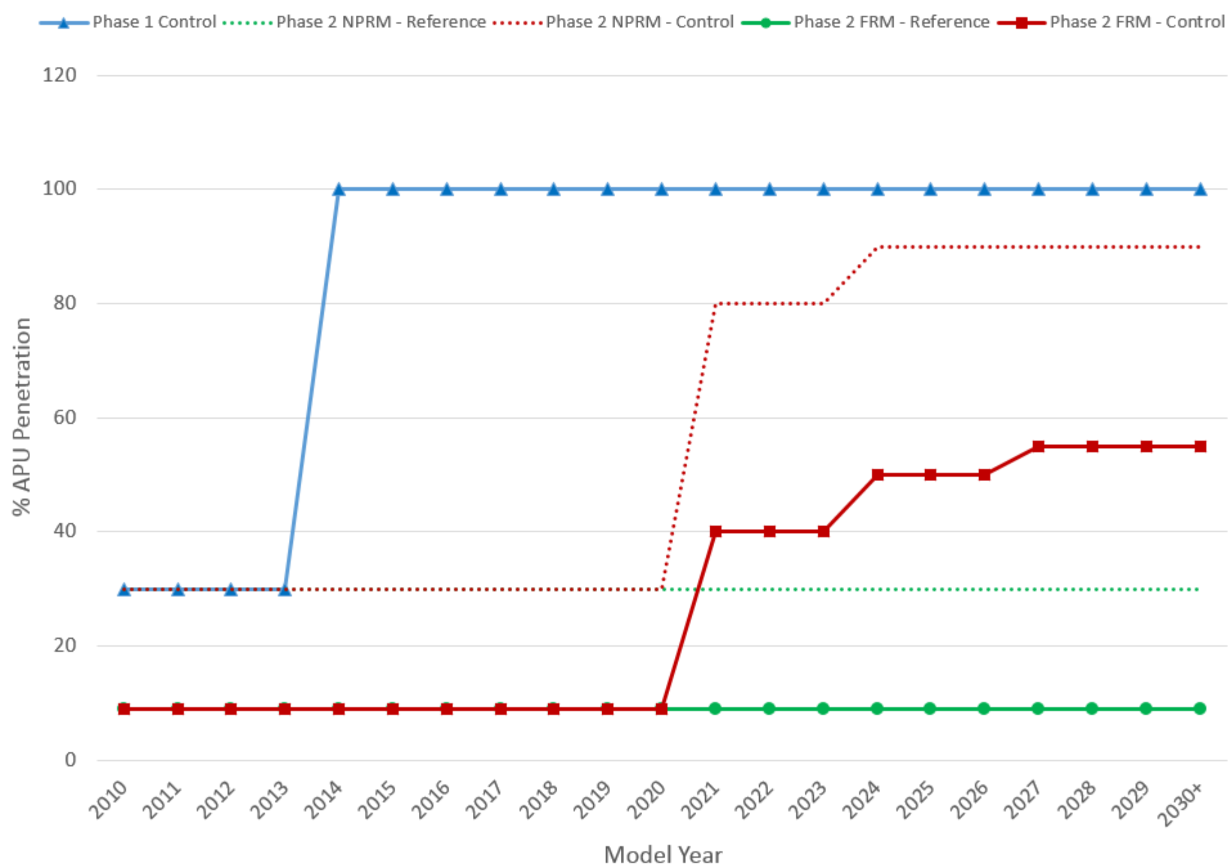

Figure 5-4 Comparison of Assumed Diesel and Battery-Powered APU Use during Extended Idle in Phase 1 and Phase 2

Considering the change in assumptions about APU use and the magnitude of impact of APUs on criteria emissions, and the revised extended idle rates, EPA conducted an analysis estimating the combined impacts of the Phase 1 and Phase 2 programs on downstream emissions for NO_X, VOC, SO_X and $PM_{2.5}$ in calendar year 2050. The analysis estimated the combined Phase 1 and Phase 2 emissions impacts by comparing the Phase 2 control case inventories to the Phase 1 reference case inventories. To be consistent with the emissions modeling done for this program, the emissions inventories for Phase 1 reference case were estimated using the same version of MOVES used for the Phase 2 final rulemaking.[T] The results are shown in Table 5-50. The differences in downstream reduction estimates between Phase 2 alone (Table 5-48) and combined Phase 1 and Phase 2 (Table 5-50) reflect the improvements in road loads from Phase 1. For NO_X and $PM_{2.5}$ only, we also estimated the combined Phase 1 and Phase 2 downstream and upstream emissions impacts for calendar year 2025, and project that the two rules combined will reduce NO_X by up to 55,000 tons and $PM_{2.5}$ by up to 33,000 tons in that year.

Table 5-50 Combined Phase 1 and Phase 2 Annual Downstream Emissions Impacts in Calendar Year 2050 using Analysis Method B [a]

CY	NO_X	VOC	SO_X	$PM_{2.5}$ [b]
2050	-100,878	-10,067	-2,249	-1,001

Notes:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

5.5.2.1.2 Upstream Impacts

The final program is projected to reduce the upstream emissions associated with fuel production and distribution because the projected fuel savings of the program will reduce the demands for gasoline and diesel. Table 5-51 summarizes the annual upstream reductions of the final program for criteria pollutants and individual air toxic pollutants in calendar years 2025, 2040 and 2050, relative to Alternative 1a. The results are shown both in changes in absolute tons and in percent reductions from the flat baseline for the heavy-duty sector.

Table 5-51 Annual Upstream Impacts of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1a using Analysis Method B [a]

POLLUTANT	CY2025		CY2040		CY2050	
	US Short Tons	% Change	US Short Tons	% Change	US Short Tons	% Change
1,3-Butadiene	-1	-4.8%	-5	-19.0%	-6	-20.6%
Acetaldehyde	-7	-3.2%	-35	-14.5%	-38	-15.9%
Acrolein	-1	-3.5%	-3	-15.2%	-4	-16.7%
Benzene	-30	-3.8%	-143	-16.1%	-166	-17.6%
CO	-3,809	-4.8%	-16,884	-18.9%	-20,227	-20.5%
Formaldehyde	-20	-4.6%	-90	-18.3%	-107	-19.9%
NO_X	-9,314	-4.8%	-41,280	-18.9%	-49,462	-20.5%
$PM_{2.5}$	-1,037	-4.7%	-4,619	-18.7%	-5,520	-20.3%
SO_X	-5,828	-4.8%	-25,811	-18.9%	-30,941	-20.5%
VOC	-4,234	-3.7%	-20,010	-15.9%	-23,240	-17.4%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[T] The emissions modeling for Phase 1 was performed using MOVES2010a.

5.5.2.1.3 Total Impacts

As shown in Table 5-52, the agencies estimate that this program will result in overall net reductions of NO_X, VOC, SO_X, CO, $PM_{2.5}$, and air toxics emissions. The results are shown both in changes in absolute tons and in percent reductions from the flat baseline for the heavy-duty sector.

Table 5-52 Annual Total Impacts (Upstream and Downstream) of Heavy-Duty Non-GHG Emissions in Calendar Years 2025, 2040 and 2050 – Final Program vs. Alt 1a using Analysis Method B [a]

POLLUTANT	CY2025		CY2040		CY2050	
	US Short Tons	% Change	US Short Tons	% Change	US Short Tons	% Change
1,3-Butadiene	-2	-0.5%	-8	-3.7%	-9	-4.1%
Acetaldehyde	-10	-0.3%	-53	-2.0%	-61	-2.1%
Acrolein	-1	-0.1%	-4	-1.3%	-5	-1.3%
Benzene	-35	-1.1%	-165	-6.8%	-192	-7.5%
CO	-13,254	-0.6%	-52,594	-3.3%	-63,869	-3.8%
Formaldehyde	-40	-0.5%	-187	-2.7%	-227	-2.9%
NO_X	-22,710	-1.9%	-101,961	-12.1%	-123,824	-13.3%
$PM_{2.5}$	-1,110	-1.9%	-5,081	-11.1%	-6,100	-12.1%
SO_X	-6,080	-4.8%	-26,933	-18.9%	-32,282	-20.5%
VOC	-5,305	-2.2%	-25,070	-11.9%	-29,253	-13.0%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

5.5.2.2 Model Year Lifetime Analysis

In addition to the annual non-GHG emissions reductions expected from the final program, the combined (downstream and upstream) non-GHG impacts for the lifetime of the impacted vehicles were estimated by heavy-duty vehicle category. Table 5-53 shows the fleet-wide reductions of NO_X, $PM_{2.5}$ and SO_X from the final program, relative to Alternative 1a, through the lifetime[U] of heavy-duty vehicles.

[U] A lifetime of 30 years is assumed in MOVES.

Table 5-53 Lifetime Non-GHG Reductions by Heavy-Duty Vehicle Category – Summary for Model Years 2018-2029 using Analysis Method B (US Short Tons) [a]

	FINAL PROGRAM (ALTERNATIVE 3)
NO-ACTION ALTERNATIVE (BASELINE)	1a (Flat)
NO_X	549,881
HD Pickups and Vans	30,239
Vocational	42,621
Tractor/Trailers	477,021
$PM_{2.5}$	32,251
HD Pickups and Vans	4,042
Vocational	4,436
Tractor/Trailers	23,773
SO_X	175,202
HD Pickups and Vans	21,464
Vocational	25,082
Tractor/Trailers	128,656

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.

5.5.2.3 Comparison between Emission Inventories for Air Quality Modeling and Final Rule Inventories

Emissions and air quality modeling decisions are made early in the analytical process because of the time and resources associated with full-scale photochemical air quality modeling. As a result, it was necessary to use emissions from the proposed program to conduct the air quality modeling for this action. The air quality inventories and the final inventories are consistent in many ways but exhibit several important differences, as illustrated by the comparison presented in Table 5-54. The final program emission reductions shown in the table reflect updates to underlying assumptions, modeling inputs, and program standards, but the largest differences between these inventories and the air quality modeling inventories can be specifically attributed to changes in our assumptions about APU use and additional requirements to control $PM_{2.5}$ emissions from APUs. For example, as described in Preamble Section III.C.3, EPA is adopting Phase 1 and Phase requirements to control $PM_{2.5}$ emissions from APUs installed in new tractors, so we do not expect increases in downstream $PM_{2.5}$ emissions from the Phase 2 program; however, the air quality inventories do not reflect these requirements for APUs, and therefore show increases in downstream $PM_{2.5}$ emissions. Assumptions about the penetration of APUs also differ between the air quality inventories and the final rule inventories; as shown in Figure 5-4, the air quality (proposal) inventories assumed more widespread penetration of APUs than was assumed for the final program (see Chapter 5.3.2.3.1.1 of this RIA and Preamble Section III.D.1.a for more detail on the APU assumptions).

Furthermore, because of the differences in methodology between the national inventories and air quality inventories, particularly the treatment of local variables, such as vehicle populations, VMT, age distributions, vehicle speed distributions, and the handling of the temperature effects in MOVES, the more detailed approach used for the air quality inventory produced different emission estimates than those described in the national inventory section above.

Table 5-54 Emissions Reductions from the AQ Inventory and the Final Program Inventory

		AQ INVENTORY	FINAL PROGRAM INVENTORY
NO_X	Downstream	-244,904	-60,681
	Upstream	-9,871	-41,280
	Total	**-254,785**	**-101,961**
$PM_{2.5}$	Downstream	1,674	-462
	Upstream	-2,202	-4,619
	Total	**-528**	**-5,082**
VOC	Downstream	-29,207	-5,060
	Upstream	-11,297	-20,010
	Total	**-40,504**	**-25,071**
SO_X	Downstream	-891	-1,122
	Upstream	-8,972	-25,811
	Total	**-9,863**	**-26,933**

References

[1] Intergovernmental Panel on Climate Change Working Group I. 2007. Climate Change 2007 – The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

[2] U.S. EPA. 2015. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013. EPA 430-R-15-003. Available at http://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Main-Text.pdf

[3] U.S. EPA. 2009. Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases under section 202(a) of the Clean Air Act. Washington, DC. pp. 180-194. Available at https://www3.epa.gov/climatechange/Downloads/endangerment/Endangerment_TSD.pdf

[4] MOVES homepage: https://www3.epa.gov/otaq/models/moves/index.htm.

[5] Argonne National Laboratory. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model versions 1.8.c. http://greet.es.anl.gov/files/372dv49w.

[6] 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4)

[7] Annual Energy Outlook 2015. http://www.eia.gov/forecasts/archive/aeo15/.

[8] U.S. EPA. Updates to MOVES for Emissions Analysis of Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2 FRM. Docket No. EPA-HQ-OAR-2016 July, 2016.

[9] Memorandum to the Docket "Runspecs, Model Inputs, MOVES Code and Database for HD GHG Phase 2 FRM Emissions Modeling" Docket No. EPA-HQ-OAR-2016. July, 2016.

[10] U.S. EPA. Regulatory Impact Analysis: Changes to Renewable Fuel Standard Program. Chapters 2 and 3. May 26, 2009. Docket No. EPA-HQ-OAR-2009-0472-0119.

[11] 2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards (77 FR 62623, October 15, 2012).

[12] Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles (76 FR 57106, September 15, 2011).

[13] Memorandum to the Docket "Upstream Emissions Modeling Files for HDGHG Phase 2 FRM" Docket No. EPA-HQ-OAR-2016. July, 2016.

[14] U.S. EPA. 2015. "Exhaust Emission Rates for Heavy-Duty On-road Vehicles in MOVES2014" EPA-420-R-15-015a.

[15] Memorandum to the Docket "FRM - Tractor-Trailer Inputs to MOVES" Docket No. EPA-HQ-OAR-2016. July, 2016.

[16] ACT Research Co., LLC. U.S. Trailers Monthly Market Indicators. Available at www.actresearch.net/reports Accessed 7/28/2014.

[17] U.S. Census Bureau. 2002 Vehicle Inventory and Use Survey. Available at https://www.census.gov/svsd/www/vius/2002.html Accessed 6/30/2014.

[18] Memorandum to the Docket "FRM - Vocational Inputs to MOVES" Docket No. EPA-HQ-OAR-2016. July, 2016.

[19] Memorandum to the Docket "VMT Rebound Inputs to MOVES for HD GHG Phase 2 FRM" Docket No. EPA-HQ-OAR-2016. July, 2016.

[20] Craig Harvey, EPA, "Calculation of Upstream Emissions for the GHG Vehicle Rule." 2009. Docket No. EPA-HQ-OAR-2009-0472-0216.

[21] The Minnesota refrigerant leakage data: https://www.pca.state.mn.us/quick-links/climate-change-mobile-air-conditioners.

[22] Eastern Research Group. "A Study of R134a Leaks in Heavy Duty Vehicles." CARB Contract 06-342. Presented during CARB Seminar on January 6, 2011.

[23] Memorandum to the Docket "Emission Inventories for Air Quality Modeling Technical Support Document" Docket No. EPA-HQ-OAR-2016. July, 2016.

Chapter 6: Health and Environmental Impacts

6.1 Health and Environmental Effects of Non-GHG Pollutants

6.1.1 Health Effects Associated with Exposure to Non-GHG Pollutants

Along with reducing GHGs, the Phase 2 standards also have an impact on non-GHG (criteria and air toxic pollutant) emissions. As discussed in Chapter 5, the standards will impact exhaust emissions of these pollutants from vehicles and will also impact emissions that occur during the refining and distribution of fuel (upstream sources).

In this section we will discuss the health effects associated with non-GHG pollutants, specifically: particulate matter, ozone, nitrogen oxides (NO_X), sulfur oxides (SO_X), carbon monoxide and air toxics. These pollutants will not be directly regulated by the standards, but the standards will affect emissions of these pollutants and precursors.

6.1.1.1 Particulate Matter

6.1.1.1.1 *Background on Particulate Matter*

Particulate matter (PM) is a highly complex mixture of solid particles and liquid droplets distributed among numerous atmospheric gases which interact with solid and liquid phases. Particles range in size from those smaller than 1 nanometer (10^{-9} meter) to over 100 micrometers (µm, or 10^{-6} meter) in diameter (for reference, a typical strand of human hair is 70 µm in diameter and a grain of salt is about 100 µm). Atmospheric particles can be grouped into several classes according to their aerodynamic and physical sizes. Generally, the three broad classes of particles include ultrafine particles (UFPs, generally considered as particulates with a diameter less than or equal to 0.1 µm [typically based on physical size, thermal diffusivity or electrical mobility]), "fine" particles ($PM_{2.5}$; particles with a nominal mean aerodynamic diameter less than or equal to 2.5 µm), and "thoracic" particles (PM_{10}; particles with a nominal mean aerodynamic diameter less than or equal to 10 µm). Particles that fall within the size range between $PM_{2.5}$ and PM_{10}, are referred to as "thoracic coarse particles" ($PM_{10-2.5}$, particles with a nominal mean aerodynamic diameter less than or equal to 10 µm and greater than 2.5 µm). EPA currently has standards that regulate $PM_{2.5}$ and PM_{10}.[A]

Particles span many sizes and shapes and may consist of hundreds of different chemicals. Particles are emitted directly from sources and are also formed through atmospheric chemical reactions; the former are often referred to as "primary" particles, and the latter as "secondary" particles. Particle concentration and composition varies by time of year and location, and, in addition to differences in source emissions, is affected by several weather-related factors, such as temperature, clouds, humidity, and wind. A further layer of complexity comes from particles'

[A] Regulatory definitions of PM size fractions, and information on reference and equivalent methods for measuring PM in ambient air, are provided in 40 CFR Parts 50, 53, and 58. With regard to national ambient air quality standards (NAAQS) which provide protection against health and welfare effects, the 24-hour PM_{10} standard provides protection against effects associated with short-term exposure to thoracic coarse particles (i.e., $PM_{10-2.5}$).

ability to shift between solid/liquid and gaseous phases, which is influenced by concentration and meteorology, especially temperature.

Fine particles are produced primarily by combustion processes and by transformations of gaseous emissions (e.g., sulfur oxides (SO_X), nitrogen oxides (NO_X) and volatile organic compounds (VOCs)) in the atmosphere. The chemical and physical properties of $PM_{2.5}$ may vary greatly with time, region, meteorology, and source category. Thus, $PM_{2.5}$ may include a complex mixture of different components including sulfates, nitrates, organic compounds, elemental carbon and metal compounds. These particles can remain in the atmosphere for days to weeks and travel through the atmosphere hundreds to thousands of kilometers.[1]

6.1.1.1.2 *Health Effects of Particulate Matter*

Scientific studies show exposure to ambient PM is associated with a broad range of health effects. These health effects are discussed in detail in the Integrated Science Assessment for Particulate Matter (PM ISA), which was finalized in December 2009.[2] The PM ISA summarizes health effects evidence for short- and long-term exposures to $PM_{2.5}$, $PM_{10-2.5}$, and ultrafine particles.[B] The PM ISA concludes that human exposures to ambient $PM_{2.5}$ are associated with a number of adverse health effects and characterizes the weight of evidence for broad health categories (e.g., cardiovascular effects, respiratory effects, etc.).[C] The discussion below highlights the PM ISA's conclusions pertaining to health effects associated with both short- and long-term PM exposures. Further discussion of health effects associated with PM can also be found in the rulemaking documents for the most recent review of the PM NAAQS completed in 2012.[3,4]

EPA has concluded that "a causal relationship exists" between both long- and short-term exposures to $PM_{2.5}$ and premature mortality and cardiovascular effects and that "a causal relationship is likely to exist" between long- and short-term $PM_{2.5}$ exposures and respiratory effects. Further, there is evidence "suggestive of a causal relationship" between long-term $PM_{2.5}$ exposures and other health effects, including developmental and reproductive effects (e.g., low birth weight, infant mortality) and carcinogenic, mutagenic, and genotoxic effects (e.g., lung cancer mortality).[D]

As summarized in the Final PM NAAQS rule, and discussed extensively in the 2009 PM ISA, the available scientific evidence significantly strengthens the link between long- and short-

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[B] The ISA also evaluated evidence for PM components, but did not reach causal determinations for components.

[C] The causal framework draws upon the assessment and integration of evidence from across epidemiological, controlled human exposure, and toxicological studies, and the related uncertainties that ultimately influence our understanding of the evidence. This framework employs a five-level hierarchy that classifies the overall weight of evidence and causality using the following categorizations: causal relationship, likely to be causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship (U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, Table 1–3).

[D] These causal inferences are based not only on the more expansive epidemiological evidence available in this review of the PM NAAQS but also reflect consideration of important progress that has been made to advance understanding of a number of potential biologic modes of action or pathways for PM-related cardiovascular and respiratory effects (U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, Chapter 5).

term exposure to $PM_{2.5}$ and premature mortality, while providing indications that the magnitude of the $PM_{2.5}$- mortality association with long-term exposures may be larger than previously estimated.[5,6] The strongest evidence comes from recent studies investigating long-term exposure to $PM_{2.5}$ and cardiovascular-related mortality. The evidence supporting a causal relationship between long-term $PM_{2.5}$ exposure and mortality also includes consideration of studies that demonstrated an improvement in community health following reductions in ambient fine particles.[7]

Several studies evaluated in the 2009 PM ISA have examined the association between cardiovascular effects and long-term $PM_{2.5}$ exposures in multi-city studies conducted in the U.S. and Europe. These studies have provided new evidence linking long-term exposure to $PM_{2.5}$ with an array of cardiovascular effects such as heart attacks, congestive heart failure, stroke, and mortality. This evidence is coherent with studies of short-term exposure to $PM_{2.5}$ that have observed associations with a continuum of effects ranging from subtle changes in indicators of cardiovascular health to serious clinical events, such as increased hospitalizations and emergency department visits due to cardiovascular disease and cardiovascular mortality.[8]

As detailed in the 2009 PM ISA, extended analyses of seminal epidemiological studies, as well as more recent epidemiological studies conducted in the U.S. and abroad, provide strong evidence of respiratory-related morbidity effects associated with long-term $PM_{2.5}$ exposure. The strongest evidence for respiratory-related effects is from studies that evaluated decrements in lung function growth (in children), increased respiratory symptoms, and asthma development. The strongest evidence from short-term $PM_{2.5}$ exposure studies has been observed for increased respiratory-related emergency department visits and hospital admissions for chronic obstructive pulmonary disease (COPD) and respiratory infections.[9]

The body of scientific evidence detailed in the 2009 PM ISA is still limited with respect to associations between long-term $PM_{2.5}$ exposures and developmental and reproductive effects as well as cancer, mutagenic, and genotoxic effects. The strongest evidence for an association between $PM_{2.5}$ and developmental and reproductive effects comes from epidemiological studies of low birth weight and infant mortality, especially due to respiratory causes during the post-neonatal period (i.e., 1 month to 12 months of age). With regard to cancer effects, ‘‘[m]ultiple epidemiologic studies have shown a consistent positive association between $PM_{2.5}$ and lung cancer mortality, but studies have generally not reported associations between $PM_{2.5}$ and lung cancer incidence.’’[10,11]

In addition to evaluating the health effects attributed to short- and long-term exposure to $PM_{2.5}$, the 2009 PM ISA also evaluated whether specific components or sources of $PM_{2.5}$ are more strongly associated with specific health effects. An evaluation of those studies resulted in the 2009 PM ISA concluding that “many [components] of PM can be linked with differing health effects and the evidence is not yet sufficient to allow differentiation of those [components] or sources that are more closely related to specific health outcomes.”[12]

For $PM_{10-2.5}$, the 2009 PM ISA concluded that available evidence was “suggestive of a causal relationship” between short-term exposures to $PM_{10-2.5}$ and cardiovascular effects (e.g., hospital admissions and ED visits, changes in cardiovascular function), respiratory effects (e.g., ED visits and hospital admissions, increase in markers of pulmonary inflammation), and premature mortality. The scientific evidence was "inadequate to infer a causal relationship" between long-term exposure to $PM_{10-2.5}$ and various health effects.[13,14,15]

For UFPs, the 2009 PM ISA concluded that the evidence was "suggestive of a causal relationship" between short-term exposures and cardiovascular effects, including changes in heart rhythm and vasomotor function (the ability of blood vessels to expand and contract). It also concluded that there was evidence "suggestive of a causal relationship" between short-term exposure to UFPs and respiratory effects, including lung function and pulmonary inflammation, with limited and inconsistent evidence for increases in ED visits and hospital admissions. Scientific evidence was "inadequate to infer a causal relationship" between short-term exposure to UFPs and additional health effects including premature mortality as well as long-term exposure to UFPs and all health outcomes evaluated.[16,17]

The 2009 PM ISA conducted an evaluation of specific groups within the general population potentially at increased risk for experiencing adverse health effects related to PM exposures.[18,19,20,21] The evidence detailed in the 2009 PM ISA expands our understanding of previously identified at-risk populations and lifestages (i.e., children, older adults, and individuals with pre-existing heart and lung disease) and supports the identification of additional at-risk populations (e.g., persons with lower socioeconomic status, genetic differences). Additionally, there is emerging, though still limited, evidence for additional potentially at-risk populations and lifestages, such as those with diabetes, people who are obese, pregnant women, and the developing fetus.[22]

6.1.1.2 Ozone

6.1.1.2.1 *Background on Ozone*

Ground-level ozone pollution is typically formed through reactions involving VOCs and NO_X in the lower atmosphere in the presence of sunlight. These pollutants, often referred to as ozone precursors, are emitted by many types of pollution sources such as highway and nonroad motor vehicles and engines, power plants, chemical plants, refineries, makers of consumer and commercial products, industrial facilities, and smaller area sources.

The science of ozone formation, transport, and accumulation is complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions, many of which are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and result in more ozone than typically occurs on a single high-temperature day. Ozone and its precursors can be transported hundreds of miles downwind of precursor emissions, resulting in elevated ozone levels even in areas with low VOC or NO_X emissions.

The highest levels of ozone are produced when both VOC and NO_X emissions are present in significant quantities on clear summer days. Relatively small amounts of NO_X enable ozone to form rapidly when VOC levels are relatively high, but ozone production is quickly limited by removal of the NO_X. Under these conditions NO_X reductions are highly effective in reducing ozone while VOC reductions have little effect. Such conditions are called "NO_X-limited." Because the contribution of VOC emissions from biogenic (natural) sources to local ambient ozone concentrations can be significant, even some areas where man-made VOC emissions are relatively low can be NO_X-limited.

Ozone concentrations in an area also can be lowered by the reaction of nitric oxide (NO) with ozone, forming nitrogen dioxide (NO_2). As the air moves downwind and the cycle continues, the NO_2 forms additional ozone. The importance of this reaction depends, in part, on the relative concentrations of NO_X, VOC, and ozone, all of which change with time and location. When NO_X levels are relatively high and VOC levels relatively low, NO_X forms inorganic nitrates (i.e., particles) but relatively little ozone. Such conditions are called "VOC-limited." Under these conditions, VOC reductions are effective in reducing ozone, but NO_X reductions can actually increase local ozone under certain circumstances. Even in VOC-limited urban areas, NO_X reductions are not expected to increase ozone levels if the NO_X reductions are sufficiently large. Rural areas are usually NO_X-limited, due to the relatively large amounts of biogenic VOC emissions in such areas. Urban areas can be either VOC- or NO_X-limited, or a mixture of both, in which ozone levels exhibit moderate sensitivity to changes in either pollutant.

6.1.1.2.2 *Health Effects of Ozone*

This section provides a summary of the health effects associated with exposure to ambient concentrations of ozone.[E] The information in this section is based on the information and conclusions in the February 2013 Integrated Science Assessment for Ozone (Ozone ISA).[23] The Ozone ISA concludes that human exposures to ambient concentrations of ozone are associated with a number of adverse health effects and characterizes the weight of evidence for these health effects.[F] The discussion below highlights the Ozone ISA's conclusions pertaining to health effects associated with both short-term and long-term periods of exposure to ozone.

For short-term exposure to ozone, the Ozone ISA concludes that respiratory effects, including lung function decrements, pulmonary inflammation, exacerbation of asthma, respiratory-related hospital admissions, and mortality, are causally associated with ozone exposure. It also concludes that cardiovascular effects, including decreased cardiac function and increased vascular disease, and total mortality are likely to be causally associated with short-term exposure to ozone and that evidence is suggestive of a causal relationship between central nervous system effects and short-term exposure to ozone.

For long-term exposure to ozone, the Ozone ISA concludes that respiratory effects, including new onset asthma, pulmonary inflammation and injury, are likely to be causally related with ozone exposure. The Ozone ISA characterizes the evidence as suggestive of a causal relationship for associations between long-term ozone exposure and cardiovascular effects, reproductive and developmental effects, central nervous system effects and total mortality. The

[E] Human exposure to ozone varies over time due to changes in ambient ozone concentration and because people move between locations which have notable different ozone concentrations. Also, the amount of ozone delivered to the lung is not only influenced by the ambient concentrations but also by the breathing route and rate.

[F] The ISA evaluates evidence and draws conclusions on the causal relationship between relevant pollutant exposures and health effects, assigning one of five "weight of evidence" determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For more information on these levels of evidence, please refer to Table II in the Preamble of the ISA.

evidence is inadequate to infer a causal relationship between chronic ozone exposure and increased risk of lung cancer.

Finally, interindividual variation in human responses to ozone exposure can result in some groups being at increased risk for detrimental effects in response to exposure. In addition, some groups are at increased risk of exposure due to their activities, such as outdoor workers and children. The Ozone ISA identified several groups that are at increased risk for ozone-related health effects. These groups are people with asthma, children and older adults, individuals with reduced intake of certain nutrients (i.e., Vitamins C and E), outdoor workers, and individuals having certain genetic variants related to oxidative metabolism or inflammation. Ozone exposure during childhood can have lasting effects through adulthood. Such effects include altered function of the respiratory and immune systems. Children absorb higher doses (normalized to lung surface area) of ambient ozone, compared to adults, due to their increased time spent outdoors, higher ventilation rates relative to body size, and a tendency to breathe a greater fraction of air through the mouth. Children also have a higher asthma prevalence compared to adults. Additional children's vulnerability and susceptibility factors are listed in Section XIV of the Preamble.

6.1.1.3 Nitrogen Oxides

6.1.1.3.1 *Background on Nitrogen Oxides*

Oxides of nitrogen (NO_X) refers to nitric oxide (NO) and nitrogen dioxide (NO_2). For the NO_X NAAQS, NO_2 is the indicator. Most NO_2 is formed in the air through the oxidation of nitric oxide (NO) emitted when fuel is burned at a high temperature. NO_X is also a major contributor to secondary $PM_{2.5}$ formation. The health effects of ambient PM are discussed in Chapter 6.1.1.1.2. NO_X along with VOCs are the two major precursors of ozone. The health effects of ozone are covered in Chapter 6.1.1.2.2.

6.1.1.3.2 *Health Effects of Nitrogen Oxides*

The most recent review of the health effects of oxides of nitrogen completed by EPA can be found in the 2016 Integrated Science Assessment for Oxides of Nitrogen - Health Criteria (Oxides of Nitrogen ISA).[G] The primary source of NO_2 is motor vehicle emissions, and ambient NO_2 concentrations tend to be highly correlated with other traffic-related pollutants. Thus, a key issue in characterizing the causality of NO_2-health effect relationships was evaluating the extent to which studies supported an effect of NO_2 that is independent of other traffic-related pollutants. EPA concluded that the findings for asthma exacerbation integrated from epidemiologic and controlled human exposure studies provided evidence that is sufficient to infer a causal relationship between respiratory effects and short-term NO_2 exposure. The strongest evidence supporting an independent effect of NO_2 exposure comes from controlled human exposure studies demonstrating increased airway responsiveness in individuals with asthma following ambient-relevant NO_2 exposures. The coherence of this evidence with epidemiologic findings for asthma hospital admissions and ED visits as well as lung function

[G] U.S. EPA. Integrated Science Assessment for Oxides of Nitrogen – Health Criteria (2016 Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/068, 2016.

decrements and increased pulmonary inflammation in children with asthma describe a plausible pathway by which NO_2 exposure can cause an asthma exacerbation. The 2016 ISA for Oxides of Nitrogen also concluded that there is likely to be a causal relationship between long-term NO_2 exposure and respiratory effects. This conclusion is based on new epidemiologic evidence for associations of NO_2 with asthma development in children combined with biological plausibility from experimental studies.

In evaluating a broader range of health effects, the 2016 ISA for Oxides of Nitrogen concluded evidence is "suggestive of, but not sufficient to infer, a causal relationship" between short-term NO_2 exposure and cardiovascular effects and mortality and between long-term NO_2 exposure and cardiovascular effects and diabetes, birth outcomes, and cancer. In addition, the scientific evidence is inadequate (insufficient consistency of epidemiologic and toxicological evidence) to infer a causal relationship for long-term NO_2 exposure with fertility, reproduction, and pregnancy, as well as with postnatal development. A key uncertainty in understanding the relationship between these non-respiratory health effects and short- or long-term exposure to NO_2 is co-pollutant confounding, particularly by other roadway pollutants. The available evidence for non-respiratory health effects does not adequately address whether NO_2 has an independent effect or whether it primarily represents effects related to other or a mixture of traffic-related pollutants.

The 2016 ISA for Oxides of Nitrogen concluded that people with asthma, children, and older adults are at increased risk for NO_2-related health effects. In these groups and lifestages, NO_2 is consistently related to larger effects on outcomes related to asthma exacerbation, for which there is confidence in the relationship with NO_2 exposure.

6.1.1.4 Sulfur Oxides

6.1.1.4.1 *Background*

Sulfur dioxide (SO_2), a member of the sulfur oxide (SO_X) family of gases, is formed from burning fuels containing sulfur (e.g., coal or oil), extracting gasoline from oil, or extracting metals from ore. SO_2 and its gas phase oxidation products can dissolve in water droplets and further oxidize to form sulfuric acid which reacts with ammonia to form sulfates, which are important components of ambient PM. The health effects of ambient PM are discussed in Chapter 6.1.1.1.2.

6.1.1.4.2 *Health Effects of Sulfur Oxides*

This section provides an overview of the health effects associated with SO_2. Additional information on the health effects of SO_2 can be found in the 2008 Integrated Science Assessment for Sulfur Oxides – Health Criteria (SO_X ISA).[24] Following an extensive evaluation of health evidence from epidemiologic and laboratory studies, EPA has concluded that there is a causal relationship between respiratory health effects and short-term exposure to SO_2. The immediate effect of SO_2 on the respiratory system in humans is bronchoconstriction. Asthmatics are more sensitive to the effects of SO_2 likely resulting from preexisting inflammation associated with this disease. In addition to those with asthma (both children and adults), potentially at-risk groups include all children and the elderly. In free-breathing laboratory studies involving controlled human exposures to SO_2, respiratory effects have consistently been observed following 5-10 min exposures at SO_2 concentrations ≥ 400 ppb in asthmatics engaged in moderate to heavy levels of exercise, with respiratory effects occurring at concentrations as low as 200 ppb in some asthmatics. A clear concentration-response relationship has been demonstrated in these studies following exposures to SO_2 at concentrations between 200 and 1000 ppb, both in terms of increasing severity of respiratory symptoms and decrements in lung function, as well as the percentage of asthmatics adversely affected.

In epidemiologic studies, respiratory effects have been observed in areas where the mean 24-hour SO_2 levels range from 1 to 30 ppb, with maximum 1 to 24-hour average SO_2 values ranging from 12 to 75 ppb. Important new multicity studies and several other studies have found an association between 24-hour average ambient SO_2 concentrations and respiratory symptoms in children, particularly those with asthma. Generally consistent associations also have been observed between ambient SO_2 concentrations and emergency department visits and hospitalizations for all respiratory causes, particularly among children and older adults (≥ 65 years), and for asthma. A limited subset of epidemiologic studies has examined potential confounding by co-pollutants using multipollutant regression models. These analyses indicate that although co-pollutant adjustment has varying degrees of influence on the SO_2 effect estimates, the effect of SO_2 on respiratory health outcomes appears to be generally robust and independent of the effects of gaseous and particulate co-pollutants, suggesting that the observed effects of SO_2 on respiratory endpoints occur independent of the effects of other ambient air pollutants.

Consistent associations between short-term exposure to SO_2 and mortality have been observed in epidemiologic studies, with larger effect estimates reported for respiratory mortality than for cardiovascular mortality. While this finding is consistent with the demonstrated effects of SO_2 on respiratory morbidity, uncertainty remains with respect to the interpretation of these observed mortality associations due to potential confounding by various co-pollutants. Therefore, EPA has concluded that the overall evidence is suggestive of a causal relationship between short-term exposure to SO_2 and mortality. Significant associations between short-term exposure to SO_2 and emergency department visits and hospital admissions for cardiovascular diseases have also been reported. However, these findings have been inconsistent across studies and do not provide adequate evidence to infer a causal relationship between SO_2 exposure and cardiovascular morbidity.

6.1.1.5 Carbon Monoxide

6.1.1.5.1 *Background*

Carbon monoxide (CO) is a colorless, odorless gas emitted from combustion processes. Nationally, particularly in urban areas, the majority of CO emissions to ambient air come from mobile sources.[25]

6.1.1.5.2 *Health Effects of Carbon Monoxide*

Information on the health effects of carbon monoxide (CO) can be found in the January 2010 Integrated Science Assessment for Carbon Monoxide (CO ISA).[26] The CO ISA presents conclusions regarding the presence of causal relationships between CO exposure and categories of adverse health effects.[H] This section provides a summary of the health effects associated with exposure to ambient concentrations of CO, along with the ISA conclusions.[I]

Controlled human exposure studies of subjects with coronary artery disease show a decrease in the time to onset of exercise-induced angina (chest pain) and electrocardiogram changes following CO exposure. In addition, epidemiologic studies observed associations between short-term CO exposure and cardiovascular morbidity, particularly increased emergency room visits and hospital admissions for coronary heart disease (including ischemic heart disease, myocardial infarction, and angina). Some epidemiologic evidence is also available for increased hospital admissions and emergency room visits for congestive heart failure and cardiovascular disease as a whole. The CO ISA concludes that a causal relationship is likely to exist between short-term exposures to CO and cardiovascular morbidity. It also concludes that available data are inadequate to conclude that a causal relationship exists between long-term exposures to CO and cardiovascular morbidity.

Animal studies show various neurological effects with in-utero CO exposure. Controlled human exposure studies report central nervous system and behavioral effects following low-level CO exposures, although the findings have not been consistent across all studies. The CO ISA concludes the evidence is suggestive of a causal relationship with both short- and long-term exposure to CO and central nervous system effects.

A number of studies cited in the CO ISA have evaluated the role of CO exposure in birth outcomes such as preterm birth or cardiac birth defects. There is limited epidemiologic evidence of a CO-induced effect on preterm births and birth defects, with weak evidence for a decrease in birth weight. Animal toxicological studies have found perinatal CO exposure to affect birth weight, as well as other developmental outcomes. The CO ISA concludes the evidence is suggestive of a causal relationship between long-term exposures to CO and developmental effects and birth outcomes.

Epidemiologic studies provide evidence of associations between short-term CO concentrations and respiratory morbidity such as changes in pulmonary function, respiratory symptoms, and hospital admissions. A limited number of epidemiologic studies considered co-pollutants such as ozone, SO_2, and PM in two-pollutant models and found that CO risk estimates were generally robust, although this limited evidence makes it difficult to disentangle effects attributed to CO itself from those of the larger complex air pollution mixture. Controlled human exposure studies have not extensively evaluated the effect of CO on respiratory morbidity. Animal studies at levels of 50-100 ppm CO show preliminary evidence of altered pulmonary vascular remodeling and oxidative injury. The CO ISA concludes that the evidence is suggestive of a causal relationship between short-term CO exposure and respiratory morbidity, and

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[H] The ISA evaluates the health evidence associated with different health effects, assigning one of five "weight of evidence" determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For definitions of these levels of evidence, please refer to Section 1.6 of the ISA.

[I] Personal exposure includes contributions from many sources, and in many different environments. Total personal exposure to CO includes both ambient and non-ambient components; and both components may contribute to adverse health effects.

inadequate to conclude that a causal relationship exists between long-term exposure and respiratory morbidity.

Finally, the CO ISA concludes that the epidemiologic evidence is suggestive of a causal relationship between short-term concentrations of CO and mortality. Epidemiologic evidence suggests an association exists between short-term exposure to CO and mortality, but limited evidence is available to evaluate cause-specific mortality outcomes associated with CO exposure. In addition, the attenuation of CO risk estimates which was often observed in co-pollutant models contributes to the uncertainty as to whether CO is acting alone or as an indicator for other combustion-related pollutants. The CO ISA also concludes that there is not likely to be a causal relationship between relevant long-term exposures to CO and mortality.

6.1.1.6 Diesel Exhaust

6.1.1.6.1 *Background on Diesel Exhaust*

Diesel exhaust consists of a complex mixture composed of particulate matter, carbon dioxide, oxygen, nitrogen, water vapor, carbon monoxide, nitrogen compounds, sulfur compounds and numerous low-molecular-weight hydrocarbons. A number of these gaseous hydrocarbon components are individually known to be toxic, including aldehydes, benzene and 1,3-butadiene. The diesel particulate matter present in diesel exhaust consists mostly of fine particles (< 2.5 µm), of which a significant fraction is ultrafine particles (< 0.1 µm). These particles have a large surface area which makes them an excellent medium for adsorbing organics and their small size makes them highly respirable. Many of the organic compounds present in the gases and on the particles, such as polycyclic organic matter, are individually known to have mutagenic and carcinogenic properties.

Diesel exhaust varies significantly in chemical composition and particle sizes between different engine types (heavy-duty, light-duty), engine operating conditions (idle, acceleration, deceleration), and fuel formulations (high/low sulfur fuel). Also, there are emissions differences between on-road and nonroad engines because the nonroad engines are generally of older technology. After being emitted in the engine exhaust, diesel exhaust undergoes dilution as well as chemical and physical changes in the atmosphere. The lifetime for some of the compounds present in diesel exhaust ranges from hours to days.

6.1.1.6.2 *Health Effects of Diesel Exhaust*

In EPA's 2002 Diesel Health Assessment Document (Diesel HAD), exposure to diesel exhaust was classified as likely to be carcinogenic to humans by inhalation from environmental exposures, in accordance with the revised draft 1996/1999 EPA cancer guidelines.[27,28] A number of other agencies (National Institute for Occupational Safety and Health, the International Agency for Research on Cancer, the World Health Organization, California EPA, and the U.S. Department of Health and Human Services) had made similar hazard classifications prior to 2002. EPA also concluded in the 2002 Diesel HAD that it was not possible to calculate a cancer unit risk for diesel exhaust due to limitations in the exposure data for the occupational groups or the absence of a dose-response relationship.

In the absence of a cancer unit risk, the Diesel HAD sought to provide additional insight into the significance of the diesel exhaust cancer hazard by estimating possible ranges of risk that might be present in the population. An exploratory analysis was used to characterize a range of possible lung cancer risk. The outcome was that environmental risks of cancer from long-term diesel exhaust exposures could plausibly range from as low as 10^{-5} to as high as 10^{-3}. Because of uncertainties, the analysis acknowledged that the risks could be lower than 10^{-5}, and a zero risk from diesel exhaust exposure could not be ruled out.

Noncancer health effects of acute and chronic exposure to diesel exhaust emissions are also of concern to EPA. EPA derived a diesel exhaust reference concentration (RfC) from consideration of four well-conducted chronic rat inhalation studies showing adverse pulmonary effects. The RfC is 5 $\mu g/m^3$ for diesel exhaust measured as diesel particulate matter. This RfC does not consider allergenic effects such as those associated with asthma or immunologic or the potential for cardiac effects. There was emerging evidence in 2002, discussed in the Diesel HAD, that exposure to diesel exhaust can exacerbate these effects, but the exposure-response data were lacking at that time to derive an RfC based on these then-emerging considerations. The EPA Diesel HAD states, “With [diesel particulate matter] being a ubiquitous component of ambient PM, there is an uncertainty about the adequacy of the existing [diesel exhaust] noncancer database to identify all of the pertinent [diesel exhaust]-caused noncancer health hazards.” The Diesel HAD also notes “that acute exposure to [diesel exhaust] has been associated with irritation of the eye, nose, and throat, respiratory symptoms (cough and phlegm), and neurophysiological symptoms such as headache, lightheadedness, nausea, vomiting, and numbness or tingling of the extremities.” The Diesel HAD noted that the cancer and noncancer hazard conclusions applied to the general use of diesel engines then on the market and as cleaner engines replace a substantial number of existing ones, the applicability of the conclusions would need to be reevaluated.

It is important to note that the Diesel HAD also briefly summarizes health effects associated with ambient PM and discusses EPA’s then-annual $PM_{2.5}$ NAAQS of 15 $\mu g/m^3$. In 2012, EPA revised the annual $PM_{2.5}$ NAAQS to 12 $\mu g/m^3$. There is a large and extensive body of human data showing a wide spectrum of adverse health effects associated with exposure to ambient PM, of which diesel exhaust is an important component. The $PM_{2.5}$ NAAQS is designed to provide protection from the noncancer health effects and premature mortality attributed to exposure to $PM_{2.5}$. The contribution of diesel PM to total ambient PM varies in different regions of the country and also, within a region, from one area to another. The contribution can be high in near-roadway environments, for example, or in other locations where diesel engine use is concentrated.

Since 2002, several new studies have been published which continue to report increased lung cancer risk with occupational exposure to diesel exhaust from older engines. Of particular note since 2011 are three new epidemiology studies which have examined lung cancer in occupational populations, for example, truck drivers, underground nonmetal miners and other diesel motor-related occupations. These studies reported increased risk of lung cancer with exposure to diesel exhaust with evidence of positive exposure-response relationships to varying degrees.[29,30,31] These newer studies (along with others that have appeared in the scientific literature) add to the evidence EPA evaluated in the 2002 Diesel HAD and further reinforces the concern that diesel exhaust exposure likely poses a lung cancer hazard. The findings from these newer studies do not necessarily apply to newer technology diesel engines since the newer engines have large reductions in the emission constituents compared to older technology diesel engines.

In light of the growing body of scientific literature evaluating the health effects of exposure to diesel exhaust, in June 2012 the World Health Organization's International Agency for Research on Cancer (IARC), a recognized international authority on the carcinogenic potential of chemicals and other agents, evaluated the full range of cancer-related health effects data for diesel engine exhaust. IARC concluded that diesel exhaust should be regarded as "carcinogenic to humans."[32] This designation was an update from its 1988 evaluation that considered the evidence to be indicative of a "probable human carcinogen."

6.1.1.7 Air Toxics

Heavy-duty vehicle emissions contribute to ambient levels of air toxics that are known or suspected human or animal carcinogens, or that have noncancer health effects. The population experiences an elevated risk of cancer and other noncancer health effects from exposure to the class of pollutants known collectively as "air toxics."[33] These compounds include, but are not limited to, benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, polycyclic organic matter, and naphthalene. These compounds were identified as national or regional risk drivers or contributors in the 2011 National-scale Air Toxics Assessment and have significant inventory contributions from mobile sources.[34]

6.1.1.7.1 *Health Effects of Benzene*

EPA's IRIS database lists benzene as a known human carcinogen (causing leukemia) by all routes of exposure, and concludes that exposure is associated with additional health effects, including genetic changes in both humans and animals and increased proliferation of bone marrow cells in mice.[35,36,37] EPA states in its IRIS database that data indicate a causal relationship between benzene exposure and acute lymphocytic leukemia and suggest a relationship between benzene exposure and chronic non-lymphocytic leukemia and chronic lymphocytic leukemia. EPA's IRIS documentation for benzene also lists a range of 2.2×10^{-6} to 7.8×10^{-6} per $\mu g/m^3$ as the unit risk estimate (URE) for benzene.[J,38] The International Agency for Research on Cancer (IARC) has determined that benzene is a human carcinogen and the U.S. Department of Health and Human Services (DHHS) has characterized benzene as a known human carcinogen.[39,40]

A number of adverse noncancer health effects including blood disorders, such as preleukemia and aplastic anemia, have also been associated with long-term exposure to benzene.[41,42] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.[43,44] EPA's inhalation reference concentration (RfC) for benzene is 30 $\mu g/m^3$. The RfC is based on suppressed absolute lymphocyte counts seen in humans under occupational exposure conditions. In addition, recent work, including studies sponsored by the Health Effects Institute (HEI), provides evidence that

[J] A unit risk estimate is defined as the increase in the lifetime risk of an individual who is exposed for a lifetime to 1 µg/m3 benzene in air.

biochemical responses are occurring at lower levels of benzene exposure than previously known.[45,46,47,48] EPA's IRIS program has not yet evaluated these new data. EPA does not currently have an acute reference concentration for benzene. The Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Level (MRL) for acute exposure to benzene is 29 $\mu g/m^3$ for 1-14 days exposure.[49,K]

6.1.1.7.2 *Health Effects of 1,3-Butadiene*

EPA has characterized 1,3-butadiene as carcinogenic to humans by inhalation.[50,51] The IARC has determined that 1,3-butadiene is a human carcinogen and the U.S. DHHS has characterized 1,3-butadiene as a known human carcinogen.[52,53,54] There are numerous studies consistently demonstrating that 1,3-butadiene is metabolized into genotoxic metabolites by experimental animals and humans. The specific mechanisms of 1,3-butadiene-induced carcinogenesis are unknown; however, the scientific evidence strongly suggests that the carcinogenic effects are mediated by genotoxic metabolites. Animal data suggest that females may be more sensitive than males for cancer effects associated with 1,3-butadiene exposure; there are insufficient data in humans from which to draw conclusions about sensitive subpopulations. The URE for 1,3-butadiene is 3×10^{-5} per $\mu g/m^3$.[55] 1,3-butadiene also causes a variety of reproductive and developmental effects in mice; no human data on these effects are available. The most sensitive effect was ovarian atrophy observed in a lifetime bioassay of female mice.[56] Based on this critical effect and the benchmark concentration methodology, an RfC for chronic health effects was calculated at 0.9 ppb (approximately 2 $\mu g/m^3$).

6.1.1.7.3 *Health Effects of Formaldehyde*

In 1991, EPA concluded that formaldehyde is a carcinogen based on nasal tumors in animal bioassays.[57] An Inhalation URE for cancer and a Reference Dose for oral noncancer effects were developed by the agency and posted on the Integrated Risk Information System (IRIS) database. Since that time, the National Toxicology Program (NTP) and International Agency for Research on Cancer (IARC) have concluded that formaldehyde is a known human carcinogen.[58,59,60]

The conclusions by IARC and NTP reflect the results of epidemiologic research published since 1991 in combination with previous animal, human and mechanistic evidence. Research conducted by the National Cancer Institute reported an increased risk of nasopharyngeal cancer and specific lymphohematopoietic malignancies among workers exposed to formaldehyde.[61,62,63] A National Institute of Occupational Safety and Health study of garment workers also reported increased risk of death due to leukemia among workers exposed to formaldehyde.[64] Extended follow-up of a cohort of British chemical workers did not report evidence of an increase in nasopharyngeal or lymphohematopoietic cancers, but a continuing statistically significant excess in lung cancers was reported.[65] Finally, a study of embalmers reported formaldehyde exposures to be associated with an increased risk of myeloid leukemia but not brain cancer.[66]

[K] A minimal risk level (MRL) is defined as an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure.

Health effects of formaldehyde in addition to cancer were reviewed by the Agency for Toxics Substances and Disease Registry in 1999[67], supplemented in 2010,[68] and by the World Health Organization.[69] These organizations reviewed the scientific literature concerning health effects linked to formaldehyde exposure to evaluate hazards and dose response relationships and defined exposure concentrations for minimal risk levels (MRLs). The health endpoints reviewed included sensory irritation of eyes and respiratory tract, reduced pulmonary function, nasal histopathology, and immune system effects. In addition, research on reproductive and developmental effects and neurological effects were discussed along with several studies that suggest that formaldehyde may increase the risk of asthma – particularly in the young.

EPA released a draft Toxicological Review of Formaldehyde – Inhalation Assessment through the IRIS program for peer review by the National Research Council (NRC) and public comment in June 2010.[70] The draft assessment reviewed more recent research from animal and human studies on cancer and other health effects. The NRC released their review report in April 2011[71] (http://www.nap.edu/catalog.php?record_id=13142). EPA is currently developing a revised draft assessment in response to this review.

6.1.1.7.4 *Health Effects of Acetaldehyde*

Acetaldehyde is classified in EPA's IRIS database as a probable human carcinogen, based on nasal tumors in rats, and is considered toxic by the inhalation, oral, and intravenous routes.[72] The URE in IRIS for acetaldehyde is 2.2×10^{-6} per $\mu g/m^3$.[73] Acetaldehyde is reasonably anticipated to be a human carcinogen by the U.S. DHHS in the 13th Report on Carcinogens and is classified as possibly carcinogenic to humans (Group 2B) by the IARC.[74,75] EPA is currently conducting a reassessment of cancer risk from inhalation exposure to acetaldehyde. Acetaldehyde is currently listed on the IRIS Program Multi-Year Agenda for reassessment within the next few years.

The primary noncancer effects of exposure to acetaldehyde vapors include irritation of the eyes, skin, and respiratory tract.[76] In short-term (4 week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure.[77,78] Data from these studies were used by EPA to develop an inhalation reference concentration of 9 $\mu g/m^3$. Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume (FEV1 test) and bronchoconstriction upon acetaldehyde inhalation.[79]

6.1.1.7.5 *Health Effects of Acrolein*

EPA most recently evaluated the toxicological and health effects literature related to acrolein in 2003 and concluded that the human carcinogenic potential of acrolein could not be determined because the available data were inadequate. No information was available on the carcinogenic effects of acrolein in humans and the animal data provided inadequate evidence of carcinogenicity.[80] The IARC determined in 1995 that acrolein was not classifiable as to its carcinogenicity in humans.[81]

Lesions to the lungs and upper respiratory tract of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein.[82] The agency has developed an RfC for acrolein of 0.02 µg/m^3 and an RfD of 0.5 µg/kg-day.[83]

Acrolein is extremely acrid and irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion and congestion. The intense irritancy of this carbonyl has been demonstrated during controlled tests in human subjects, who suffer intolerable eye and nasal mucosal sensory reactions within minutes of exposure.[84] These data and additional studies regarding acute effects of human exposure to acrolein are summarized in EPA's 2003 Toxicological Review of Acrolein.[85] Studies in humans indicate that levels as low as 0.09 ppm (0.21 mg/m^3) for five minutes may elicit subjective complaints of eye irritation with increasing concentrations leading to more extensive eye, nose and respiratory symptoms. Acute exposures in animal studies report bronchial hyper-responsiveness. Based on animal data (more pronounced respiratory irritancy in mice with allergic airway disease in comparison to non-diseased mice[86]) and demonstration of similar effects in humans (e.g., reduction in respiratory rate), individuals with compromised respiratory function (e.g., emphysema, asthma) are expected to be at increased risk of developing adverse responses to strong respiratory irritants such as acrolein. EPA does not currently have an acute reference concentration for acrolein. The available health effect reference values for acrolein have been summarized by EPA and include an ATSDR MRL for acute exposure to acrolein of 7 µg/m^3 for 1-14 days exposure; and Reference Exposure Level (REL) values from the California Office of Environmental Health Hazard Assessment (OEHHA) for one-hour and 8-hour exposures of 2.5 µg/m^3 and 0.7 µg/m^3, respectively.[87]

6.1.1.7.6 *Health Effects of Polycyclic Organic Matter (POM)*

The term polycyclic organic matter (POM) defines a broad class of compounds that includes the polycyclic aromatic hydrocarbon compounds (PAHs). One of these compounds, naphthalene, is discussed separately below. POM compounds are formed primarily from combustion and are present in the atmosphere in gas and particulate form. Cancer is the major concern from exposure to POM. Epidemiologic studies have reported an increase in lung cancer in humans exposed to diesel exhaust, coke oven emissions, roofing tar emissions, and cigarette smoke; all of these mixtures contain POM compounds.[88][89] Animal studies have reported respiratory tract tumors from inhalation exposure to benzo[a]pyrene and alimentary tract and liver tumors from oral exposure to benzo[a]pyrene.[90] In 1997 EPA classified seven PAHs (benzo[a]pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, dibenz[a,h]anthracene, and indeno[1,2,3-cd]pyrene) as Group B2, probable human carcinogens.[91] Since that time, studies have found that maternal exposures to PAHs in a population of pregnant women were associated with several adverse birth outcomes, including low birth weight and reduced length at birth, as well as impaired cognitive development in preschool children (3 years of age).[92,93] These and similar studies are being evaluated as a part of the ongoing IRIS reassessment of health effects associated with exposure to benzo[a]pyrene.

6.1.1.7.7 *Health Effects of Naphthalene*

Naphthalene is found in small quantities in gasoline and diesel fuels. Naphthalene emissions have been measured in larger quantities in both gasoline and diesel exhaust compared with evaporative emissions from mobile sources, indicating it is primarily a product of combustion. Acute (short-term) exposure of humans to naphthalene by inhalation, ingestion, or dermal contact is associated with hemolytic anemia and damage to the liver and the nervous system.[94] Chronic (long term) exposure of workers and rodents to naphthalene has been reported to cause cataracts and retinal damage.[95] EPA released an external review draft of a reassessment of the inhalation carcinogenicity of naphthalene based on a number of recent animal carcinogenicity studies.[96] The draft reassessment completed external peer review.[97] Based on external peer review comments received, a revised draft assessment that considers all routes of exposure, as well as cancer and noncancer effects, is under development. The external review draft does not represent official agency opinion and was released solely for the purposes of external peer review and public comment. The National Toxicology Program listed naphthalene as "reasonably anticipated to be a human carcinogen" in 2004 on the basis of bioassays reporting clear evidence of carcinogenicity in rats and some evidence of carcinogenicity in mice.[98] California EPA has released a new risk assessment for naphthalene, and the IARC has reevaluated naphthalene and re-classified it as Group 2B: possibly carcinogenic to humans.[99]

Naphthalene also causes a number of chronic non-cancer effects in animals, including abnormal cell changes and growth in respiratory and nasal tissues.[100] The current EPA IRIS assessment includes noncancer data on hyperplasia and metaplasia in nasal tissue that form the basis of the inhalation RfC of 3 μg/m^3.[101] The ATSDR MRL for acute exposure to naphthalene is 0.6 mg/kg/day.

6.1.1.7.8 *Health Effects of Other Air Toxics*

In addition to the compounds described above, other compounds in gaseous hydrocarbon and PM emissions from vehicles will be affected by the rules. Mobile source air toxic compounds that would potentially be impacted include ethylbenzene, propionaldehyde, toluene, and xylene. Information regarding the health effects of these compounds can be found in EPA's IRIS database.[102]

6.1.1.8 Exposure and Health Effects Associated with Traffic

In addition to health concerns resulting from specific air pollutants, a large number of studies have examined the health status of populations near major roadways. These studies frequently have employed exposure metrics that are not specific to individual pollutants, but rather reflect the large number of different pollutants found in elevation near major roads.

In this section of the RIA, information on health effects associated with air quality near major roads or traffic in general is summarized. Generally, the section makes use of publications that systematically review literature on a given health topic. In particular, this section makes frequent reference of a report of by the Health Effects Institute (HEI) Panel on the Health Effects of Traffic-Related Air Pollution, published in 2010 as a review of relevant studies.[L,103] Other systematic reviews of relevant literature are cited were appropriate.

[L] It should be noted that there are no peer reviewed EPA-authored reviews of traffic-related health studies. The HEI panel primarily used epidemiology studies for inferring whether there was sufficient evidence of a causal association

6.1.1.8.1 *Populations near Major Roads*

Numerous studies have estimated the size and demographics of populations that live near major roads. Other studies have estimated the number of schools near major roads, and the populations of students in such schools.

Every two years, the U.S. Census Bureau's American Housing Survey (AHS) has reported whether housing units are within 300 feet of an "airport, railroad, or highway with four or more lanes." The 2009 survey reports that over 22 million homes, or 17 percent of all housing units in the U.S., were located in such areas. Assuming that populations and housing units are in the same locations, this corresponds to a population of more than 50 million U.S. residents in close proximity to high-traffic roadways or other transportation sources. According to the Central Intelligence Agency's World Factbook, in 2010, the United States had 6,506,204 km or roadways, 224,792 km of railways, and 15,079 airports. As such, highways represent the overwhelming majority of transportation facilities described by this factor in the AHS.

The AHS reports are published every two years, and until 2011 recorded whether homes were located near highways with four or more lanes, railroads, or airports. As such, trends in the AHS can be reported to describe whether a greater or lesser proportion of homes are located near major roads over time. Figure 6-1 depicts trends in the number and proportion of homes located near major transportation sources, which generally indicate large roadways. As the figure indicates, since 2005, there has been a substantial increase in the number and percentage of homes located near major transportation sources. As such, the population in close proximity to these sources, which may be affected by near-road air quality and health concerns, appears to have increased over time.

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exists between a particular health effect and traffic-related air pollution. In its weight-of-evidence determinations, the panel also placed "considerable weight" on controlled human exposure studies. However, it restricted consideration of other toxicological studies to whether or not the studies provided "general mechanistic support" for the inferences of causality made on the basis of epidemiology.

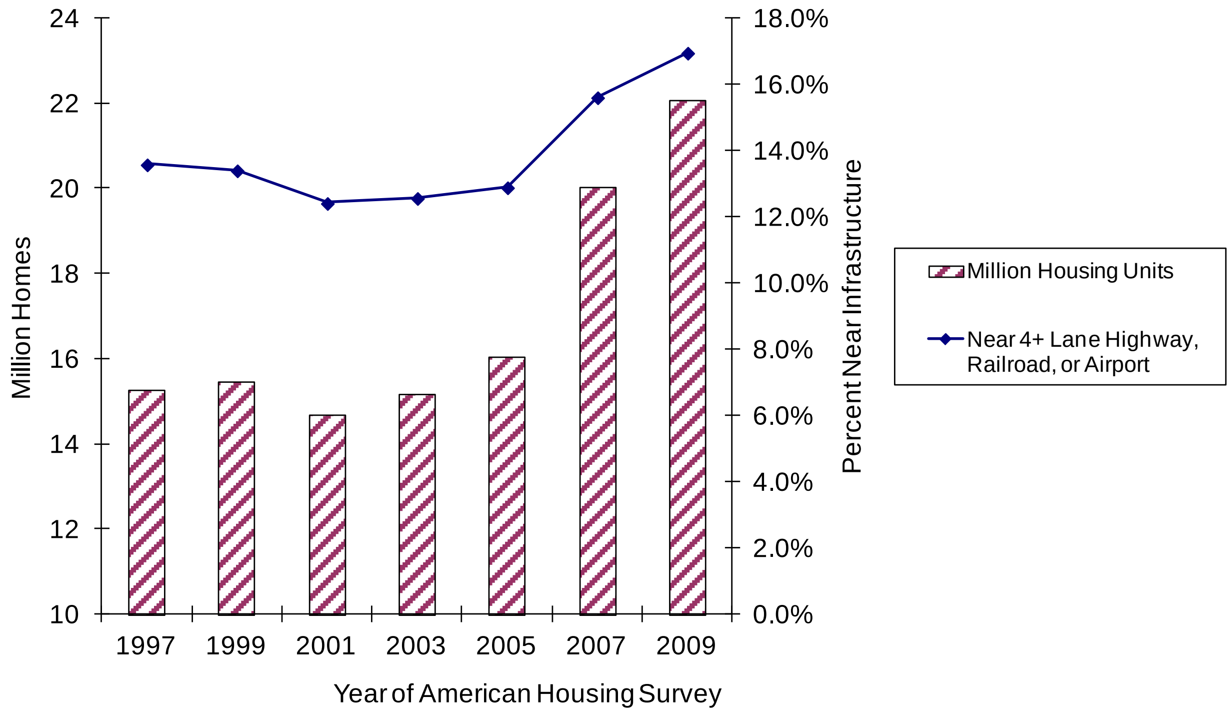

Figure 6-1 Trends in Populations near Large Highways, Railroads, and Airports

Furthermore, according to data from the 2008 American Time Use Survey (ATUS), conducted by the Bureau of Labor Statistics (BTS), Americans spend more than an hour traveling each day, on average.[104] Although the ATUS does not indicate their mode of travel, the majority of trips undertaken nationally is by motor vehicle.[105] As such, daily travel activity brings nearly all residents into a high-exposure microenvironment for part of the day.

6.1.1.8.2 *Premature Mortality*

The HEI panel report concluded that evidence linking traffic-associated air pollution with premature mortality from all causes was "suggestive but not sufficient" to infer a causal relationship. This conclusion was based largely on several long-term studies that "qualitatively" examined whether or not someone was exposed to traffic-associated air pollution. In addition, based on several short-term studies of exposure, the panel concluded that there was "suggestive but not sufficient" evidence to infer a causal relation between traffic-related exposure and cardiovascular mortality.

6.1.1.8.3 *Cardiovascular Effects*

6.1.1.8.3.1 Cardiac Physiology

Exposure to traffic-associated pollutants has been associated with changes in cardiac physiology, including cardiac function. One common measure of cardiac function is heart rate variability (HRV), an indicator of the heart's ability to respond to variations in stress, reflecting the nervous system's ability to regulate the heart.[M] Reduced HRV is associated with adverse cardiovascular events, such as myocardial infarction, in heart disease patients. The HEI panel concluded that available evidence provides evidence for a causal association between exposure to traffic-related pollutants and reduced control of HRV by the nervous system. Overall, the panel concluded that the evidence was "suggestive but not sufficient" to infer a causal relation between traffic-related pollutants and cardiac function. Studies suggest that the HRV changes from traffic-related air pollution result in changes to heart rhythms, which can lead to arrhythmia.[106,107]

6.1.1.8.3.2 Heart Attack and Atherosclerosis

The HEI panel concluded that epidemiologic evidence of the association between traffic-related pollutants and heart attacks and atherosclerosis was "suggestive but not sufficient" to infer a causal association. In addition, the panel concluded that the toxicology studies they reviewed provided "suggestive evidence that exposure to traffic emissions, including ambient and laboratory-generated [PM] and diesel- and gasoline-engine exhaust, alters cardiovascular function." The panel noted there are few studies of human volunteers exposed to real-world traffic mixture, which were not entirely consistent. The panel notes that the studies provide consistent evidence for exposure to PM and impaired cardiovascular responses. In addition to the HEI study, several other reviews of available evidence conclude that there is evidence supporting a causal association between traffic-related air pollution and cardiovascular disease.[108]

A number of mechanisms for cardiovascular disease are highlighted in the HEI and AHA report, including modified blood vessel endothelial function (e.g., the ability to dilate), atherosclerosis, and oxidative stress. The HEI review cites "two well executed studies" in which hospitalization for acute myocardial infarction (i.e., heart attack) were associated with traffic exposures and a prospective study finding higher rates of arterial hardening and coronary heart disease near traffic.

6.1.1.8.4 *Respiratory Effects*

6.1.1.8.4.1 Asthma

Pediatric asthma and asthma symptoms are the effects that have been evaluated by the largest number of studies in the epidemiologic literature on the topic. In general, studies consistently show effects of residential or school exposure to traffic and asthma symptoms, and the effects are frequently statistically significant. Studies have employed both short-term and long-term exposure metrics, and a range of different respiratory measures. HEI Special Report 17 (HEI Panel on the Health Effects of Traffic-Related Air Pollution, 2010) concluded that there is sufficient evidence for a causal association between exposure to traffic-related air pollution and exacerbation of asthma symptoms in children.

[M] The autonomic nervous system (ANS) consists of sympathetic and parasympathetic components. The sympathetic ANS signals body systems to "fight or flight." The parasympathetic ANS signals the body to "rest and digest." In general, HRV is indicative of parasympathetic control of the heart.

While there is general consistency in studies examining asthma incidence in children, the available studies employ different definitions of asthma (e.g., self-reported vs. hospital records), methods of exposure assessment, and population age ranges. As such, the overall evidence, while supportive of an association between traffic exposure and new onset asthma, are less consistent than for asthma symptoms. The HEI report determined that evidence is between "sufficient" and "suggestive" of a causal relationship between exposure to traffic-related air pollution and incident (new onset) asthma in children (HEI Panel on the Health Effects of Traffic-Related Air Pollution, 2010). A recent meta-analysis of studies on incident asthma and air pollution in general, based on studies dominated by traffic-linked exposure metrics, also concluded that available evidence is consistent with HEI's conclusion (Anderson et al., 2011). The study reported excess main risk estimates for different pollutants ranging from 7-16 percent per 10 $\mu g/m^3$ of long-term exposure (random effects models). Other qualitative reviews (Salam et al., 2008; Braback and Forsberg, 2009) conclude that available evidence is consistent with the hypothesis that traffic-associated air pollutants are associated with incident asthma.

6.1.1.8.4.2 Chronic Obstructive Pulmonary Disease (COPD)

The HEI panel reviewed available studies examining COPD in the context of traffic-associated air pollution. Because of how the panel selected studies for inclusion in review, there were only two studies that they used to review the available evidence. Both studies reported some positive associations, but not for all traffic metrics. The small number of studies and lack of consistency across traffic metrics led the panel to conclude that there is insufficient evidence for traffic-associated air pollution causing COPD.

6.1.1.8.4.3 Allergy

There are numerous human and animal experimental studies that provides strongly suggestive evidence that traffic-related air pollutants can enhance allergic responses to common allergens.[109,110,111] However, in its review of 16 epidemiologic studies that address traffic-related air pollution's effect on allergies, the HEI expert panel (HEI, 2010) reported that only two such studies showed consistently positive associations. As a result, despite the strongly suggestive experimental evidence, the panel concluded that there is "inadequate/insufficient" evidence of an association between allergy and traffic-associated air pollution. As noted above, the HEI panel considered toxicological studies only based on whether or not they provide mechanistic support for observations and inferences derived from epidemiology.

6.1.1.8.4.4 Lung Function

There are numerous measurements of breathing (spirometry) that indicate the presence or degree of airway disease, such as asthma and chronic obstructive pulmonary disease (COPD). Forced vital capacity (FVC) is measured when a patient maximally fills their lungs and then blows their hardest in completely exhaling. The peak expiratory flow (PEF) is the maximum air flow achievable during exhalation. The forced expiratory volume in the first second of exhalation is referred to as FEV_1. FEV_1 and PEF reflect the function of the large airways. FVC and FEV_1, along with their ratio (FVC/FEV_1) are used to classify airway obstruction in asthma and COPD. Measurements of air flow at various times during forced exhalation, such as 25 percent, 50 percent, and 75 percent, are also used. The flow at 75 percent of forced exhalation (FEF_{75}) reflects the status of small airways, which asthma and COPD affect.

The HEI panel concluded that the available literature suggests that long-term exposure to traffic-related air pollution is associated with reduced lung function in adolescents and young adults and that lung function is lower in populations in areas with high traffic-related air pollutant levels. However, the panel noted the difficulty of disentangling traffic-specific exposures from urban air pollution in general. The studies reviewed that were more specifically oriented toward traffic were not consistent in their findings. As a result, the panel found that the evidence linking lung function and traffic exposure is “inadequate and insufficient” to infer a causal relationship.

6.1.1.8.5 *Reproductive and Developmental Effects*

Several studies have reported associations between traffic-related air pollution and adverse birth outcomes, such as preterm birth and low birth weight. At the time of the HEI review, the panel concluded that evidence for adverse birth outcomes being causally associated with traffic-related exposures was “inadequate and insufficient.” Only four studies met the panel’s inclusion criteria, and had limited geographic coverage. One study provided evidence of small but consistently increased risks using multiple exposure metrics. No studies were at the time available that examined traffic-specific exposures and congenital abnormalities. Since then, several studies investigating birth outcomes have been published, but no new systematic reviews. One new meta-analysis of air pollution and congenital abnormalities has been published, though none of the reviewed studies includes traffic-specific exposure information.

The HEI panel also reviewed toxicological studies of traffic-related air pollutants and fertility. While numerous studies examining animal or human exposure and sperm count have been published, the panel concluded that the generally high exposure concentrations employed in the studies limited the applicability to typical ambient concentrations. Because there was no overlap in the effects studied by epidemiology and toxicology studies, no synthesis review of the combined literature was undertaken.

Since the HEI panel’s publication, a systematic review and meta-analysis of air pollution and congenital abnormalities was published.[112] In that review, only one study directly included nearby traffic in its exposure analysis. As such, there are no systematic reviews that specifically address traffic’s impact on congenital abnormalities.

6.1.1.8.6 *Cancer*

6.1.1.8.6.1 Childhood Cancer

In 2014, Boothe et al. published a systematic review and meta-analysis of studies of childhood leukemia risks associated for populations near major roads.[113] The study concluded that childhood leukemia was positively associated with residential exposure during childhood, but not during the prenatal period. Other literature reviews have not concluded that available evidence supports an association between childhood leukemia and traffic exposure.[114,115] For example, the HEI panel concluded that the available epidemiologic evidence was “inadequate and insufficient" to infer a causal relationship between traffic-related air pollution and childhood cancer.

6.1.1.8.6.2 Adult Cancer

Several studies have examined the risk of adult lung cancers in relation to exposure to traffic-related air pollutants. The HEI panel evaluated four such studies, and rated the available evidence as "inadequate and insufficient" to infer a causal relation for non-occupational lung cancer.

6.1.1.8.7 *Neurological Effects*

The HEI panel found that current toxicologic and epidemiologic literature on the neurotoxicity of traffic-related air pollution was inadequate for their evaluation. The panel noted that there were a number of toxicologic studies of traffic-associated pollutants, but found them to have diverse exposure protocols, animal models, and endpoints, making them unsuitable for systematic evaluation.

6.1.2 Environmental Effects Associated with Exposure to Non-GHG Pollutants

Along with reducing GHGs, the Phase 2 standards also have an impact on non-GHG (criteria and air toxic pollutant) emissions. As discussed in Chapter 5, the standards will impact exhaust emissions of these pollutants from vehicles and will also impact emissions that occur during the refining and distribution of fuel (upstream sources).

In this section we will discuss the environmental effects associated with non-GHG pollutants, specifically: particulate matter, ozone, NO_X, SO_X and air toxics.

6.1.2.1 Visibility Degradation

Visibility can be defined as the degree to which the atmosphere is transparent to visible light.[116] Visibility impairment is caused by light scattering and absorption by suspended particles and gases. Fine particles with significant light-extinction efficiencies include sulfates, nitrates, organic carbon, elemental carbon, and soil.[117] Visibility is important because it has direct significance to people's enjoyment of daily activities in all parts of the country. Individuals value good visibility for the well-being it provides them directly, where they live and work, and in places where they enjoy recreational opportunities. Visibility is also highly valued in significant natural areas, such as national parks and wilderness areas, and special emphasis is given to protecting visibility in these areas. For more information on visibility see the final 2009 PM ISA.[118]

The extent to which any amount of light extinction affects a person's ability to view a scene depends on both scene and light characteristics. For example, the appearance of a nearby object (e.g., a building) is generally less sensitive to a change in light extinction than the appearance of a similar object at a greater distance. See Figure 6-2 for an illustration of the important factors affecting visibility.

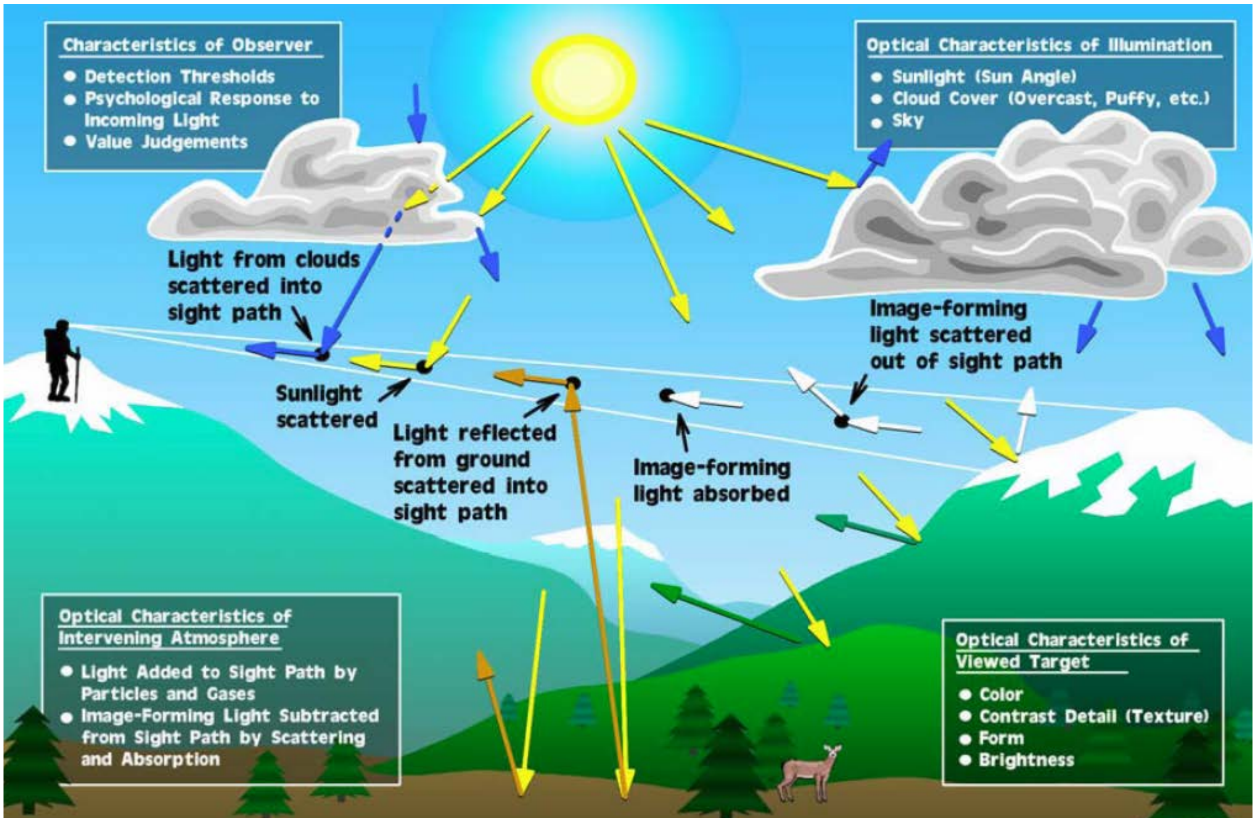

Figure 6-2 Important Factors Involved in Seeing a Scenic Vista (Malm, 1999)

EPA is working to address visibility impairment. Reductions in air pollution from implementation of various programs associated with the Clean Air Act Amendments of 1990 (CAAA) provisions have resulted in substantial improvements in visibility and will continue to do so in the future. Because trends in haze are closely associated with trends in particulate sulfate and nitrate due to the relationship between their concentration and light extinction, visibility trends have improved as emissions of SO_2 and NO_X have decreased over time due to air pollution regulations such as the Acid Rain Program.[119]

In the Clean Air Act Amendments of 1977, Congress recognized visibility's value to society by establishing a national goal to protect national parks and wilderness areas from visibility impairment caused by manmade pollution.[N] In 1999, EPA finalized the regional haze program (64 FR 35714) to protect the visibility in Mandatory Class I Federal areas. There are 156 national parks, forests and wilderness areas categorized as Mandatory Class I Federal areas (62 FR 38680-38681, July 18, 1997). These areas are defined in CAA section 162 as those national parks exceeding 6,000 acres, wilderness areas and memorial parks exceeding 5,000 acres, and all international parks which were in existence on August 7, 1977. Figure 6-3 shows the location of the 156 Mandatory Class I Federal areas.

[N] See Section 169(a) of the Clean Air Act.

Figure 6-3 Mandatory Class I Federal Areas in the U.S.

EPA has also concluded that $PM_{2.5}$ causes adverse effects on visibility in other areas that are not targeted by the Regional Haze Rule, such as urban areas, depending on $PM_{2.5}$ concentrations and other factors such as dry chemical composition and relative humidity (i.e., an indicator of the water composition of the particles). EPA revised the $PM_{2.5}$ standards in December 2012 and established a target level of protection that is expected to be met through attainment of the existing secondary standards for $PM_{2.5}$.

6.1.2.2 Visibility Monitoring

In conjunction with the U.S. National Park Service, the U.S. Forest Service, other Federal land managers, and State organizations in the U.S., EPA has supported visibility monitoring in national parks and wilderness areas since 1988. The monitoring network was originally established at 20 sites, but it has now been expanded to 110 sites that represent all but one of the 156 Mandatory Federal Class I areas across the country (see Figure 6-3). This long-term visibility monitoring network is known as IMPROVE (Interagency Monitoring of Protected Visual Environments).

IMPROVE provides direct measurement of fine particles that contribute to visibility impairment. The IMPROVE network employs aerosol measurements at all sites, and optical and scene measurements at some of the sites. Aerosol measurements are taken for PM_{10} and $PM_{2.5}$ mass, and for key constituents of $PM_{2.5}$, such as sulfate, nitrate, organic and elemental carbon OC and EC), soil dust, and several other elements. Measurements for specific aerosol constituents are used to calculate "reconstructed" aerosol light extinction by multiplying the mass for each constituent by its empirically-derived scattering and/or absorption efficiency, with adjustment for the relative humidity. The IMPROVE program utilizes both an “original” and a “revised” reconstruction formula for this purpose, with the latter explicitly accounting for sea salt concentrations. Knowledge of the main constituents of a site's light extinction "budget" is critical for source apportionment and control strategy development. In addition to this indirect method of assessing light extinction, there are optical measurements which directly measure light extinction or its components. Such measurements are made principally with a nephelometer to measure light scattering, some sites also include an aethalometer for light absorption, or a few sites use a transmissometer, which measures total light extinction. Scene characteristics are typically recorded using digital or video photography and are used to determine the quality of visibility conditions (such as effects on color and contrast) associated with specific levels of light extinction as measured under both direct and aerosol-related methods. Directly measured light extinction is used under the IMPROVE protocol to cross check that the aerosol-derived light extinction levels are reasonable in establishing current visibility conditions. Aerosol-derived light extinction is used to document spatial and temporal trends and to determine how changes in atmospheric constituents would affect future visibility conditions.

Annual average visibility conditions (reflecting light extinction due to both anthropogenic and non-anthropogenic sources) vary regionally across the U.S. Visibility is typically worse in the summer months, and the rural East generally has higher levels of impairment than remote sites in the West. Figures 9-9 through 9-11 in the PM ISA detail the percent contributions to particulate light extinction for ammonium nitrate and sulfate, EC and OC, and coarse mass and fine soil, by season.[120]

6.1.2.3 Plant and Ecosystem Effects of Ozone

The welfare effects of ozone can be observed across a variety of scales, i.e. subcellular, cellular, leaf, whole plant, population and ecosystem. Ozone effects that begin at small spatial scales, such as the leaf of an individual plant, when they occur at sufficient magnitudes (or to a sufficient degree) can result in effects being propagated along a continuum to larger and larger spatial scales. For example, effects at the individual plant level, such as altered rates of leaf gas exchange, growth and reproduction, can, when widespread, result in broad changes in ecosystems, such as productivity, carbon storage, water cycling, nutrient cycling, and community composition.

Ozone can produce both acute and chronic injury in sensitive species depending on the concentration level and the duration of the exposure.[121] In those sensitive species[O], effects from repeated exposure to ozone throughout the growing season of the plant tend to accumulate, so that even low concentrations experienced for a longer duration have the potential to create chronic stress on vegetation.[122,P] Ozone damage to sensitive species includes impaired photosynthesis and visible injury to leaves. The impairment of photosynthesis, the process by which the plant makes carbohydrates (its source of energy and food), can lead to reduced crop yields, timber production, and plant productivity and growth. Impaired photosynthesis can also

[O] 73 FR 16491 (March 27, 2008). Only a small percentage of all the plant species growing within the U.S. (over 43,000 species have been catalogued in the USDA PLANTS database) have been studied with respect to ozone sensitivity.

[P] The concentration at which ozone levels overwhelm a plant's ability to detoxify or compensate for oxidant exposure varies. Thus, whether a plant is classified as sensitive or tolerant depends in part on the exposure levels being considered.

lead to a reduction in root growth and carbohydrate storage below ground, resulting in other, more subtle plant and ecosystems impacts.[123] These latter impacts include increased susceptibility of plants to insect attack, disease, harsh weather, interspecies competition and overall decreased plant vigor. The adverse effects of ozone on areas with sensitive species could potentially lead to species shifts and loss from the affected ecosystems[Q], resulting in a loss or reduction in associated ecosystem goods and services.[124] Additionally, visible ozone injury to leaves can result in a loss of aesthetic value in areas of special scenic significance like national parks and wilderness areas and reduced use of sensitive ornamentals in landscaping.[125]

The Integrated Science Assessment (ISA) for Ozone presents more detailed information on how ozone affects vegetation and ecosystems.[126] The ISA concludes that ambient concentrations of ozone are associated with a number of adverse welfare effects and characterizes the weight of evidence for different effects associated with ozone.[R] The ISA concludes that visible foliar injury effects on vegetation, reduced vegetation growth, reduced productivity in terrestrial ecosystems, reduced yield and quality of agricultural crops, and alteration of below-ground biogeochemical cycles are causally associated with exposure to ozone. It also concludes that reduced carbon sequestration in terrestrial ecosystems, alteration of terrestrial ecosystem water cycling, and alteration of terrestrial community composition are likely to be causally associated with exposure to ozone.

6.1.2.4 Deposition of Particulate Matter, Nitrogen and Sulfur

Particulate matter contributes to adverse effects on vegetation and ecosystems, and to soiling and materials damage. These welfare effects result predominantly from exposure to excess amounts of specific chemical species, regardless of their source or predominant form (particle, gas or liquid). The following characterizations of the nature of these environmental effects are based on information contained in the 2009 PM ISA and the 2008 Integrated Science Assessment for Oxides of Nitrogen and Sulfur- Ecological Criteria (secondary NO_X/SO_X ISA).[127, 128]

6.1.2.4.1 *Deposition of Nitrogen and Sulfur*

Nitrogen and sulfur interactions in the environment are highly complex as shown in Figure 6-4. Both nitrogen and sulfur are essential, and sometimes limiting, nutrients needed for growth and productivity of ecosystem components (e.g. algae, plants). In terrestrial and aquatic ecosystems excesses of nitrogen or sulfur can lead to acidification and nutrient enrichment.[129] In addition, in aquatic ecosystems, sulfur deposition can increase mercury methylation.

[Q] Per footnote above, ozone impacts could be occurring in areas where plant species sensitive to ozone have not yet been studied or identified.

[R] The Ozone ISA evaluates the evidence associated with different ozone related health and welfare effects, assigning one of five “weight of evidence” determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For more information on these levels of evidence, please refer to Table II of the ISA.

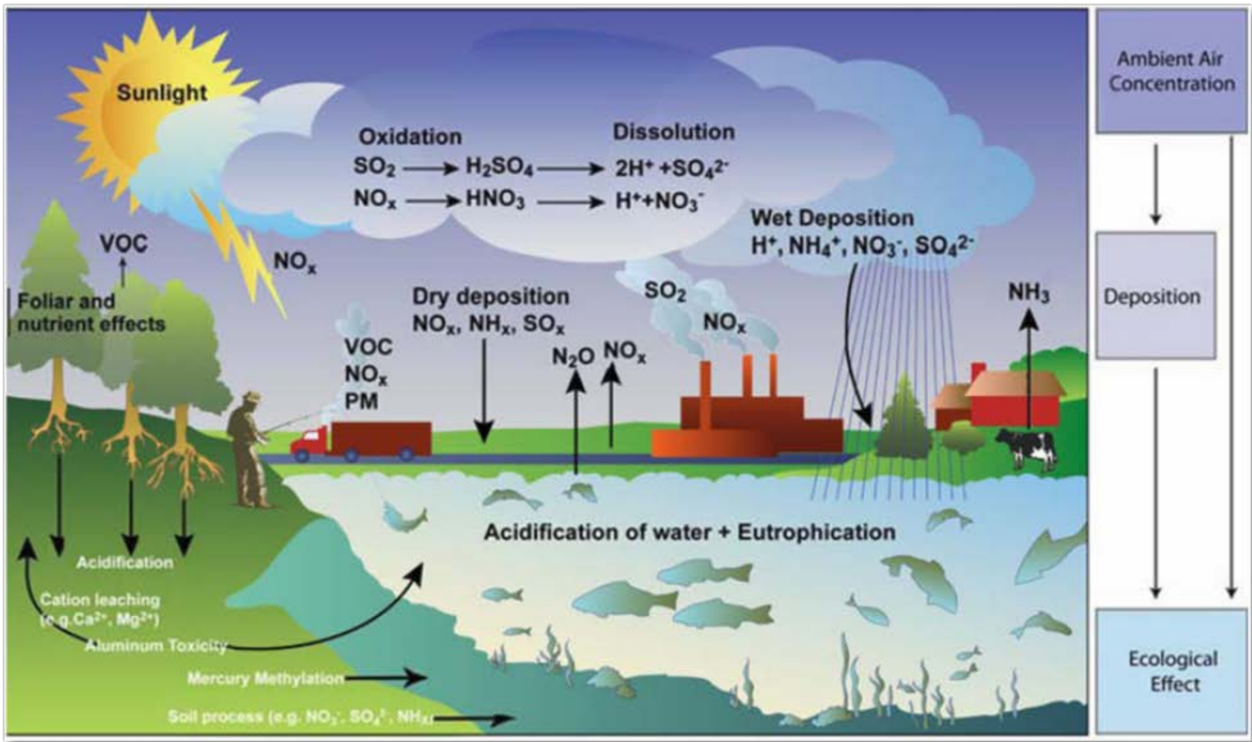

Figure 6-4 Nitrogen and Sulfur Cycling, and Interactions in the Environment

Source: U.S. EPA, 2008c

6.1.2.4.1.1 Ecological Effects of Acidification

Deposition of nitrogen and sulfur can cause acidification, which alters biogeochemistry and affects animal and plant life in terrestrial and aquatic ecosystems across the U.S. Soil acidification is a natural process, but is often accelerated by acidifying deposition, which can decrease concentrations of exchangeable base cations in soils.[130] Biological effects of acidification in terrestrial ecosystems are generally linked to aluminum toxicity and decreased ability of plant roots to take up base cations.[131] Decreases in the acid neutralizing capacity and increases in inorganic aluminum concentration contribute to declines in zooplankton, macro invertebrates, and fish species richness in aquatic ecosystems.[132]

Geology (particularly surficial geology) is the principal factor governing the sensitivity of terrestrial and aquatic ecosystems to acidification from nitrogen and sulfur deposition.[133] Geologic formations having low base cation supply generally underlie the watersheds of acid-sensitive lakes and streams. Other factors contribute to the sensitivity of soils and surface waters to acidifying deposition, including topography, soil chemistry, land use, and hydrologic flow path.[134]

6.1.2.4.1.1.1 Aquatic Acidification

Aquatic effects of acidification have been well studied in the U.S. and elsewhere at various trophic levels. These studies indicate that aquatic biota have been affected by acidification at virtually all levels of the food web in acid sensitive aquatic ecosystems. Effects have been most clearly documented for fish, aquatic insects, other invertebrates, and algae. Biological effects are primarily attributable to a combination of low pH and high inorganic aluminum concentrations. Such conditions occur more frequently during rainfall and snowmelt that cause high flows of water and less commonly during low-flow conditions, except where chronic acidity conditions are severe. Biological effects of episodes include reduced fish condition factor[A], changes in species composition and declines in aquatic species richness across multiple taxa, ecosystems and regions.

Because acidification primarily affects the diversity and abundance of aquatic biota, it also affects the ecosystem services, e.g., recreational and subsistence fishing, that are derived from the fish and other aquatic life found in these surface waters. In the northeastern United States, the surface waters affected by acidification are a source of food for some recreational and subsistence fishermen and for other consumers with particularly high rates of self-caught fish consumption, such as the Hmong and Chippewa ethnic groups.[135,136]

6.1.2.4.1.1.2 Terrestrial Acidification

Acidifying deposition has altered major biogeochemical processes in the U.S. by increasing the nitrogen and sulfur content of soils, accelerating nitrate and sulfate leaching from soil to drainage waters, depleting base cations (especially calcium and magnesium) from soils, and increasing the mobility of aluminum. Inorganic aluminum is toxic to some tree roots. Plants affected by high levels of aluminum from the soil often have reduced root growth, which restricts the ability of the plant to take up water and nutrients, especially calcium.[137] These direct effects can, in turn, influence the response of these plants to climatic stresses such as droughts and cold temperatures. They can also influence the sensitivity of plants to other stresses, including insect pests and disease leading to increased mortality of canopy trees.[138] In the U.S., terrestrial effects of acidification are best described for forested ecosystems (especially red spruce and sugar maple ecosystems) with additional information on other plant communities, including shrubs and lichen.[139]

Both coniferous and deciduous forests throughout the eastern U.S. are experiencing gradual losses of base cation nutrients from the soil due to accelerated leaching from acidifying deposition. This change in nutrient availability may reduce the quality of forest nutrition over the long term. Evidence suggests that red spruce and sugar maple in some areas in the eastern U.S. have experienced declining health because of this deposition. For red spruce, (*Picea rubens*) dieback or decline has been observed across high elevation landscapes of the northeastern U.S., and to a lesser extent, the southeastern U.S., and acidifying deposition has been implicated as a causal factor.[140]

6.1.2.4.1.2 Ecological Effects from Nitrogen Enrichment

6.1.2.4.1.2.1 Aquatic Enrichment

Eutrophication in estuaries is associated with a range of adverse ecological effects including low dissolved oxygen (DO), harmful algal blooms (HABs), loss of submerged aquatic vegetation (SAV), and low water clarity. Low DO disrupts aquatic habitats, causing stress to fish and shellfish, which, in the short-term, can lead to episodic fish kills and, in the long-term, can damage overall growth in fish and shellfish populations. Low DO also degrades the aesthetic qualities of surface water. In addition to often being toxic to fish and shellfish, and leading to fish kills and aesthetic impairments of estuaries, HABs can, in some instances, also be harmful to human health. SAV provides critical habitat for many aquatic species in estuaries and, in some instances, can also protect shorelines by reducing wave strength; therefore, declines in SAV due to nutrient enrichment are an important source of concern. Low water clarity is in part the result of accumulations of both algae and sediments in estuarine waters. In addition to contributing to declines in SAV, high levels of turbidity also degrade the aesthetic qualities of the estuarine environment.

An assessment of estuaries nationwide by the National Oceanic and Atmospheric Administration (NOAA) concluded that 64 estuaries (out of 99 with available data) suffered from moderate or high levels of eutrophication due to excessive inputs of both N and phosphorus.[141] For estuaries in the Mid-Atlantic region, the contribution of atmospheric deposition to total N loads is estimated to range between 10 percent and 58 percent.[142] Estuaries in the eastern United States are an important source of food production, in particular fish and shellfish production. The estuaries are capable of supporting large stocks of resident commercial species, and they serve as the breeding grounds and interim habitat for several migratory species. Eutrophication in estuaries may also affect the demand for seafood after well-publicized toxic blooms, water-based recreation, and erosion protection provided by SAV.

6.1.2.4.1.2.2 Terrestrial Enrichment

Terrestrial enrichment occurs when terrestrial ecosystems receive N loadings in excess of natural background levels, through either atmospheric deposition or direct application. Atmospheric N deposition is associated with changes in the types and number of species and biodiversity in terrestrial systems. Nitrogen enrichment occurs over a long time period; as a result, it may take as much as 50 years or more to see changes in ecosystem conditions and indicators. One of the main provisioning services potentially affected by N deposition is grazing opportunities offered by grasslands for livestock production in the Central U.S. Although N deposition on these grasslands can offer supplementary nutritive value and promote overall grass production, there are concerns that fertilization may favor invasive grasses and shift the species composition away from native grasses. This process may ultimately reduce the productivity of grasslands for livestock production.

Terrestrial enrichment also affects habitats, for example the Coastal Sage Scrub (CSS) and Mixed Conifer Forest (MCF) habitats which are an integral part of the California landscape. Together the ranges of these habitats include the densely populated and valuable coastline and the mountain areas. Numerous threatened and endangered species at both the state and federal levels reside in CSS and MCF. Fire regulation is also an important regulating service that could be affected by nutrient enrichment of the CSS and MCF ecosystems by encouraging growth of more flammable grasses, increasing fuel loads, and altering the fire cycle.

6.1.2.4.1.3 Vegetation Effects Associated with Gaseous Sulfur Dioxide

Uptake of gaseous sulfur dioxide in a plant canopy is a complex process involving adsorption to surfaces (leaves, stems, and soil) and absorption into leaves. SO_2 penetrates into leaves through the stomata, although there is evidence for limited pathways via the cuticle.[143]

Pollutants must be transported from the bulk air to the leaf boundary layer in order to get to the stomata. When the stomata are closed, as occurs under dark or drought conditions, resistance to gas uptake is very high and the plant has a very low degree of susceptibility to injury. In contrast, mosses and lichens do not have a protective cuticle barrier to gaseous pollutants or stomates and are generally more sensitive to gaseous sulfur and nitrogen than vascular plants.[144] Acute foliar injury usually happens within hours of exposure, involves a rapid absorption of a toxic dose, and involves collapse or necrosis of plant tissues. Another type of visible injury is termed chronic injury and is usually a result of variable SO_2 exposures over the growing season. Besides foliar injury, chronic exposure to low SO_2 concentrations can result in reduced photosynthesis, growth, and yield of plants.[145] These effects are cumulative over the season and are often not associated with visible foliar injury. As with foliar injury, these effects vary among species and growing environment. SO_2 is also considered the primary factor causing the death of lichens in many urban and industrial areas.[146]

6.1.2.4.1.4 Mercury Methylation

Mercury is a persistent, bioaccumulative toxic metal that is emitted in three forms: gaseous elemental Hg (Hg^0), oxidized Hg compounds (Hg^{+2}), and particle-bound Hg (Hg_P). Methylmercury (MeHg) is formed by microbial action in the top layers of sediment and soils, after Hg has precipitated from the air and deposited into waterbodies or land. Once formed, MeHg is taken up by aquatic organisms and bioaccumulates up the aquatic food web. Larger predatory fish may have MeHg concentrations many times, typically on the order of one million times, that of the concentrations in the freshwater body in which they live. The NO_X SO_X ISA—Ecological Criteria concluded that evidence is sufficient to infer a causal relationship between sulfur deposition and increased mercury methylation in wetlands and aquatic environments.[147] Specifically, there appears to be a relationship between SO_4^{2-} deposition and mercury methylation; however, the rate of mercury methylation varies according to several spatial and biogeochemical factors whose influence has not been fully quantified. Therefore, the correlation between SO_4^{2-} deposition and MeHg cannot yet be quantified for the purpose of interpolating the association across waterbodies or regions. Nevertheless, because changes in MeHg in ecosystems represent changes in significant human and ecological health risks, the association between sulfur and mercury cannot be neglected.[148]

6.1.2.4.2 *Deposition of Metallic and Organic Constituents of PM*

Several significant ecological effects are associated with deposition of chemical constituents of ambient PM such as metals and organics.[149] The trace metal constituents of PM include cadmium, copper, chromium, mercury, nickel, zinc, and lead. The organics include persistent organic pollutants (POPs), polyaromatic hydrocarbons (PAHs) and polybromiated diphenyl ethers (PBDEs). Exposure to PM for direct effects occur via deposition (e.g., wet, dry or occult) to vegetation surfaces, while indirect effects occur via deposition to ecosystem soils or surface waters where the deposited constituents of PM then interacts with biological organisms. While both fine and coarse-mode particles may affect plants and other organisms, more often the chemical constituents drive the ecosystem response to PM.[150] Ecological effects of PM include direct effects to metabolic processes of plant foliage; contribution to total metal loading resulting in alteration of soil biogeochemistry and microbiology, plant and animal growth and reproduction; and contribution to total organics loading resulting in bioaccumulation and biomagnification.

Particulate matter can adversely impact plants and ecosystem services provided by plants by deposition to vegetative surfaces.[151] Particulates deposited on the surfaces of leaves and needles can block light, altering the radiation received by the plant. PM deposition near sources of heavy deposition can obstruct stomata limiting gas exchange, damage leaf cuticles and increase plant temperatures.[152] Plants growing on roadsides exhibit impact damage from near-road PM deposition, having higher levels of organics and heavy metals, and accumulate salt from road de-icing during winter months.[153] In addition, atmospheric PM can convert direct solar radiation to diffuse radiation, which is more uniformly distributed in a tree canopy, allowing radiation to reach lower leaves.[154] Decreases in crop yields (a provisioning service) due to reductions in solar radiation have been attributed to regional scale air pollution in other counties with especially severe regional haze.[155]

In addition to damage to plant surfaces, deposited PM can be taken up by plants from soil or foliage. Copper, zinc, and nickel have been shown to be directly toxic to vegetation under field conditions.[156] The ability of vegetation to take up heavy metals is dependent upon the amount, solubility and chemical composition of the deposited PM. Uptake of PM by plants from soils and vegetative surfaces can disrupt photosynthesis, alter pigments and mineral content, reduce plant vigor, decrease frost hardiness and impair root development.

Particulate matter can also contain organic air toxic pollutants, including PAHs, which are a class of polycyclic organic matter (POM). PAHs can accumulate in sediments and bioaccumulate in freshwater, flora and fauna. The uptake of organics depends on the plant species, site of deposition, physical and chemical properties of the organic compound and prevailing environmental conditions.[157] Different species can have different uptake rates of PAHs. For example, zucchini (Cucurbita pepo) accumulated significantly more PAHs than related plant species.[158] PAHs can accumulate to high enough concentrations in some coastal environments to pose an environmental health threat that includes cancer in fish populations, toxicity to organisms living in the sediment and risks to those (e.g., migratory birds) that consume these organisms.[159,160] Atmospheric deposition of particles is thought to be the major source of PAHs to the sediments of Lake Michigan, Chesapeake Bay, Tampa Bay and other coastal areas of the U.S.[161]

Contamination of plant leaves by heavy metals can lead to elevated concentrations in the soil. Trace metals absorbed into the plant, frequently bind to the leaf tissue, and then are lost when the leaf drops. As the fallen leaves decompose, the heavy metals are transferred into the soil.[162,163] Many of the major indirect plant responses to PM deposition are chiefly soil-mediated and depend on the chemical composition of individual components of deposited PM. Upon entering the soil environment, PM pollutants can alter ecological processes of energy flow and nutrient cycling, inhibit nutrient uptake to plants, change microbial community structure and, affect biodiversity. Accumulation of heavy metals in soils depends on factors such as local soil characteristics, geologic origin of parent soils, and metal bioavailability. Heavy metals, such as zinc, copper, and cadmium, and some pesticides can interfere with microorganisms that are responsible for decomposition of soil litter, an important regulating ecosystem service that serves as a source of soil nutrients.[164] Surface litter decomposition is reduced in soils having high metal concentrations. Soil communities have associated bacteria, fungi, and invertebrates that are essential to soil nutrient cycling processes. Changes to the relative species abundance and community composition are associated with deposited PM to soil biota.[165]

Atmospheric deposition can be the primary source of some organics and metals to watersheds. Deposition of PM to surfaces in urban settings increases the metal and organic component of storm water runoff.[166] This atmospherically-associated pollutant burden can then be toxic to aquatic biota. The contribution of atmospherically deposited PAHs to aquatic food webs was demonstrated in high elevation mountain lakes with no other anthropogenic contaminant sources.[167] Metals associated with PM deposition limit phytoplankton growth, affecting aquatic trophic structure. Long-range atmospheric transport of 47 pesticides and degradation products to the snowpack in seven national parks in the Western U.S. was recently quantified indicating PM-associated contaminant inputs to receiving waters during spring snowmelt.[168]

The recently completed Western Airborne Contaminants Assessment Project (WACAP) is the most comprehensive database on contaminant transport and PM depositional effects on sensitive ecosystems in the Western U.S.[169] In this project, the transport, fate, and ecological impacts of anthropogenic contaminants from atmospheric sources were assessed from 2002 to 2007 in seven ecosystem components (air, snow, water, sediment, lichen, conifer needles and fish) in eight core national parks. The study concluded that bioaccumulation of semi-volatile organic compounds occurred throughout park ecosystems, an elevational gradient in PM deposition exists with greater accumulation in higher altitude areas, and contaminants accumulate in proximity to individual agriculture and industry sources, which is counter to the original working hypothesis that most of the contaminants would originate from Eastern Europe and Asia.

6.1.2.4.3 *Materials Damage and Soiling*

Building materials including metals, stones, cements, and paints undergo natural weathering processes from exposure to environmental elements (e.g., wind, moisture, temperature fluctuations, sunlight, etc.). Pollution can worsen and accelerate these effects. Deposition of PM is associated with both physical damage (materials damage effects) and impaired aesthetic qualities (soiling effects). Wet and dry deposition of PM can physically affect materials, adding to the effects of natural weathering processes, by potentially promoting or accelerating the corrosion of metals, by degrading paints and by deteriorating building materials such as stone, concrete and marble.[170] The effects of PM are exacerbated by the presence of acidic gases and can be additive or synergistic due to the complex mixture of pollutants in the air and surface characteristics of the material. Acidic deposition has been shown to have an effect on materials including zinc/galvanized steel and other metal, carbonate stone (as monuments and building facings), and surface coatings (paints).[171] The effects on historic buildings and outdoor works of art are of particular concern because of the uniqueness and irreplaceability of many of these objects.

6.1.2.5 Environmental Effects of Air Toxics

Emissions from producing, transporting and combusting fuel contribute to ambient levels of pollutants that contribute to adverse effects on vegetation. Volatile organic compounds (VOCs), some of which are considered air toxics, have long been suspected to play a role in vegetation damage.[172] In laboratory experiments, a wide range of tolerance to VOCs has been observed.[173] Decreases in harvested seed pod weight have been reported for the more sensitive plants, and some studies have reported effects on seed germination, flowering and fruit ripening. Effects of individual VOCs or their role in conjunction with other stressors (e.g., acidification, drought, temperature extremes) have not been well studied. In a recent study of a mixture of VOCs including ethanol and toluene on herbaceous plants, significant effects on seed production, leaf water content and photosynthetic efficiency were reported for some plant species.[174]

Research suggests an adverse impact of vehicle exhaust on plants, which has in some cases been attributed to aromatic compounds and in other cases to nitrogen oxides.[175,176,177] The impacts of VOCs on plant reproduction may have long-term implications for biodiversity and survival of native species near major roadways. Most of the studies of the impacts of VOCs on vegetation have focused on short-term exposure and few studies have focused on long-term effects of VOCs on vegetation and the potential for metabolites of these compounds to affect herbivores or insects.

6.2 Impacts of the Rules on Concentrations of Non-GHG Pollutants

Along with reducing GHGs, the Phase 2 standards also have an impact on non-GHG (criteria and air toxic pollutant) emissions. As discussed in Chapter 5, the standards will impact exhaust emissions of these pollutants from vehicles and will also impact emissions that occur during the refining and distribution of fuel (upstream sources).

This section first discusses current concentrations of non-GHG pollutants and then discusses the projected impacts of the standards on ambient concentrations of non-GHG pollutants in 2040. Additional information on the air quality modeling methodology and results of the air quality modeling can be found in Appendix 6A.

6.2.1 Current Concentrations of Non-GHG Pollutants

Nationally, levels of $PM_{2.5}$, ozone, NO_X, SO_X, CO and air toxics are declining.[178] However as of April 22, 2016, more than 125 million people lived in counties designated nonattainment for one or more of the NAAQS, and this figure does not include the people living in areas with a risk of exceeding the NAAQS in the future.[S] Many Americans continue to be exposed to ambient concentrations of air toxics at levels which have the potential to cause adverse health effects.[179] In addition, populations who live, work, or attend school near major roads experience elevated exposure concentrations to a wide range of air pollutants.[180]

[S] Data come from Summary Nonattainment Area Population Exposure Report, current as of April 22, 2016 at: https://www3.epa.gov/airquality/greenbk/popexp.html.

6.2.1.1 Current Concentrations of Particulate Matter

As described in Chapter 6.1, PM causes adverse health effects, and EPA has set national standards to provide requisite protection against those health effects. There are two primary NAAQS for $PM_{2.5}$: an annual standard (12.0 micrograms per cubic meter ($\mu g/m^3$)) and a 24-hour standard (35 $\mu g/m^3$), and two secondary NAAQS for $PM_{2.5}$: an annual standard (15.0 $\mu g/m^3$) and a 24-hour standard (35 $\mu g/m^3$). The initial $PM_{2.5}$ standards were set in 1997 and revisions to the standards were finalized in 2006 and in December 2012.

There are many areas of the country that are currently in nonattainment for the annual and 24-hour $PM_{2.5}$ NAAQS. In 2005 the EPA designated 39 nonattainment areas for the 1997 $PM_{2.5}$ NAAQS.[181] As of April 22, 2016, more than 23 million people lived in the 7 areas that are still designated as nonattainment for the 1997 annual $PM_{2.5}$ NAAQS. These $PM_{2.5}$ nonattainment areas are comprised of 33 full or partial counties. In December 2014 EPA designated 14 nonattainment areas for the 2012 $PM_{2.5}$ NAAQS.[182] As of April 22, 2016, 9 of these areas remain designated as nonattainment, and they are composed of 20 full or partial counties with a population of over 23 million. On November 13, 2009 and February 3, 2011, the EPA designated 32 nonattainment areas for the 2006 24-hour $PM_{2.5}$ NAAQS.[183] As of April 22, 2016, 16 of these areas remain designated as nonattainment for the 2006 $PM_{2.5}$ NAAQS, and they are composed of 46 full or partial counties with a population of over 32 million. In total, there are currently 24 $PM_{2.5}$ nonattainment areas with a population of more than 39 million people.[T] Nonattainment areas for the $PM_{2.5}$ NAAQS are pictured in Figure 6-5.

[T] The 39 million total is calculated by summing, without double counting, the 1997, 2006 and 2012 $PM_{2.5}$ nonattainment populations contained in the Summary Nonattainment Area Population Exposure report (https://www3.epa.gov/airquality/greenbk/popexp.html). If there is a population associated with more than one of the 1997, 2006 and 2012 nonattainment areas, and they are not the same, then the larger of the populations is included in the sum.

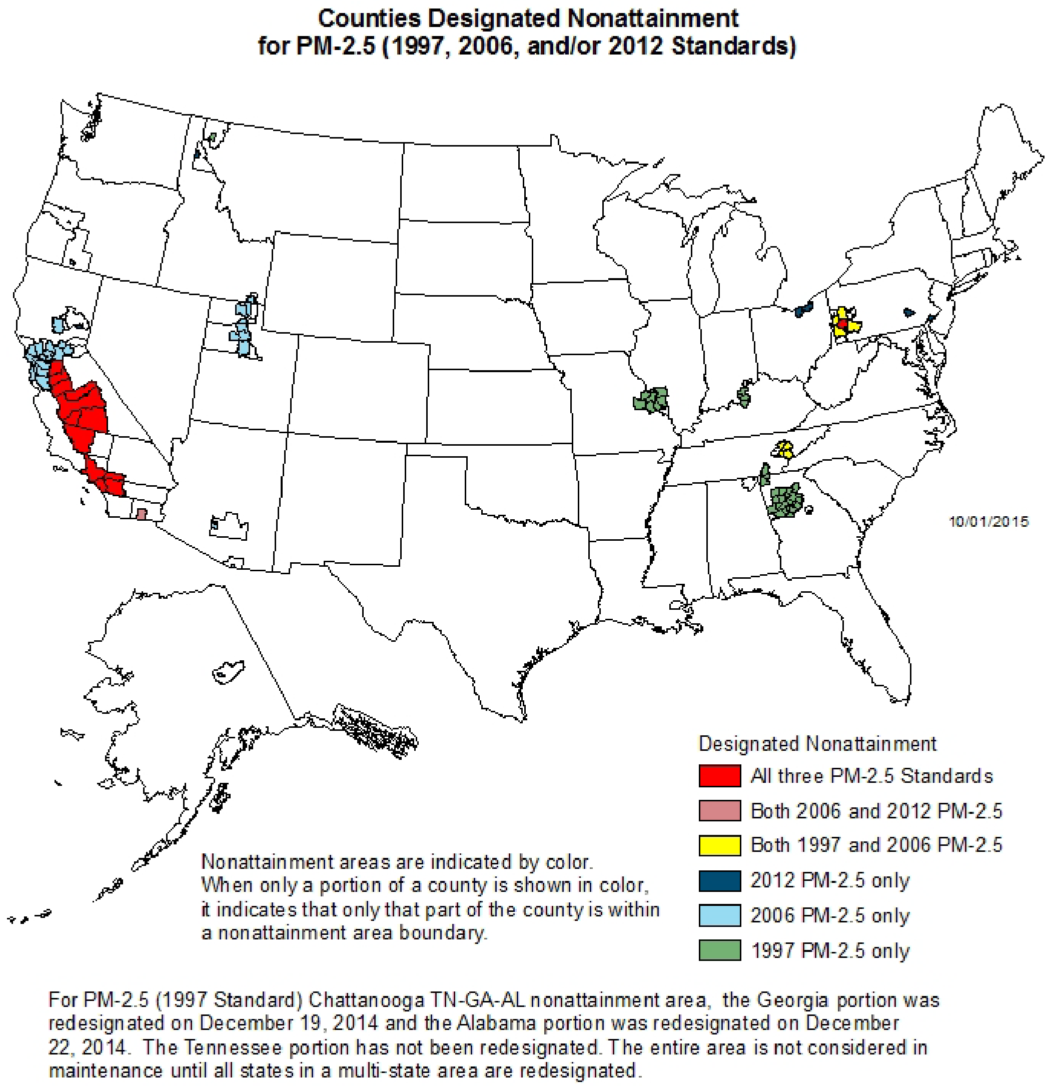

Figure 6-5 $PM_{2.5}$ Nonattainment Areas

The EPA has already adopted many mobile source emission control programs that are expected to reduce ambient PM concentrations. As a result of these and other federal, state and local programs, the number of areas that fail to meet the $PM_{2.5}$ NAAQS in the future is expected to decrease. However, even with the implementation of all current state and federal regulations, there are projected to be counties violating the $PM_{2.5}$ NAAQS well into the future. States will need to meet the 2006 24-hour standards in the 2015-2019 timeframe and the 2012 primary annual standard in the 2021-2025 timeframe. The emission reductions and improvements in ambient $PM_{2.5}$ concentrations from this action, which will take effect as early as model year 2018, will be helpful to states as they work to attain and maintain the $PM_{2.5}$ NAAQS.[U] The standards can assist areas with attainment dates in 2018 and beyond in attaining the NAAQS as

[U] The final Phase 2 trailer standards and PM controls for APUs begin with model year 2018.

expeditiously as practicable and may relieve areas with already stringent local regulations from some of the burden associated with adopting additional local controls.

6.2.1.2 Current Concentrations of Ozone

As described in Chapter6.1, ozone causes adverse health effects, and EPA has set national ambient air quality standards to protect against those health effects. The primary and secondary NAAQS for ozone are 8-hour standards with a level of 0.07 ppm. The most recent revision to the ozone standards was in 2015; the previous 8-hour ozone primary standard, set in 2008, had a level of 0.075 ppm. Nonattainment designations for the 2008 ozone standard were finalized on April 30, 2012, and May 31, 2012.[184] As of April 22, 2016, there were 44 ozone nonattainment areas for the 2008 ozone NAAQS, composed of 216 full or partial counties, with a population of more than 120 million. Nonattainment areas for the 2008 ozone NAAQS are pictured in Figure 6-6. In addition, EPA plans to finalize nonattainment areas for the 2015 ozone NAAQS in October 2017.

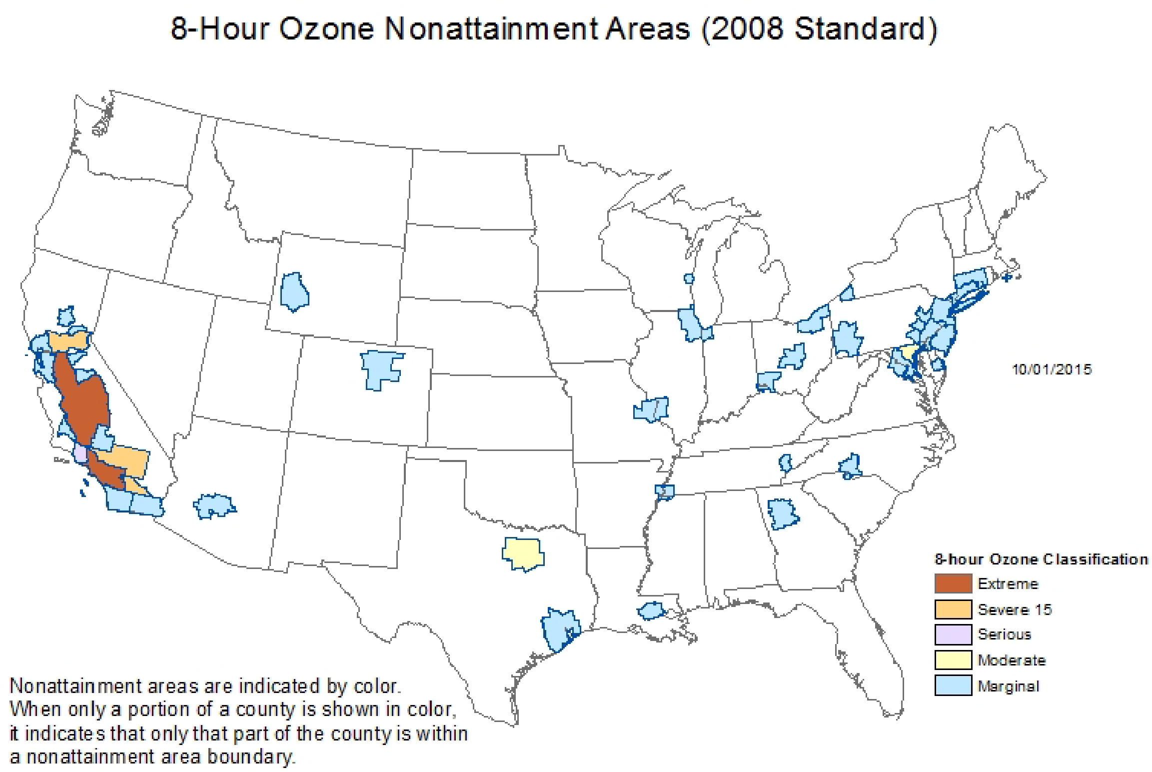

Figure 6-6 8-hour Ozone Nonattainment Areas (2008 Standard)

States with ozone nonattainment areas are required to take action to bring those areas into attainment. The attainment date assigned to an ozone nonattainment area is based on the area's classification. Most ozone nonattainment areas were required to attain the 1997 8-hour ozone NAAQS in the 2007 to 2013 time frame and then to maintain it thereafter. The attainment dates for areas designated nonattainment for the 2008 8-hour ozone NAAQS are in the 2015 to 2032 timeframe, depending on the severity of the problem in each area. Nonattainment area attainment dates associated with areas designated for the 2015 NAAQS will be in the 2020-2037 timeframe, depending on the severity of the problem in each area.[185]

EPA has already adopted many emission control programs that are expected to reduce ambient ozone levels. As a result of these and other federal, state and local programs, 8-hour ozone levels are expected to improve in the future. However, even with the implementation of all current state and federal regulations, there are projected to be counties violating the ozone NAAQS well into the future. The emission reductions from this action, which will take effect as early as model year 2018, will be helpful to states as they work to attain and maintain the ozone NAAQS.[V] The standards can assist areas with attainment dates in 2018 and beyond in attaining the NAAQS as expeditiously as practicable and may relieve areas with already stringent local regulations from some of the burden associated with adopting additional local controls

6.2.1.3 Current Concentrations of Nitrogen Oxides

EPA most recently completed a review of the primary NAAQS for NO_2 in January 2010. There are two primary NAAQS for NO_2: an annual standard (53 ppb) and a 1-hour standard (100 ppb). EPA promulgated area designations in the Federal Register on February 17, 2012. In this initial round of designations, all areas of the country were designated as "unclassifiable/attainment" for the 2010 NO_2 NAAQS based on data from the existing air quality monitoring network. EPA and state agencies are working to establish an expanded network of NO_2 monitors, expected to be deployed in the 2013-2017 time frame. Once three years of air quality data have been collected from the expanded network, EPA will be able to evaluate NO_2 air quality in additional locations.[186,187]

6.2.1.4 Current Concentrations of Sulfur Oxides

EPA most recently completed a review of the primary SO_2 NAAQS in June 2010. The current primary NAAQS for SO_2 is a 1-hour standard of 75 ppb. EPA finalized the initial area designations for 29 nonattainment areas in 16 states in a notice published in the Federal Register on August 5, 2013. In this first round of designations, EPA only designated nonattainment areas that were violating the standard based on existing air quality monitoring data provided by the states. The agency did not have sufficient information to designate any area as "attainment" or make final decisions about areas for which additional modeling or monitoring is needed (78 FR 47191, August 5, 2013). On March 2, 2015, the U.S. District Court for the Northern District of California accepted, as an enforceable order, an agreement between the EPA and Sierra Club and Natural Resources Defense Council to resolve litigation concerning the deadline for completing designations.[W] The court's order directs the EPA to complete designations for all remaining areas in the country in up to three additional rounds: the first round by July 2, 2016, the second round by December 31, 2017, and the final round by December 31, 2020.

[V] The final Phase 2 trailer standards begin with model year 2018.

[W] *Sierra Club v. McCarthy*, No. 3-13-cv-3953 (SI) (N.D. Cal. Mar. 2, 2015).

6.2.1.5 Current Concentrations of Carbon Monoxide

There are two primary NAAQS for CO: an 8-hour standard (9 ppm) and a 1-hour standard (35 ppm). The primary NAAQS for CO were retained in August 2011. There are currently no CO nonattainment areas; as of September 27, 2010, all CO nonattainment areas have been redesignated to attainment. The designations were based on the existing community-wide monitoring network. EPA is making changes to the ambient air monitoring requirements for CO. The new requirements are expected to result in approximately 52 CO monitors operating near roads within 52 urban areas by January 2015 (76 FR 54294, August 31, 2011).

6.2.1.6 Current Concentrations of Diesel Exhaust PM (DPM)

Because DPM is part of overall ambient PM and cannot be easily distinguished from overall PM, we do not have direct measurements of DPM in the ambient air. DPM concentrations are estimated using ambient air quality modeling based on DPM emission inventories. DPM emission inventories are computed as the exhaust PM emissions from mobile sources combusting diesel or residual oil fuel. DPM concentrations were recently estimated as part of the 2011 NATA.[188]

Concentrations of DPM were calculated at the census tract level in the 2011 NATA. Figure 6-7 below summarizes the distribution of ambient DPM concentrations at the national scale. Areas with high concentrations are clustered in the Northeast, Great Lake States, California, and the Gulf Coast States, and are also distributed throughout the rest of the U.S. Table 6-1 presents a distribution of ambient DPM concentrations across the country. The median DPM concentration calculated nationwide is 0.76 $\mu g/m^3$. Half of the DPM can be attributed to heavy-duty diesel vehicles.

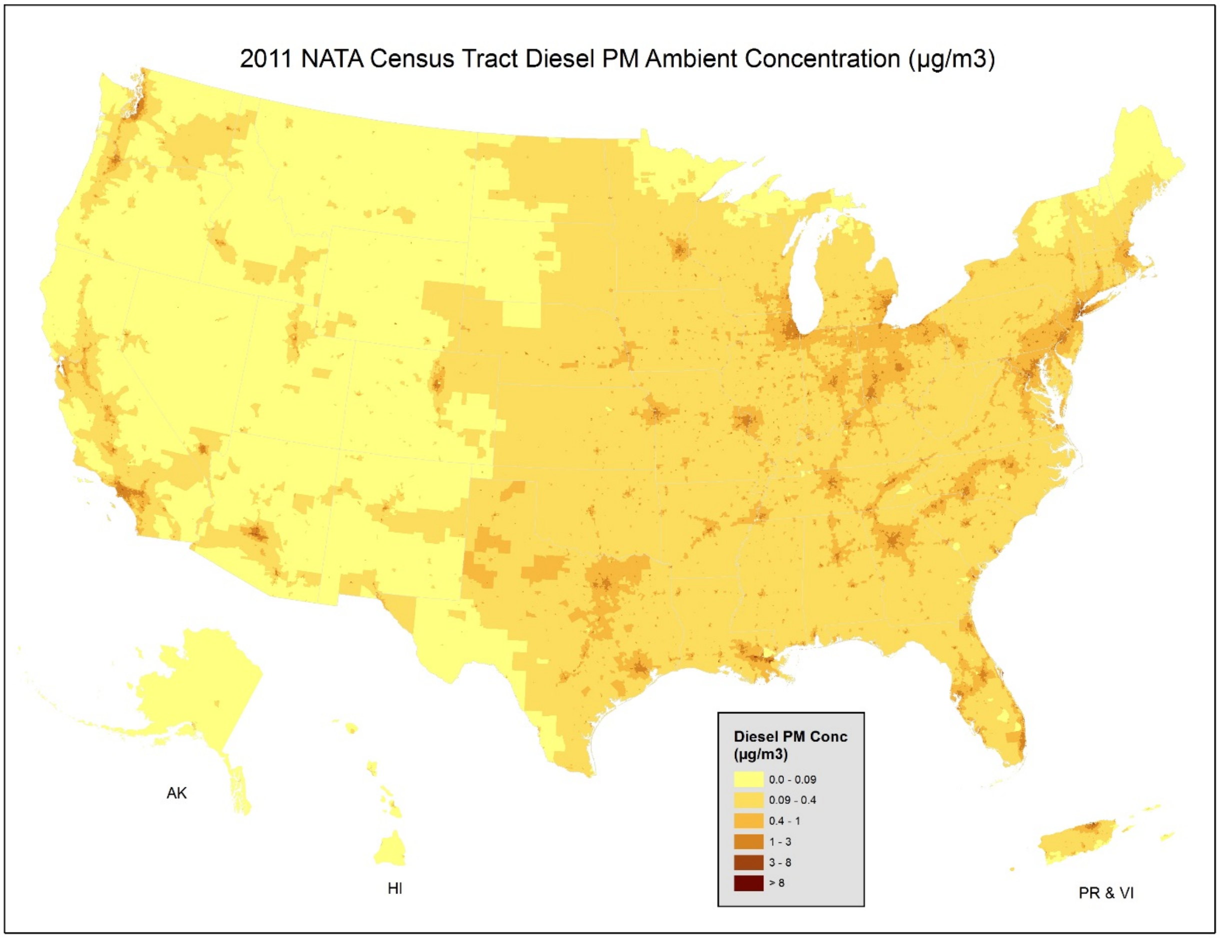

Figure 6-7 Estimated County Ambient Concentration of Diesel Particulate Matter

Table 6-1 Distribution of Census Tract Ambient Concentrations of DPM at the National Scale in 2011 NATA[a]

	AMBIENT CONCENTRATION (MG/M^3)
5th Percentile	0.15
25th Percentile	0.39
50th Percentile	0.76
75th Percentile	1.24
95th Percentile	2.37
Heavy-Duty Vehicle Contribution to Median Census Tract Concentrations	50%

Note:
[a] This table is generated from data contained in the diesel particulate matter Microsoft Access database file found in the results section of the 2011 NATA webpage (https://www3.epa.gov/national-air-toxics-assessment/2011-nata-assessment-results#pollutant).

6.2.1.7 Current Concentrations of Air Toxics

The majority of Americans continue to be exposed to ambient concentrations of air toxics at levels which have the potential to cause adverse health effects.[189] The levels of air toxics to which people are exposed vary depending on where people live and work and the kinds of activities in which they engage, as discussed in detail in EPA's most recent Mobile Source Air Toxics (MSAT) Rule.[190] In order to identify and prioritize air toxics, emission source types and locations which are of greatest potential concern, EPA conducts the National-Scale Air Toxics Assessment (NATA). The most recent NATA was conducted for calendar year 2011, and was released in December 2015.[191] NATA for 2011 includes four steps:

1) Compiling a national emissions inventory of air toxics emissions from outdoor sources

2) Estimating ambient concentrations of air toxics across the United States

3) Estimating population exposures across the United States

4) Characterizing potential public health risk due to inhalation of air toxics including both cancer and noncancer effects

According to the NATA for 2011, mobile sources were responsible for 50 percent of outdoor anthropogenic toxic emissions and were the largest contributor to cancer and noncancer risk from directly emitted pollutants.[X,192] Mobile sources are also large contributors to precursor emissions which react to form secondary concentrations of air toxics. Formaldehyde is the largest contributor to cancer risk of all 71 pollutants quantitatively assessed in the 2011 NATA. Mobile sources were responsible for more than 25 percent of primary anthropogenic emissions of this pollutant in 2011 and are major contributors to formaldehyde precursor emissions. Benzene is also a large contributor to cancer risk, and mobile sources account for almost 80 percent of ambient exposure. Over the years, EPA has implemented a number of mobile source and fuel controls which have resulted in VOC reductions, which also reduced formaldehyde, benzene and other air toxic emissions.

6.2.1.8 Current Visibility Levels

Designated $PM_{2.5}$ nonattainment areas indicate that, as of October 1, 2015, over 46 million people live in nonattainment areas for the $PM_{2.5}$ NAAQS. Thus, at least these populations would likely be experiencing visibility impairment, as well as many thousands of individuals who travel to these areas. In addition, while visibility trends have improved in Mandatory Class I Federal areas, these areas continue to suffer from visibility impairment.[193,194] Calculated from light extinction efficiencies from Trijonis et al. (1987, 1988), annual average visual range under natural conditions in the East is estimated to be 150 km ± 45 km (i.e., 65 to 120 miles) and 230 km ± 35 km (i.e., 120 to 165 miles) in the West.[195,196,197] In summary, visibility impairment is

[X] NATA also includes estimates of risk attributable to background concentrations, which includes contributions from long-range transport, persistent air toxics, and natural sources; as well as secondary concentrations, where toxics are formed via secondary formation. Mobile sources substantially contribute to long-range transport and secondarily formed air toxics.

experienced throughout the U.S., in multi-state regions, urban areas, and remote Mandatory Class I Federal areas.

6.2.1.9 Current Levels of Nitrogen and Sulfur Deposition

Over the past two decades, the EPA has undertaken numerous efforts to reduce nitrogen and sulfur deposition across the U.S. Analyses of long-term monitoring data for the U.S. show that deposition of both nitrogen and sulfur compounds has decreased over the last 25 years. The data show that reductions were more substantial for sulfur compounds than for nitrogen compounds. At 34 long-term monitoring sites in the eastern U.S., where data are most abundant, average total sulfur deposition decreased by 75 percent between 1989-1991 and 2011-2013, while average total nitrogen deposition decreased by 39 percent over the same time frames. [198] Although total nitrogen and sulfur deposition has decreased over time, many areas continue to be negatively impacted by deposition.

6.2.2 Projected Concentrations of Non-GHG Pollutants

Reductions in emissions of NO_X, VOC, $PM_{2.5}$ and air toxics expected as a result of the Phase 2 standards will lead to improvements in air quality, specifically decreases in ambient concentrations of $PM_{2.5}$, ozone, NO_2 and air toxics, as well as better visibility and reduced deposition.

Emissions and air quality modeling decisions are made early in the analytical process because of the time and resources associated with full-scale photochemical air quality modeling. As a result, the inventories used in the air quality modeling and the benefits modeling are different from the final emissions inventories. The air quality inventories and the final inventories are consistent in many ways, but there are some important differences which are discussed in Chapter 6.2.2.3. Chapter 5.5.2.3 of the RIA also has more detail on the differences between the air quality and final inventories.

6.2.2.1 Air Quality Modeling Results

This section summarizes the results of our air quality modeling, and more detail is available in Appendix 6.A to the RIA. Specifically, for the year 2040 we compare a reference scenario (a scenario without the standards) to a control scenario that includes the standards in the air quality inventory. The standards in the air quality inventory are based on the Phase 2 proposal. As mentioned above, the inventories used for the air quality modeling and the final inventories are consistent in many ways but there are some important differences. For example, the air quality modeling inventory predicted increases in downstream $PM_{2.5}$ emissions that we do not expect to occur. The air quality modeling inventory also predicts larger reductions in NOx emissions than the final inventory. The implications of these differences are noted in the following discussion of the air quality modeling results.

6.2.2.1.1 *Particulate Matter*

The air quality modeling indicates that for the majority of the country, annual and 24-hour $PM_{2.5}$ design values (DV) will decrease due to these standards. The magnitude of $PM_{2.5}$

reductions that will actually result from the final standards is difficult to predict because of the differences between the air quality modeling inventory and the final inventory. However, we do expect reductions in ambient concentrations of $PM_{2.5,}$ because the final standards will decrease primary $PM_{2.5,}$ NO_X, SO_X and VOC emissions.

As described in Section 5.5.2.3, the air quality modeling used inventories that do not reflect the new requirements for controlling $PM_{2.5}$ emissions from APUs installed in new tractors and therefore show increases in downstream $PM_{2.5}$ emissions that we now do not expect to occur. Although in most areas this direct $PM_{2.5}$ increase is outweighed by reductions in secondary $PM_{2.5}$, the air quality modeling does predict ambient $PM_{2.5}$ increases in a few places. We do not expect these increases in $PM_{2.5}$ DV to actually occur, because there will be no increases in downstream $PM_{2.5}$ emissions. The air quality inventories and the final rule inventories also have different assumptions about the usage of diesel-powered APUs. The air quality inventories assumed more widespread usage of diesel-powered APUs than was assumed for the final rule. As a result, the NO_X reductions in the air quality inventories are larger than we expect to occur, and the air quality modeling overestimates the reductions in ambient $PM_{2.5}$ due to secondary nitrate formation.

6.2.2.1.2 *Ozone*

EPA expects reductions in ambient ozone concentrations due to these final standards. Air quality modeling results indicate that 8-hour ozone DV will be reduced across the country. However, the magnitude of the reductions that will actually result from the final standards is difficult to estimate because the air quality modeling inventories included larger NOx emission reductions than we now expect to occur. As described in Chapter 5.5.2.3, the air quality inventories and the final rule inventories make different assumptions about the usage of diesel-powered APUs. The air quality inventories assumed more widespread usage of diesel-powered APUs than was assumed for the final rule, and as a result the NOx reductions and 8-hour ozone reductions are overestimated in the air quality modeling. While we expect the reductions in upstream and downstream NOx and VOC emissions to result in decreased 8-hour ozone DVs, the complex and non-linear chemistry governing ozone formation prevents us from estimating the magnitude without additional air quality modeling.

Maps and summary tables of the projected impacts of the air quality inventories on 8-hour ozone DV are included in Appendix 6.A.

6.2.2.1.3 *Nitrogen Dioxide*

EPA expects reductions in ambient nitrogen dioxide (NO_2) concentrations due to these final standards. Air quality modeling results indicate that annual average NO_2 concentrations will be reduced across the country. However, the magnitude of the reductions that will actually result from the final standards is difficult to estimate because the air quality modeling inventories included larger NOx emission reductions than we now expect to occur. As described in Chapter 5.5.2.3, the air quality inventories and the final rule inventories make different assumptions about the usage of diesel-powered APUs. The air quality inventories assumed more widespread usage of diesel-powered APUs than was assumed for the final rule, and as a result the reductions in ambient NO_2 concentrations are overestimated in the air quality modeling. Appendix 6A includes maps of absolute and percent change in NO_2 concentrations using air quality inventories.

6.2.2.1.4 *Air Toxics*

In this section, we describe results of our modeling of air toxics concentrations in 2040 with the Phase 2 standards included in the air quality inventory. Although there are a large number of compounds which are considered air toxics, we focused on those which were identified as national and regional-scale cancer and noncancer risk drivers in the 2011 NATA assessment and were also likely to be more significantly impacted by the standards. These compounds include benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein.

Our modeling indicates that the standards will have relatively little impact on national average ambient concentrations of the modeled air toxics. Annual absolute changes in ambient concentrations are generally less than 0.2 $\mu g/m^3$ for benzene, formaldehyde, and acetaldehyde and less than 0.005 $\mu g/m^3$ for acrolein and 1,3-butadiene. Naphthalene changes are in the range of 0.005 $\mu g/m^3$ along major roadways and in urban areas.

Appendix 6A includes air toxics concentration maps as well as population metrics, including the population living in areas with increases or decreases in concentrations of various magnitudes.

6.2.2.1.5 *Visibility*

Air quality modeling was used to project visibility conditions in 135 Mandatory Class I Federal areas across the U.S. The results show that in 2040 all the modeled areas would continue to have annual average deciview levels above background.[Y] As described in Chapter 5.5.2.3, the air quality modeling used inventories that do not reflect the new requirements for controlling $PM_{2.5}$ emissions from APUs installed in new tractors and therefore show increases in downstream $PM_{2.5}$ emissions that we now do not expect to occur. Although in most areas this direct $PM_{2.5}$ increase is outweighed by reductions in secondary $PM_{2.5}$, the air quality modeling does predict visibility to decrease in one area. We do not expect this decrease in visibility to actually occur, because there will be no increases in downstream $PM_{2.5}$ emissions. The air quality inventories and the final rule inventories also have different assumptions about the usage of diesel-powered APUs. The air quality inventories assumed more widespread usage of diesel-powered APUs than was assumed for the final rule. As a result, the NO_X reductions in the air quality inventories are larger than we expect to occur, and the air quality modeling overestimates the reductions in ambient $PM_{2.5}$ due to secondary nitrate formation. Appendix 6A contains the full visibility results from 2040 for the 135 analyzed areas.

[Y] The level of visibility impairment in an area is based on the light-extinction coefficient and a unit less visibility index, called a "deciview," which is used in the valuation of visibility. The deciview metric provides a scale for perceived visual changes over the entire range of conditions, from clear to hazy. Under many scenic conditions, the average person can generally perceive a change of one deciview. The higher the deciview value, the worse the visibility. Thus, an improvement in visibility is a decrease in deciview value.

6.2.2.1.6 *Deposition of Nitrogen and Sulfur*

Air quality modeling results indicate that nitrogen and sulfur deposition will be reduced in many areas of the country. The decreases in nitrogen and sulfur deposition are likely due to the projected reductions in emissions. As described in Chapter 6.2.2.3.1, the NO_X reductions assumed in the air quality inventories are larger than we expect to occur and reductions in nitrogen deposition are over-estimated in the air quality modeling. While the magnitude of the reductions in nitrogen deposition from the final rule is difficult to estimate, EPA does expect reductions in nitrogen deposition due to these final standards.

Maps of the projected impacts of the air quality inventories on nitrogen and sulfur deposition are included in Appendix 6.A.

6.3 Changes in Atmospheric CO_2 Concentrations, Global Mean Temperature, Sea Level Rise, and Ocean pH Associated with the Program's GHG Emissions Reductions

6.3.1 Introduction

The impact of GHG emissions on the climate has been reviewed in the 2009 Endangerment and Cause or Contribute Findings for Greenhouse Gases under section 202(a) of the Clean Air Act, the 2012-2016 light-duty vehicle rulemaking, the 2014-2018 heavy-duty vehicle GHG rulemaking, and the 2017-2025 light-duty vehicle rulemaking. See 74 FR at 66496; 75 FR at 25491; 76 FR at 57294; 77 FR at 62894. This section briefly discusses again some of the climate impact context for transportation emissions.

Once emitted, GHGs that are the subject of this regulation can remain in the atmosphere for decades to millennia, meaning that 1) their concentrations become well-mixed throughout the global atmosphere regardless of emission origin, and 2) their effects on climate are long lasting. GHG emissions come mainly from the combustion of fossil fuels (coal, oil, and gas), with additional contributions from the clearing of forests, agricultural activities, cement production, and some industrial activities. Transportation activities, in aggregate, were the second largest contributor to total U.S. GHG emissions in 2010 (27 percent of total emissions).[Z]

EPA Administrator relied on thorough and peer-reviewed assessments of climate change science prepared by the Intergovernmental Panel on Climate Change ("IPCC"), the United States Global Change Research Program ("USGCRP"), and the National Research Council of the National Academies ("NRC") [AA] as the primary scientific and technical basis for the Endangerment and Cause or Contribute Findings for Greenhouse Gases under section 202(a) of the Clean Air Act (74 FR 66496, December 15, 2009). These assessments comprehensively address the scientific issues EPA Administrator had to examine, providing her both data and information on a wide range of issues pertinent to the Endangerment Finding. These

[Z] U.S. EPA (2012) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010. EPA 430-R-12-001. Available at http://epa.gov/climatechange/emissions/downloads12/US-GHG-Inventory-2012-Main-Text.pdf

[AA] For a complete list of core references from IPCC, USGCRP/CCSP, NRC and others relied upon for development of the TSD for EPA's Endangerment and Cause or Contribute Findings see Section 1(b), specifically, Table 1.1 of the TSD. (Docket EPA-HQ-OAR-2010-0799).

assessments have been rigorously reviewed by the expert community, and also by United States government agencies and scientists, including by EPA itself.

Based on these assessments, EPA Administrator determined that the emissions from new motor vehicles and engines contributes to elevated concentrations of greenhouse gases, that these greenhouse gases cause warming; that the recent warming has been attributed to the increase in greenhouse gases; and that warming of the climate endangers the public health and welfare of current and future generations. The D.C. Circuit has emphatically upheld the reasonableness of these findings. Coalition for Responsible Regulation v. EPA, 684 F. 3d 102, 121 (D.C. Cir. 2012) upholding all of EPA's findings and stating "EPA had before it substantial record evidence that anthropogenic emissions of greenhouse gases 'very likely' caused warming of the climate over the last several decades. EPA further had evidence of current and future effects of this warming on public health and welfare. Relying again upon substantial scientific evidence, EPA determined that anthropogenically induced climate change threatens both public health and public welfare. It found that extreme weather events, changes in air quality, increases in food- and water-borne pathogens, and increases in temperatures are likely to have adverse health effects. The record also supports EPA's conclusion that climate change endangers human welfare by creating risk to food production and agriculture, forestry, energy, infrastructure, ecosystems, and wildlife. Substantial evidence further supported EPA's conclusion that the warming resulting from the greenhouse gas emissions could be expected to create risks to water resources and in general to coastal areas as a result of expected increase in sea level.")

A number of major peer-reviewed scientific assessments have been released since the administrative record concerning the Endangerment Finding closed following EPA's 2010 Reconsideration Denial[199]. These assessments include the "Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation"[200], the 2013-14 Fifth Assessment Report (AR5)[201], the 2014 National Climate Assessment report[202], the "Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean"[203], "Report on Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia"[204], "National Security Implications for U.S. Naval Forces" (National Security Implications)[205], "Understanding Earth's Deep Past: Lessons for Our Climate Future"[206], "Sea Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future"[207], "Climate and Social Stress: Implications for Security Analysis"[208], and "Abrupt Impacts of Climate Change" (Abrupt Impacts) assessments[209].

EPA has reviewed these assessments and finds that in general, the improved understanding of the climate system they present are consistent with the assessments underlying the 2009 Endangerment Finding.

The most recent assessments to be released were the IPCC AR5 assessments between September 2013 and April 2014, the NRC Abrupt Impacts assessment in December of 2013, and the U.S. National Climate Assessment in May of 2014. The NRC Abrupt Impacts report examines the potential for tipping points, thresholds beyond which major and rapid changes occur in the Earth's climate system or other systems impacted by the climate. The Abrupt Impacts report did find less cause for concern than some previous assessments regarding some abrupt events within the next century such as disruption of the Atlantic Meridional Overturning Circulation (AMOC) and sudden releases of high-latitude methane from hydrates and permafrost, but found that the potential for abrupt changes in ecosystems, weather and climate extremes, and groundwater supplies critical for agriculture now seem more likely, severe, and imminent. The assessment found that some abrupt changes were already underway (Arctic sea ice retreat and increases in extinction risk due to the speed of climate change), but cautioned that even abrupt changes such as the AMOC disruption that are not expected in this century can have severe impacts when they happen.

The IPCC AR5 assessments are also generally consistent with the underlying science supporting the 2009 Endangerment Finding. For example, confidence in attributing recent warming to human causes has increased: the IPCC stated that it is extremely likely (>95 percent confidence) that human influences have been the dominant cause of recent warming. Moreover, the IPCC found that the last 30 years were likely (>66 percent confidence) the warmest 30 year period in the Northern Hemisphere of the past 1400 years, that the rate of ice loss of worldwide glaciers and the Greenland and Antarctic ice sheets has likely increased, that there is medium confidence that the recent summer sea ice retreat in the Arctic is larger than has been in 1450 years, and that concentrations of carbon dioxide and several other of the major greenhouse gases are higher than they have been in at least 800,000 years. Climate-change induced impacts have been observed in changing precipitation patterns, melting snow and ice, species migration, negative impacts on crops, increased heat and decreased cold mortality, and altered ranges for water-borne illnesses and disease vectors. Additional risks from future changes include death, injury, and disrupted livelihoods in coastal zones and regions vulnerable to inland flooding, food insecurity linked to warming, drought, and flooding, especially for poor populations, reduced access to drinking and irrigation water for those with minimal capital in semi-arid regions, and decreased biodiversity in marine ecosystems, especially in the Arctic and tropics, with implications for coastal livelihoods. The IPCC determined that "[c]ontinued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gases emissions."

Finally, the recently released National Climate Assessment stated, "Climate change is already affecting the American people in far reaching ways. Certain types of extreme weather events with links to climate change have become more frequent and/or intense, including prolonged periods of heat, heavy downpours, and, in some regions, floods and droughts. In addition, warming is causing sea level to rise and glaciers and Arctic sea ice to melt, and oceans are becoming more acidic as they absorb carbon dioxide. These and other aspects of climate change are disrupting people's lives and damaging some sectors of our economy."

Assessments from these bodies represent the current state of knowledge, comprehensively cover and synthesize thousands of individual studies to obtain the majority conclusions from the body of scientific literature and undergo a rigorous and exacting standard of review by the peer expert community and U.S. government.

Based on modeling analysis performed by EPA, reductions in CO_2 and other GHG emissions associated with these final rules will affect future climate change. Since GHGs are well-mixed in the atmosphere and have long atmospheric lifetimes, changes in GHG emissions will affect atmospheric concentrations of greenhouse gases and future climate for decades to millennia, depending on the gas. This section provides estimates of the projected change in atmospheric CO_2 concentrations based on the emission reductions estimated for these final rules, compared to the reference case. In addition, this section analyzes the response to the changes in GHG concentrations of the following climate-related variables: global mean temperature, sea level rise, and ocean pH. See Chapter 5 in this RIA for the estimated net GHG emissions reductions over time.

6.3.2 Projected Change in Atmospheric CO_2 Concentrations, Global Mean Surface Temperature and Sea Level Rise

To assess the impact of the emissions reductions resulting from the final rules, EPA estimated changes in projected atmospheric CO_2 concentrations, global mean surface temperature and sea-level rise to 2100 using the GCAM (Global Change Assessment Model, formerly MiniCAM), integrated assessment model[BB,210] coupled with the MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change) simple climate model.[CC,211,212] GCAM was used to create the globally and temporally consistent set of climate relevant emissions required for running MAGICC. MAGICC was then used to estimate the projected change in relevant climate variables over time. Given the magnitude of the estimated emissions reductions associated with the rules, a simple climate model such as MAGICC is appropriate for estimating the atmospheric and climate response.

6.3.2.1 Methodology

Emissions reductions associated with the rules were evaluated with respect to a baseline reference case. An emissions scenario was developed by applying the estimated emissions reductions from the final program relative to the baseline to the GCAM reference (no climate policy) scenario (used as the basis for the Representative Concentration Pathway RCP4.5).[213] Specifically, the annual CO_2, N_2O, CH_4, NO_X and SO_2 emissions reductions estimated from the final program were applied as net reductions to the GCAM global baseline net emissions for each substance. The emissions reductions past 2050 for all emissions were scaled with total U.S. road transportation fuel consumption from the GCAM reference scenario. This was chosen as a simple scale factor given that both direct and upstream emissions changes are included in the emissions reduction scenario provided. Road transport fuel consumption past 2050 does not change significantly and thus emissions reductions remain relatively constant from 2050 through 2100.

[BB] GCAM is a long-term, global integrated assessment model of energy, economy, agriculture and land use that considers the sources of emissions of a suite of greenhouse gases (GHG's), emitted in 14 globally disaggregated regions, the fate of emissions to the atmosphere, and the consequences of changing concentrations of greenhouse related gases for climate change. GCAM begins with a representation of demographic and economic developments in each region and combines these with assumptions about technology development to describe an internally consistent representation of energy, agriculture, land-use, and economic developments that in turn shape global emissions.

[CC] MAGICC consists of a suite of coupled gas-cycle, climate and ice-melt models integrated into a single framework. The framework allows the user to determine changes in greenhouse-gas concentrations, global-mean surface air temperature and sea-level resulting from anthropogenic emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), reactive gases (CO, NO_X, VOCs), the halocarbons (e.g. HCFCs, HFCs, PFCs) and sulfur dioxide (SO_2). MAGICC emulates the global-mean temperature responses of more sophisticated coupled Atmosphere/Ocean General Circulation Models (AOGCMs) with high accuracy.

The GCAM reference scenario[214] depicts a world in which global population reaches a maximum of more than 9 billion in 2065 and then declines to 8.7 billion in 2100 while global GDP grows by an order of magnitude and global energy consumption triples. The reference scenario includes no explicit policies to limit carbon emissions, and therefore fossil fuels continue to dominate global energy consumption, despite substantial growth in nuclear and renewable energy. Atmospheric CO_2 concentrations rise throughout the century and reach 760 to 820 ppmv by 2100, depending on climatic parameters, with total radiative forcing increasing more than 5 Watts per square meter (W/m^2) above 1990 levels by 2100. Forest land declines in the reference scenario to accommodate increases in land use for food and bioenergy crops. Even with the assumed agricultural productivity increases, the amount of land devoted to crops increases in the first half of the century due to increases in population and income (higher income drives increases in land-intensive meat consumption). After 2050 the rate of growth in food demand slows, in part due to declining population. As a result the amount of cropland and also land use change (LUC) emissions decline as agricultural crop productivity continues to increase.

The GCAM reference scenario uses non-CO_2 and pollutant emissions implemented as described in Smith and Wigley (2006); land-use change emissions as described in Wise et al. (2009); and updated base-year estimates of global GHG emissions. This scenario was created as part of the Climate Change Science Program (CCSP) effort to develop a set of long-term global emissions scenarios that incorporate an update of economic and technology data and utilize improved scenario development tools compared to the IPCC *Special Report on Emissions Scenarios* (SRES) (IPCC 2000).

Using MAGICC 5.3 v2,[215] the change in atmospheric CO_2 concentrations, global mean temperature, and sea level were projected at five-year time steps to 2100 for both the reference (no climate policy) scenario and the emissions reduction scenario specific to the final program. To capture some of the uncertainty in the climate system, the changes in projected atmospheric CO_2 concentrations, global mean temperature and sea level were estimated across a range of plausible climate sensitivities, 1.5°C to 6.0°C.[DD] The range as illustrated in Chapter 10, Box 10.2, Figure 2 of the IPCC's Working Group I is approximately consistent with the 10-90 percent probability distribution of the individual cumulative distributions of climate sensitivity.[216] Other uncertainties, such as uncertainties regarding the carbon cycle, ocean heat uptake, or aerosol forcing, were not addressed.

MAGICC calculates the forcing response at the global scale from changes in atmospheric concentrations of CO_2, CH_4, N_2O, HFCs, and tropospheric ozone. It also includes the effects of temperature changes on stratospheric ozone and the effects of CH_4 emissions on stratospheric water vapor. Changes in CH_4, NO_X, VOC, and CO emissions affect both O_3 concentrations and CH_4 concentrations. MAGICC includes the relative climate forcing effects of changes in sulfate

[DD] In IPCC reports, equilibrium climate sensitivity refers to the equilibrium change in the annual mean global surface temperature following a doubling of the atmospheric equivalent carbon dioxide concentration. The most recent IPCC AR5 assessment states that climate sensitivity is "likely" to be in the range of 1.5°C to 4.5°C, "extremely unlikely" to be less than 1°C, and "very unlikely" to be greater than 6 °C." Intergovernmental Panel on Climate Change (IPCC). 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

concentrations due to changing SO_2 emissions, including both the direct effect of sulfate particles and the indirect effects related to cloud interactions. However, MAGICC does not calculate the effect of changes in concentrations of other aerosols such as nitrates, black carbon, or organic carbon, making the assumption that the sulfate cooling effect is a proxy for the sum of all the aerosol effects. Therefore, the climate effects of changes in $PM_{2.5}$ emissions and precursors (besides SO_2) presented in Chapter 5 were not included in the calculations in this chapter. MAGICC also calculates all climate effects at the global scale. This global scale captures the climate effects of the long-lived, well-mixed greenhouse gases, but does not address the fact that short-lived climate forcers such as aerosols and ozone can have effects that vary with location and timing of emissions. Black carbon in particular is known to cause a positive forcing or warming effect by absorbing incoming solar radiation, but there are uncertainties about the magnitude of that warming effect and the interaction of black carbon (and other co-emitted aerosol species) with clouds. See 77 FR 38890, 38991-993 (June 29, 2012). While black carbon is likely to be an important contributor to climate change, it would be premature to include quantification of black carbon climate impacts in an analysis of the final standards at this time. See generally, EPA, Response to Comments to the Endangerment Finding Vol. 9 Section 9.1.6.1, the discussion of black carbon in the endangerment finding at 74 FR at 66520, EPA's discussion in the recent proposal to revise the PM NAAQS (77 FR at 38991-993), and the recently published EPA Report to Congress on Black Carbon. Additionally, the magnitude of $PM_{2.5}$ emissions changes (and therefore, black carbon emission changes) related to these standards are small in comparison to the changes in the pollutants which have been included in the MAGICC model simulations.

To compute the changes in atmospheric CO_2 concentration, global mean temperature, and sea level rise specifically attributable to the impacts of the standards, the difference in emissions between the final program and the baseline scenario was subtracted from the GCAM reference emissions scenario. As a result of the final program's emissions reductions relative to the baseline case, by 2100 the concentration of atmospheric CO_2 is projected to be reduced by approximately 1.2 to 1.3 parts per million by volume (ppmv), the global mean temperature is projected to be reduced by approximately 0.0027 to 0.0065°C, and global mean sea level rise is projected to be reduced by approximately 0.026 to 0.058 cm. For sea level rise, the calculations in MAGICC do not include the possible effects of accelerated ice flow in Greenland and/or Antarctica; including these effects would show correspondingly larger benefits of mitigation.

Figure 6-8 provides the results over time for the estimated reductions in atmospheric CO_2 concentration associated with the final program compared to the baseline scenario. Figure 6-9 provides the estimated change in projected global mean temperatures associated with the final program. Figure 6-10 provides the estimated reductions in global mean sea level rise associated with the final program. The range of reductions in global mean temperature and sea level rise due to uncertainty in climate sensitivity is larger than that for CO_2 concentrations because CO_2 concentrations are only weakly coupled to climate sensitivity through the dependence on temperature of the rate of ocean absorption of CO_2, whereas the magnitude of temperature change response to CO_2 changes (and therefore sea level rise) is more tightly coupled to climate sensitivity in the MAGICC model.

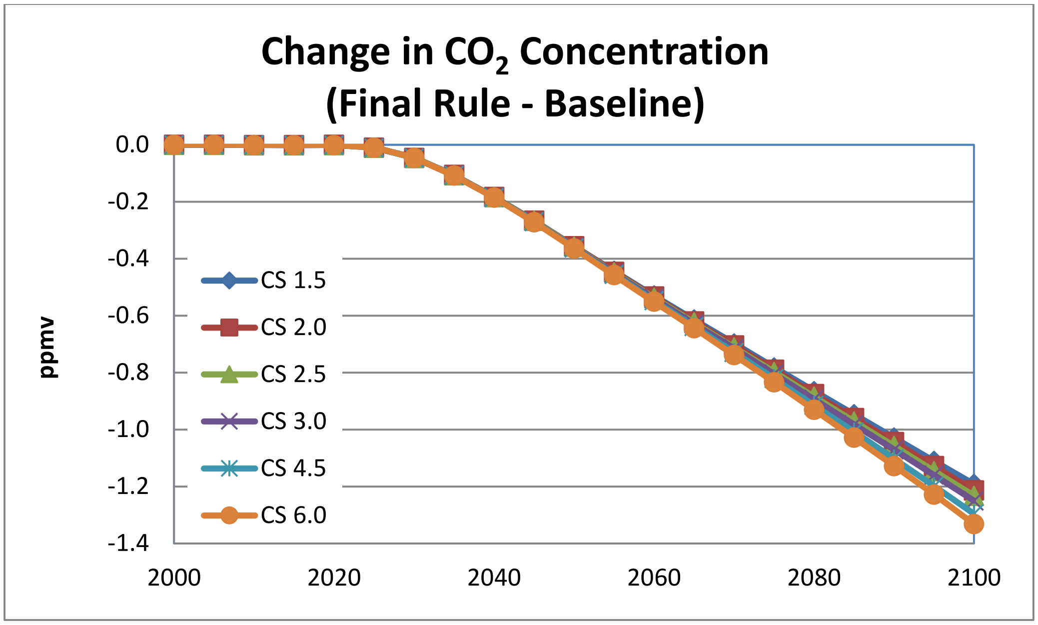

Figure 6-8 Estimated Projected Reductions in Atmospheric CO_2 Concentrations (parts per million by volume) from the Baseline for the Heavy-Duty Final Program (climate sensitivity (CS) cases ranging from 1.5-6°C)

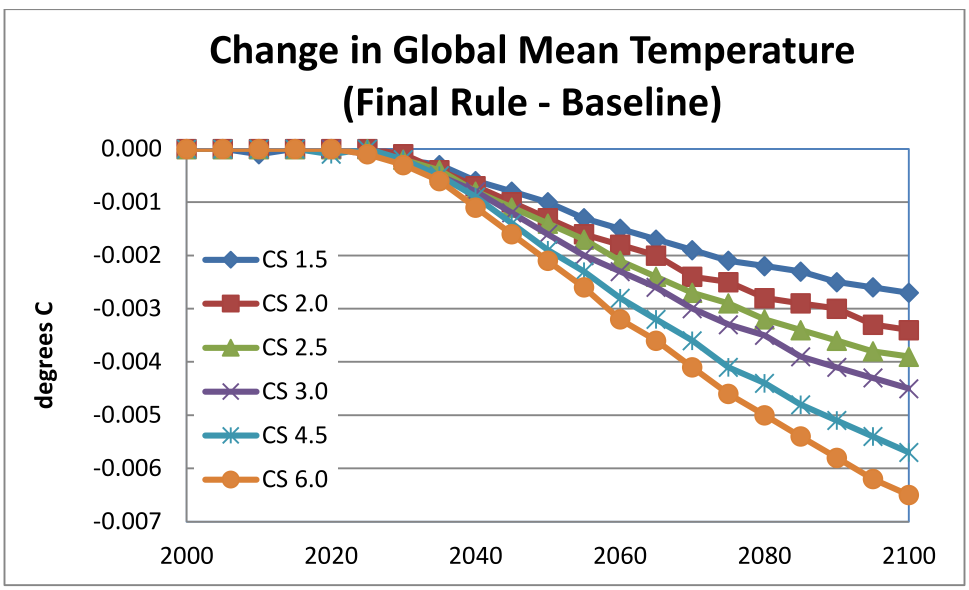

Figure 6-9 Estimated Projected Reductions in Global Mean Surface Temperatures from the Baseline for the Heavy-Duty Final Program (climate sensitivity (CS) cases ranging from 1.5-6°C)

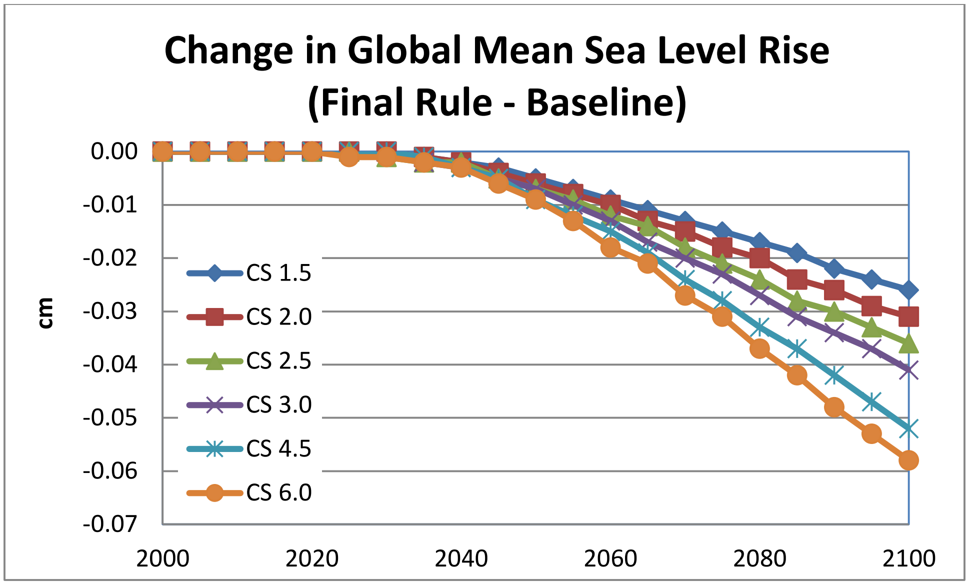

Figure 6-10 Estimated Projected Reductions in Global Mean Sea Level Rise from the Baseline for the Heavy-Duty Final Program (climate sensitivity (CS) cases ranging from 1.5-6°C)

The results in Figure 6-9 and Figure 6-10 show reductions in the projected global mean temperature and sea level respectively, across all climate sensitivities. The projected reductions are small relative to the change in temperature (1.8 – 4.8 ºC) and sea level rise (23 – 56 cm) from 1990 to 2100 from the MAGICC simulations for the GCAM reference case. However, this is to be expected given the magnitude of emissions reductions expected from the rules in the context of global emissions. These reductions are quantifiable, directionally consistent, and will contribute to reducing the risks associated with climate change. Notably, these effects are occurring everywhere around the globe, so benefits that appear to be marginal for any one location, such as a reduction in sea level rise of half a millimeter, can be sizable when the effects are summed along thousands of miles of coastline. Climate change is a global phenomenon and EPA recognizes that this one national action alone will not prevent it; EPA notes this would be true for any given GHG mitigation action when taken alone or when considered in isolation. EPA also notes that a substantial portion of CO_2 emitted into the atmosphere is not removed by natural processes for millennia, and therefore each unit of CO_2 not emitted into the atmosphere due to this rule avoids essentially permanent climate change on centennial time scales. Again, it should be noted that the calculations in MAGICC do not include the possible effects of accelerated ice flow in Greenland and/or Antarctica: the recent NRC report estimated a likely sea level increase for the A1B SRES scenario of 0.5 to 1.0 meters, almost double the estimate from MAGICC, so projected reductions in sea level rise may be similarly underestimated.[217] If other uncertainties besides climate sensitivity were included in the analysis, the resulting ranges of projected changes would likely be slightly larger.

6.3.3 Estimated Projected Change in Ocean pH

For these rules, EPA analyzes another key climate-related variable and calculates projected change in ocean pH for tropical waters. For this analysis, changes in ocean pH are related to the change in the atmospheric concentration of carbon dioxide (CO_2) resulting from the emissions reductions associated with the final program. EPA used the program developed for CO_2 System Calculations CO2SYS,[218] version 1.05, a program which performs calculations relating parameters of the carbon dioxide (CO_2) system in seawater. The program was developed by Ernie Lewis at Brookhaven National Laboratory and Doug Wallace at the Institut für Meereskunde in Germany, supported by the U.S. Department of Energy, Office of Biological and Environmental Research, under Contract No. DE-ACO2-76CH00016.

The CO2SYS program uses two of the four measurable parameters of the CO_2 system [total alkalinity (TA), total inorganic CO_2 (TC), pH, and either fugacity (fCO_2) or partial pressure of CO_2 (pCO_2)] to calculate the other two parameters given a specific set of input conditions (temperature and pressure) and output conditions chosen by the user. EPA utilized the Excel version (Pierrot et al. 2006)[219] of the program to compute pH for three scenarios: the baseline scenario at a climate sensitivity of 3 degrees for which the CO_2 concentrations was calculated to be 784.87 in 2100, the final program relative to the baseline with a CO_2 concentration of 783.62, and a calculation for 1990 with a CO_2 concentration of 353.63.

Using the set of seawater parameters detailed below, EPA calculated pH levels for the three scenarios. The pH of the emissions standards relative to the baseline scenario pH was +0.0006 units (more basic). For comparison, the difference between the baseline scenario in 2100 and the pH in 1990 was -0.30 pH units (more acidic).

The CO2SYS program required the input of a number of variables and constants for each scenario for calculating the result for both the reference case and the final program's emissions reduction baseline cases. EPA used the following inputs, with justification and references for these inputs provided in brackets:

1) Input mode: Single-input
2) Choice of constants: Mehrbach et al. (1973)[220], refit by Dickson and Millero (1987)[221]
3) Choice of fCO_2 or pCO_2: pCO_2
4) Choice of KSO4: Dickson (1990)[222] Choice of KSO4: Dickson (1990)[223]
5) Choice of pH scale: Total scale Choice of pH scale: Total scale
6) $[B]_T$ value: Uppstrom, 1974

The program provides several choices of constants for saltwater that are needed for the calculations. EPA calculated pH values using all choices and found that in all cases the choice had an indistinguishable effect on the results. In addition, EPA ran the model using a variety of other required input values to test whether the model was sensitive to these inputs. EPA found the model was not sensitive to these inputs in terms of the incremental change in pH calculated for each climate sensitivity case. The input values are derived from certified reference materials of sterilized natural sea water (Dickson, 2003, 2005, and 2009).[224] Based on the projected atmospheric CO_2 concentration reductions that would result from the final program's baseline case (1.3 ppmv for a climate sensitivity of 3.0), the modeling program calculates an increase in ocean pH of approximately 0.0006 pH units in 2100. Thus, this analysis indicates the projected decrease in atmospheric CO_2 concentrations from the final program yields an increase in ocean pH. Table 6-2 contains the projected changes in ocean pH based the change in atmospheric CO_2 concentrations which were derived from the MAGICC modeling.

Table 6-2 Impact of the Rule's GHG Emissions Reductions on Ocean pH

CLIMATE SENSITIVITY	DIFFERENCE IN CO_2[A]	YEAR	PROJECTED CHANGE
3.0	-1.3 ppmv	2100	0.0006

Note:
[a] Represents the change in atmospheric CO_2 concentrations in 2100 based on the difference from the rule relative to the base case from the GCAM reference scenario used in the MAGICC modeling.

6.3.4 Summary of Climate Analyses

EPA's analysis of the impact of the final program's emissions reductions on global climate conditions is intended to quantify these potential reductions using the best available science. While EPA's modeling results of the impact of the final program alone show small differences in climate effects (CO_2 concentration, global mean temperature, sea level rise, and ocean pH), in comparison to the total projected changes, they yield results that are repeatable and directionally consistent within the modeling frameworks used. The results are summarized in Table 6-3, Impact of GHG Emissions Reductions on Projected Changes in Global Climate Associated with the Final Program.

These projected reductions are proportionally representative of changes to U.S. GHG emissions in the transportation sector. While not formally estimated for this final program, a reduction in projected global mean temperature and sea level rise implies a reduction in the risks associated with climate change. The figures for these variables illustrate that across a range of climate sensitivities projected global mean temperature and sea level rise increase less in the final program scenario than in the reference (no climate policy) case. The benefits of GHG emissions reductions can be characterized both qualitatively and quantitatively, some of which can be monetized (see Chapter 9). There are substantial uncertainties in modeling the global risks of climate change, which complicates quantification and cost-benefits assessments. Changes in climate variables are a meaningful proxy for changes in the risk of all potential impacts--including those that can be monetized, and those that have not been monetized but can be quantified in physical terms (e.g., water availability), as well as those that have not yet been quantified or are extremely difficult to quantify (e.g., forest disturbance and catastrophic events such as collapse of large ice sheets and subsequent sea level rise).

Table 6-3 Impact of GHG Emissions Reductions on Projected Changes in Global Climate Associated with the Final Program (Based on a Range of Climate Sensitivities from 1.5-6°C)

VARIABLE	UNITS	YEAR	PROJECTED CHANGE
Atmospheric CO_2 Concentration	ppmv	2100	-1.2 to -1.3
Global Mean Surface Temperature	ºC	2100	-0.0027 to -0.0065
Sea Level Rise	cm	2100	-0.026 to -0.058
Ocean pH	pH units	2100	+0.0006[a]

Note:
[a] The value for projected change in ocean pH is based on a climate sensitivity of 3.0.

Appendix 6.A to Chapter 6 - Air Quality Modeling Results

6A.1 Air Quality Modeling Methodology

Air quality models use mathematical and numerical techniques to simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere. Based on inputs of meteorological data and source information, these models are designed to characterize primary pollutants that are emitted directly into the atmosphere and secondary pollutants that are formed as a result of complex chemical reactions within the atmosphere. Photochemical air quality models have become widely recognized and routinely utilized tools for regulatory analysis by assessing the effectiveness of control strategies. These models are applied at multiple spatial scales - local, regional, national, and global. This section provides detailed information on the photochemical model used for our air quality analysis (the Community Multi-scale Air Quality (CMAQ) model), atmospheric reactions and the role of chemical mechanisms in modeling, and model uncertainties and limitations. Further discussion of the air quality modeling methodology is included in the Air Quality Modeling Technical Support Document (AQM TSD) found in the docket for this rule.

6A1.1 Air Quality Modeling Analysis Overview

A national-scale air quality modeling analysis was performed to estimate future year 8-hour ozone concentrations, annual $PM_{2.5}$ concentrations, 24-hour $PM_{2.5}$ concentrations, annual NO_2 concentrations, air toxics concentrations, visibility levels and nitrogen and sulfur deposition levels for 2040. The 2011-based CMAQ modeling platform was used as the basis for the air quality modeling for this rule. This platform represents a structured system of connected modeling-related tools and data that provide a consistent and transparent basis for assessing the air quality response to projected changes in emissions. The base year of data used to construct this platform includes emissions and meteorology for 2011. The platform was developed by the U.S. EPA's Office of Air Quality Planning and Standards in collaboration with the Office of Research and Development and is intended to support a variety of regulatory and research model applications and analyses.

The CMAQ modeling system is a non-proprietary, publicly available, peer-reviewed, state-of-the-science, three-dimensional, grid-based Eulerian air quality model designed to estimate the formation and fate of oxidant precursors, primary and secondary PM concentrations, acid deposition, and air toxics, over regional and urban spatial scales for given input sets of meteorological conditions and emissions.[225,226,227] The CMAQ model version 5.1, which was an upcoming new community version in late 2015, was most recently peer-reviewed in September of 2015 for the U.S. EPA.[228] The CMAQ model is a well-known and well-respected tool and has been used in numerous national and international applications.[229,230,231] This 2011 multi-pollutant modeling platform used the most recent multi-pollutant CMAQ code available at the time of air quality modeling (CMAQ version 5.0.2 multi pollutant version[EE]).

[EE] CMAQ version 5.0.2 was released in April 2014. It is available from the Community Modeling and Analysis System (CMAS) as well as previous peer-review reports at: http://www.cmascenter.org.

CMAQ includes many science modules that simulate the emission, production, decay, deposition and transport of organic and inorganic gas-phase and particle-phase pollutants in the atmosphere. We used CMAQ v5.0.2 which reflects updates to version 5.0 to improve the underlying science algorithms as well as include new diagnostic/scientific modules which are detailed at http:www.cmascenter.org.[232,233,234] Chapter 6A1.6 of this RIA discusses the chemical mechanism and SOA formation.

6A1.2 Model Domain and Configuration

The CMAQ modeling domain encompasses all of the lower 48 states and portions of Canada and Mexico, see Figure 6A-1. The modeling domain is made up of a 12 kilometer (km) grid and contains 25 vertical layers with the top of the modeling domain at about 17,600 meters, or 50 millibars (mb) of atmospheric pressure.

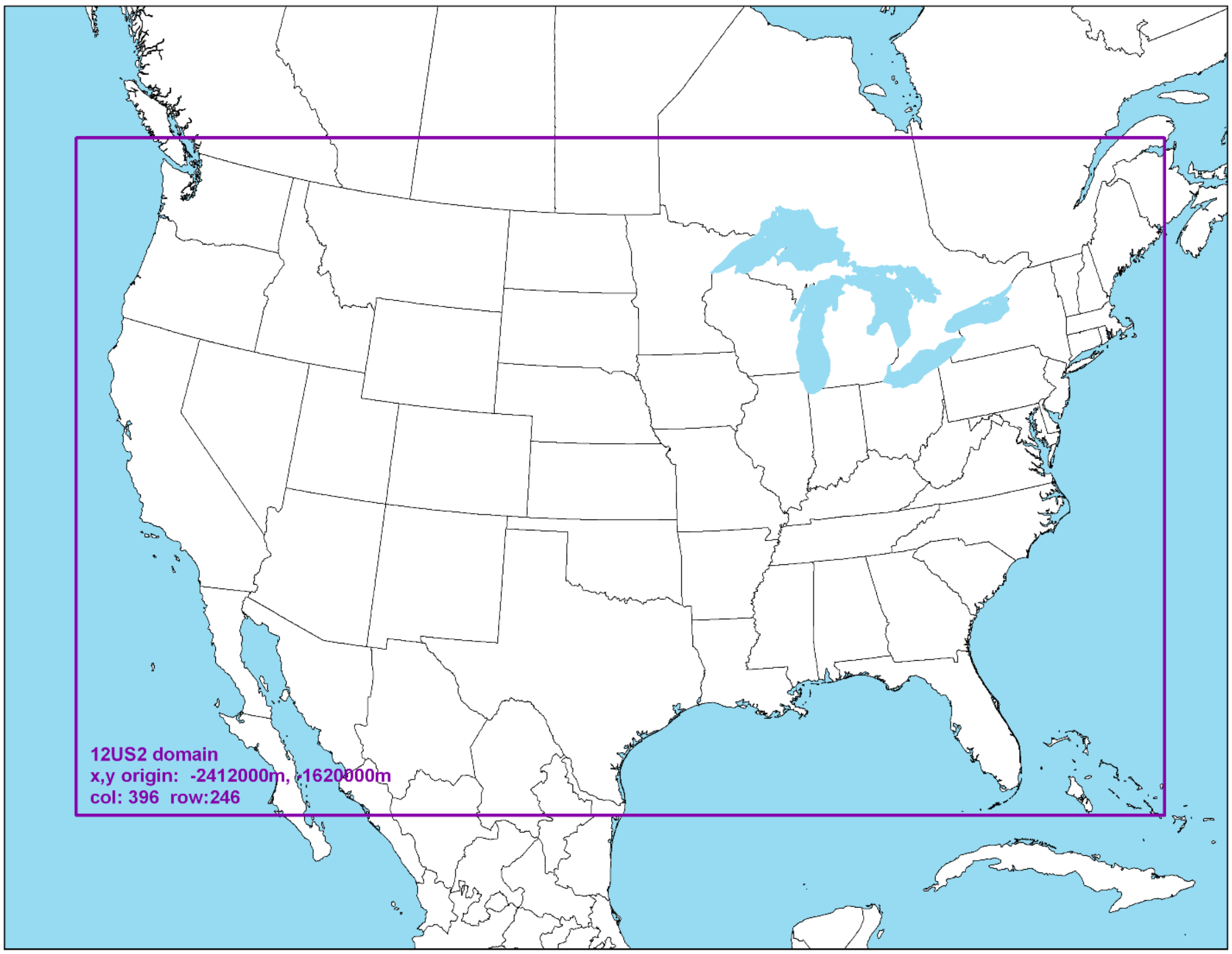

Figure 6A-1 Map of the CMAQ 12-km US Modeling Domain

6A1.3 Model Inputs

The key inputs to the CMAQ model include emissions from anthropogenic and biogenic sources, meteorological data, and initial and boundary conditions.

The CMAQ meteorological input files were derived from simulations of the Weather Research and Forecasting Model (WRF) version 3.4, Advanced Research WRF (ARW) core [235] for the entire year of 2011 over model domains that are slightly larger than those shown in Figure 6A-1. The WRF Model is a next-generation mesoscale numerical weather prediction system developed for both operational forecasting and atmospheric research applications (http://wrf-model.org). The meteorology for the national 12 km grid was developed by EPA and are described in more detail within the AQM TSD. The meteorological outputs from WRF were processed to create model-ready inputs for CMAQ using the Meteorology-Chemistry Interface Processor (MCIP) version 4.1.3. Outputs include: horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each grid cell in each vertical layer.[236] The 2011 CMAQ meteorological inputs will be derived from Version 3.4 of the Weather Research Forecasting Model (WRF).[237] These inputs included hourly-varying horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each grid cell in each vertical layer. Details of the annual 2011 meteorological model simulation and evaluation will be described in more detail within the air quality modeling technical support document.

The lateral boundary and initial species concentrations are provided by a three-dimensional global atmospheric chemistry model, the GEOS-Chem model[238] (standard version 8-03-02 with 8-02-01 chemistry). The global GEOS-Chem model simulates atmospheric chemical and physical processes driven by assimilated meteorological observations from the NASA's Goddard Earth Observing System (GEOS-5; additional information available at: http://gmao.gsfc.nasa.gov/GEOS/ and http://wiki.seas.harvard.edu/geos-chem/index.php/GEOS-5). This model was run for 2011 with a grid resolution of 2.0 degrees x 2.5 degrees (latitude-longitude). The predictions were used to provide one-way dynamic boundary conditions at one-hour intervals and an initial concentration field for the CMAQ simulations. A GEOS-Chem evaluation was conducted for the purpose of validating the 2011 GEOS-Chem simulation for predicting selected measurements relevant to their use as boundary conditions for CMAQ. This evaluation included using satellite retrievals paired with GEOS-Chem grid cells.[239] More information is available about the GEOS-Chem model and other applications using this tool at: http://acmg.seas.harvard.edu/geos.

The emissions inputs used for the 2011 base year and 2040 reference and control scenarios analyzed for this rule are summarized in Chapter 5 of this RIA and described in more detail in the Emission Inventories for Air Quality Modeling Technical Support Document (IAQ TSD).

6A1.4 CMAQ Evaluation

An operational model performance evaluation for ozone, $PM_{2.5}$ and its related speciated components (e.g., sulfate, nitrate, elemental carbon, organic carbon, etc.), nitrate and sulfate deposition, and specific air toxics (formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and acrolein) was conducted using 2011 state/local monitoring data in order to estimate the ability of the CMAQ modeling system to replicate base year concentrations. The evaluation included statistical measures of model performance based upon model-predicted versus observed concentrations that were paired in space and time. Model performance statistics were calculated for several spatial scales and temporal periods. Statistics were calculated for individual monitoring sites and for each of nine climate regions of the 12-km U.S. modeling domain. The regions include the Northeast, Ohio Valley, Upper Midwest, Southeast, South, Southwest, Northern Rockies, Northwest and West[FF], which are defined based upon the states contained within the National Oceanic and Atmospheric Administration (NOAA) climate regions as were originally identified in Karl and Koss (1984).[240]

The "acceptability" of model performance was judged by comparing our results to those found in recent regional $PM_{2.5}$ model applications for other, non-EPA studies.[GG] Overall, the performance for the 2011 modeling platform is within the range or close to that of these other applications. The model was able to reproduce historical concentrations of ozone and $PM_{2.5}$ over land with low bias and error results. Model predictions of annual formaldehyde, acetaldehyde and benzene showed relatively small bias and error results when compared to observations. The model yielded larger bias and error results for 1,3 butadiene and acrolein based on limited monitoring sites. A more detailed summary of the 2011 CMAQ model performance evaluation is available within the AQM TSD found in the docket of this rule.

6A1.5 Model Simulation Scenarios

As part of our analysis for this rulemaking, the CMAQ modeling system was used to calculate 8-hour ozone concentrations, daily and annual $PM_{2.5}$ concentrations, annual NO_2 concentrations, annual and seasonal (summer and winter) air toxics concentrations, visibility levels and annual nitrogen and sulfur deposition total levels for each of the following emissions scenarios:

- 2011 Base year

- 2040 Phase 2 reference case

- 2040 Phase 2 control case

As mentioned above, the inventories used for the air quality modeling and the final inventories are consistent in many ways but there are some important differences. For example, EPA is adopting Phase 1 and Phase 2 requirements to control $PM_{2.5}$ emissions from APUs installed in new tractors, therefore we do not expect increases in $PM_{2.5}$ emissions from the Phase 2 program; however, the air quality inventories do not reflect these requirements and therefore show increases in downstream $PM_{2.5}$ emissions. Chapter 5.5.2.3 of the RIA has more detail on the differences between the air quality and final inventories. The IAQ TSD, found in the docket for this rule (EPA-HQ-OAR-2014-0827), also contains a detailed discussion of the emissions inputs used in our air quality modeling.

[FF] The nine climate regions are defined by States where: Northeast includes CT, DE, ME, MA, MD, NH, NJ, NY, PA, RI, and VT; Ohio Valley includes IL, IN, KY, MO, OH, TN, and WV; Upper Midwest includes IA, MI, MN, and WI; Southeast includes AL, FL, GA, NC, SC, and VA; South includes AR, KS, LA, MS, OK, and TX; Southwest includes AZ, CO, NM, and UT; Northern Rockies includes MT, NE, ND, SD, WY; Northwest includes ID, OR, and WA; and West includes CA and NV. Note most monitoring sites in the West region are located in California, therefore for the West will be mostly representative of California ozone air quality.

[GG] These other modeling studies represent a wide range of modeling analyses which cover various models, model configurations, domains, years and/or episodes, chemical mechanisms, and aerosol modules.

We use the predictions from the model in a relative sense by combining the 2011 base-year predictions with predictions from each future-year scenario and applying these modeled ratios to ambient air quality observations to estimate 8-hour ozone concentrations, daily and annual $PM_{2.5}$ concentrations, annual NO_2 concentrations and visibility impairment for each of the 2040 scenarios. The ambient air quality observations are average conditions, on a site-by-site basis, for a period centered around the model base year (i.e., 2009-2013).

The projected daily and annual $PM_{2.5}$ design values were calculated using the Speciated Modeled Attainment Test (SMAT) approach. The SMAT uses a Federal Reference Method (FRM) mass construction methodology that results in reduced nitrates (relative to the amount measured by routine speciation networks), higher mass associated with sulfates (reflecting water included in FRM measurements), and a measure of organic carbonaceous mass that is derived from the difference between measured $PM_{2.5}$ and its non-carbon components. This characterization of $PM_{2.5}$ mass also reflects crustal material and other minor constituents. The resulting characterization provides a complete mass balance. It does not have any unknown mass that is sometimes presented as the difference between measured $PM_{2.5}$ mass and the characterized chemical components derived from routine speciation measurements. However, the assumption that all mass difference is organic carbon has not been validated in many areas of the U.S. The SMAT methodology uses the following $PM_{2.5}$ species components: sulfates, nitrates, ammonium, organic carbon mass, elemental carbon, crustal, water, and blank mass (a fixed value of 0.5 $\mu g/m^3$). More complete details of the SMAT procedures can be found in the report "Procedures for Estimating Future $PM_{2.5}$ Values for the CAIR Final Rule by Application of the (Revised) Speciated Modeled Attainment Test (SMAT)."[241] For this latest analysis, several datasets and techniques were updated. These changes are fully described within the technical support document for the Final Transport Rule AQM TSD.[242] The projected 8-hour ozone design values were calculated using the approach identified in EPA's guidance on air quality modeling attainment demonstrations.[243]

Additionally, we conducted an analysis to compare the absolute and percent differences between the future year reference and control cases for annual and seasonal formaldehyde, acetaldehyde, benzene, 1,3-butadiene, naphthalene, and acrolein, as well as annual nitrate and sulfate deposition. These data were not compared in a relative sense due to the limited observational data available.

6A1.6 Chemical Mechanisms in Modeling

This analysis looks at air quality impacts of criteria pollutants including NO_X, VOC, CO, $PM_{2.5}$, SO_2, and air toxics, specifically benzene, 1,3-butadiene, formaldehyde, acetaldehyde, naphthalene and acrolein. The air toxics were added as explicit model species to the carbon bond 5 (CB05) mechanisms used in CMAQv5.0.1.[244] Emissions of all the pollutants included in the rule inventories, except ethanol, were generated using the Motor Vehicle Emissions Simulator (MOVES) VOC emissions and toxic-to-VOC ratios calculated using EPAct data.[245] Ethanol emissions for air quality modeling were based on speciation of VOC using different ethanol profiles (E0, E10 and E85) (see Inventory for Air Quality Modeling Technical Support Document for more information). In addition to direct emissions, photochemical processes mechanisms are responsible for formation of some of these compounds in the atmosphere from precursor emissions. For some pollutants such as PM, formaldehyde, and acetaldehyde, many photochemical processes are involved. CMAQ therefore also requires inventories for a large number of other air toxics and precursor pollutants. Methods used to develop the air quality inventories can be found in Chapter 5.3.5.

In the CB05 mechanism, the chemistry of thousands of different VOCs in the atmosphere are represented by a much smaller number of model species which characterize the general behavior of a subset of chemical bond types; this condensation is necessary to allow the use of complex photochemistry in a fully 3-D air quality model.[246]

Complete combustion of ethanol in fuel produces carbon dioxide (CO_2) and water (H2O). Incomplete combustion results in the production of other air pollutants, such as acetaldehyde and other aldehydes, and the release of unburned ethanol. Ethanol is also present in evaporative emissions. In the atmosphere, ethanol from unburned fuel and evaporative emissions can undergo photodegradation to form aldehydes (acetaldehyde and formaldehyde) and peroxyacetyl nitrate (PAN), and also plays a role in ground-level ozone formation. Mechanisms for these reactions are included in CMAQ. Additionally, alkenes and other hydrocarbons are considered because any increase in acetyl peroxy radicals due to ethanol increases might be counterbalanced by a decrease in radicals resulting from decreases in other hydrocarbons, particularly alkenes.

CMAQ includes 63 inorganic reactions to account for the cycling of all relevant oxidized nitrogen species and cycling of radicals, including the termination of NO_2 and formation of nitric acid (HNO3) without PAN formation.[HH]

NO_2 + ·OH + M → HNO3 + M k = 1.19 x 10-11 cm3molecule-1s-1

The CB05 mechanism also includes more than 90 organic reactions that include alternate pathways for the formation of acetyl peroxy radical, such as by reaction of alkenes, alkanes, and aromatics. Alternate reactions of acetyl peroxy radical, such as oxidation of NO to form NO_2, which again leads to ozone formation, are also included.

Atmospheric reactions and chemical mechanisms involving several key formation pathways are discussed in more detail in the following sections.

6A1.6.1 Acetaldehyde

Acetaldehyde is the main photodegradation product of ethanol, as well as other precursor hydrocarbons. Acetaldehyde is also a product of fuel combustion. In the atmosphere, acetaldehyde can react with the OH radical and O_2 to form the acetyl peroxy radical [$CH_3C(O)OO\cdot$].[II] When NO_X is present in the atmosphere this radical species can then further react with nitric oxide (NO), to produce formaldehyde (HCHO), or with nitrogen dioxide (NO_2),

[HH] All rate coefficients are listed at 298 K and, if applicable, 1 bar of air.
[II] Acetaldehyde is not the only source of acetyl peroxy radicals in the atmosphere. For example, dicarbonyl compounds (methylglyoxal, biacetyl, and others) also form acetyl radicals, which can further react to form peroxyacetyl nitrate (PAN).

to produce PAN [$CH_3C(O)OONO_2$]. An overview of these reactions and the corresponding reaction rates are provided below.[JJ]

CH_3CHO + $\cdot OH \rightarrow CH_3C\cdot O + H_2O$ k = 1.5×10^{-11} $cm^3 molecule^{-1} s^{-1}$ [247]

$CH_3C\cdot O + O_2 + M \rightarrow$ **$CH_3C(O)OO\cdot$** + M

$CH_3C(O)OO\cdot$ + ***NO*** $\rightarrow CH_3C(O)O\cdot$ + ***NO_2*** k = 2.0×10^{-11} $cm^3 molecule^{-1} s^{-1}$ [248]

$CH_3C(O)O\cdot \rightarrow \cdot CH_3 + CO_2$

$\cdot CH_3 + O_2 + M \rightarrow CH_3OO\cdot + M$

$CH_3OO\cdot + NO \rightarrow CH_3O\cdot + NO_2$

$CH_3O\cdot + O_2 \rightarrow$ **HCHO** + HO_2

$CH_3C(O)OO\cdot$ + NO_2 + M $\rightarrow$ **$CH_3C(O)OONO_2$** + M k = 1.0×10^{-11} $cm^3 molecule^{-1} s^{-1}$ [249]

Acetaldehyde can react with the NO_3 radical, ground state oxygen atom (O_3P) and chlorine, although these reactions are much slower. Acetaldehyde can also photolyze (hν), which predominantly produces $\cdot CH_3$ (which reacts as shown above to form $CH_3OO\cdot$) and HCO (which rapidly forms HO_2 and CO):

CH_3CHO + hν +2 $O_2 \rightarrow CH_3OO\cdot + HO_2 + CO$ λ = 240-380 nm [250]

As mentioned above, $CH_3OO\cdot$ can react in the atmosphere to produce formaldehyde (HCHO). Formaldehyde is also a product of hydrocarbon combustion. In the atmosphere, the most important reactions of formaldehyde are photolysis and reaction with the OH, with atmospheric lifetimes of approximately 3 hours and 13 hours, respectively.[251] Formaldehyde can also react with NO_3 radical, ground state oxygen atom (O^3P) and chlorine, although these reactions are much slower. Formaldehyde is removed mainly by photolysis whereas the higher aldehydes, those with two or more carbons such as acetaldehyde, react predominantly with OH radicals. The photolysis of formaldehyde is an important source of new hydroperoxy radicals (HO_2), which can lead to ozone formation and regenerate OH radicals.

HCHO + hν + 2 $O_2 \rightarrow 2\ HO_2 + CO$ λ = 240-360 nm [252]

$HO_2 + NO \rightarrow NO_2 + OH$

Photolysis of HCHO can also proceed by a competing pathway which makes only stable products: H_2 and CO.

CB05 mechanisms for acetaldehyde formation warrant a detailed discussion given the increase in vehicle and engine exhaust emissions for this pollutant and ethanol, which can form

[JJ] All rate coefficients are listed at 298 K and, if applicable, 1 bar of air.

acetaldehyde in the air. Acetaldehyde is represented explicitly in the CB05 chemical mechanism[253,254] by the ALD2 model species, which can be both formed from other VOCs and can decay via reactions with oxidants and radicals. The reaction rates for acetaldehyde, as well as for the inorganic reactions that produce and cycle radicals, and the representative reactions of other VOCs have all been updated to be consistent with recommendations in the literature.[255]

The decay reactions of acetaldehyde are fewer in number and can be characterized well because they are explicit representations. In CB05, acetaldehyde can photolyze or react with molecular oxygen ($O(^3P)$), hydroxyl radical (OH), or nitrate radicals. The reaction rates are based on expert recommendations,[256] and the photolysis rate is from IUPAC recommendations.

In CMAQ v5.0, the acetaldehyde that is formed from photochemical reactions is tracked separately from that which is due to direct emission and transport of direct emissions. In CB05, there are 25 different reactions that form acetaldehyde in molar yields ranging from 0.02 (ozone reacting with lumped products from isoprene oxidation) to 2.0 (cross reaction of acylperoxy radicals, CXO_3). The specific parent VOCs that contribute the most to acetaldehyde concentrations vary spatially and temporally depending on characteristics of the ambient air, but alkenes in particular are found to play a large role.[257] The IOLE model species, which represents internal carbon-carbon double bonds, has high emissions and relatively high yields of acetaldehyde. The OLE model species, representing terminal carbon double bonds, also plays a role because it has high emissions although lower acetaldehyde yields. Production from peroxyproprional nitrate and other peroxyacylnitrates (PANX) and aldehydes with 3 or more carbon atoms can in some instances increase acetaldehyde, but because they also are a sink of radicals, their effect is smaller. Thus, the amount of acetaldehyde (and formaldehyde as well) formed in the ambient air, as well as emitted in the exhaust (the latter being accounted for in emission inventories), is affected by changes in these precursor compounds due to the addition of ethanol to fuels (e.g., decreases in alkenes would cause some decrease of acetaldehyde, and to a larger extent, formaldehyde).

The reaction of ethanol (CH_3CH_2OH) with OH is slower than some other important reactions but can be an important source of acetaldehyde if the emissions are large. Based on kinetic data for molecular reactions, the only important chemical loss process for ethanol (and other alcohols) is reaction with the hydroxyl radical (·OH).[258] This reaction produces acetaldehyde (CH_3CHO) with a 90 percent yield.[259] The lifetime of ethanol in the atmosphere can be calculated from the rate coefficient, k, and due to reaction with the OH radical, occurs on the order of a day in polluted urban areas or several days in unpolluted areas. [KK] For example, an atmospheric lifetime for acetaldehyde under nominal oxidant conditions, OH of 1.0×10^{-6} $cm^3 molecule^{-1} s^{-1}$, would be 3.5 days.

In CB05, reaction of one molecule of ethanol yields 0.90 molecules of acetaldehyde. It assumes the majority of the reaction occurs through H-atom abstraction of the more weakly-bonded methylene group, which reacts with oxygen to form acetaldehyde and hydroperoxy radical (HO_2), and the remainder of the reaction occurs at the –CH3 and –OH groups, creating

[KK] All rate coefficients are listed at 298 K and, if applicable, 1 bar of air.

formaldehyde (HCHO), oxidizing NO to NO_2 (represented by model species XO_2) and creating glycoaldehyde, which is represented as ALDX:

$$CH_3CHOH + OH \rightarrow HO_2 + 0.90\ CH_3CHO + 0.05\ ALDX + 0.10\ HCHO + 0.10\ XO_2$$

6A1.6.2 Organic Aerosols

Organic aerosol (OA) can be classified as either primary or secondary depending on whether it is emitted into the atmosphere as a particle (primary organic aerosol, POA) or formed in the atmosphere (SOA). SOA precursors include volatile organic compounds (VOCs) as well as low-volatility compounds that can react to form even lower volatility compounds. Current research suggests SOA contributes significantly to ambient OA concentrations, and in Southeast and Midwest States may make up more than 50 percent (although the contribution varies from area to area) of the organic fraction of $PM_{2.5}$ during the summer (but less in the winter).[260,261] A wide range of laboratory studies conducted over the past twenty years show that anthropogenic aromatic hydrocarbons and long-chain alkanes, along with biogenic isoprene, monoterpenes, and sesquiterpenes, contribute to SOA formation.[262,263,264,265,266] Modeling studies, as well as carbon isotope measurements, indicate that a significant fraction of SOA results from the oxidation of biogenic hydrocarbons.[267,268] Based on parameters derived from laboratory chamber experiments, SOA chemical mechanisms have been developed and integrated into air quality models such as the CMAQ model and have been used to predict OA concentrations.[269]

Secondary organic aerosol (SOA) chemistry in CMAQ v5.0 is largely based on recommendations of Edney et al. (2007) and Carlton et al. (2008) as initially implemented in CMAQ v4.7.[270,271,272] In previous versions of CMAQ, all SOA was semivolatile and resulted from the oxidation of compounds emitted entirely in the gas-phase. Starting with CMAQ v4.7, parameters in existing pathways were revised and new formation mechanisms were added. Some of the new pathways, such as low-NO_X oxidation of aromatics and particle-phase oligomerization, result in nonvolatile SOA.

New to CMAQ v5.0 is the heterogeneous oxidation of primary organic aerosol (POA).[273] Specifically, primary organic aerosol is tracked separately in terms of its carbon and non-carbon organic matter. Non-carbon organic matter (such as oxygen and hydrogen) is added to the reduced carbon as a result of heterogeneous reaction with OH. Diesel POA is emitted with an organic matter to organic carbon (OM/OC) ratio of 1.25. The ratio increases due to exposure with OH. In the absence of removal, this oxidation process results in increasing organic aerosol concentrations. These OM/OC ratios assist with post-processing of model output for comparison with measured OC from routine networks.

Over the past 10 years, ambient OA concentrations have been routinely measured in the U.S. and some of these data have been used to determine, by employing source/receptor methods, the contributions of the major OA sources, including biomass burning and vehicular gasoline and diesel exhaust. Since mobile sources are a significant source of VOC emissions, currently accounting for almost 40 percent of anthropogenic VOC,[274] mobile sources are also an important source of SOA, particularly in populated areas.

Toluene is an important contributor to anthropogenic SOA.[275,276] Mobile sources are the most significant contributor to ambient toluene concentrations as shown by analyses done for the 2011 National Air Toxics Assessment (NATA)[277] and the Mobile Source Air Toxics (MSAT) Rule.[278] The 2011 NATA indicates that onroad and nonroad mobile sources accounted for around 50 percent (1.35 $\mu g/m^3$) of the total average nationwide ambient concentration of toluene (2.61 $\mu g/m^3$.

The amount of toluene in gasoline influences the amount of toluene emitted in vehicle exhaust and evaporative emissions, although, like benzene, some toluene is formed in the combustion process. In turn, levels of toluene and other aromatics in gasoline are potentially influenced by the amount of ethanol blended into the fuel. Due to the high octane quality of ethanol, it greatly reduces the need for and levels of other high-octane components such as aromatics including toluene (which is the major aromatic compound in gasoline). Since toluene contributes to SOA and the toluene level of gasoline is decreasing, it is important to assess the effect of these reductions on ambient PM.

In addition to toluene, other mobile-source hydrocarbons such as benzene, xylene, and alkanes form SOA. Similar to toluene, the SOA produced by benzene and xylene from low-NO_X pathways is expected to be less volatile and be produced in higher yields than SOA from high-NO_X conditions.[279] Oxidation of alkanes with longer chains as well as cyclic alkanes form SOA with relatively higher yields than small straight-chain alkanes.[280]

It is unlikely that ethanol would form SOA directly or affect SOA formation indirectly through changes in the radical populations due to increasing ethanol exhaust. Nevertheless, scientists at the U.S. EPA's Office of Research and Development recently directed experiments to investigate ethanol's SOA forming potential.[281] The experiments were conducted under conditions where peroxy radical reactions would dominate over reaction with NO (i.e., irradiations performed in the absence of NO_X and OH produced from the photolysis of hydrogen peroxide). This was the most likely scenario under which SOA formation could occur, since a highly oxygenated C4 organic could form. As expected, no SOA was produced. From these experiments, the upper limit for the aerosol yield is less than 0.01 percent based on scanning mobility particle sizer (SMPS) data. Given the lack of aerosol formation found in these initial smog chamber experiments, these data were not published.

In general, measurements of OA represent the sum of POA and SOA and the fraction of aerosol that is secondary in nature can only be estimated. One of the most widely applied method of estimating total ambient SOA concentrations is the EC tracer method using ambient data which estimates the OC/EC ratio in primary source emissions.[282,283] SOA concentrations have also been estimated using OM (organic mass) to OC (organic carbon) ratios, which can indicate that SOA formation has occurred, or by subtracting the source/receptor-based total POA from the measured OC concentration.[284] Aerosol mass spectrometer (AMS) measurements along with positive matrix factorization (PMF) can also be used to identify surrogates for POA and SOA in ambient as well as chamber experiments. Such methods, however, may not be quantitatively accurate and provide limited information on the contribution of individual biogenic and anthropogenic SOA sources, which is critical information needed to assess the impact of specific sources and the associated health risk. These methods assume that OM containing additional mass from oxidation of OC comes about largely (or solely) from SOA formation. In particular, the contributions of anthropogenic SOA sources, including those of aromatic precursors, are required to determine exposures and risks associated with replacing fossil fuels with biofuels.

Upon release into the atmosphere, numerous VOC compounds can react with free radicals in the atmosphere to form SOA. While this has been investigated in the laboratory, there is relatively little information available on the specific chemical composition of SOA compounds themselves from specific VOC precursors. This absence of complete compositional data from the precursors has made the identification of aromatically-derived SOA in ambient samples challenging, which in turn has prevented observation-based measurements of individual SOA source contributions to ambient PM levels.

As a first step in estimating ambient SOA concentrations, EPA has developed a tracer-based method.[285,286] The method is based on using mass fractions of SOA tracer compounds, measured in smog chamber-generated SOA samples, to convert ambient concentrations of SOA tracer compounds to ambient SOA concentrations. This method consists of irradiating the SOA precursor of interest in a smog chamber in the presence of NO_X, collecting the SOA produced on filters, and then analyzing the samples for highly polar compounds using advanced analytical chemistry methods. Employing this method, candidate tracers have been identified for several VOC compounds which are emitted in significant quantities and known to produce SOA in the atmosphere. Some of these SOA-forming compounds include toluene, a variety of monoterpenes, isoprene, and β-caryophyllene, the latter three of which are emitted by vegetation and are more significant sources of SOA than toluene. Smog chamber work can also be used to investigate SOA chemical formation mechanisms.[287,288,289,290]

Although these concentrations are only estimates, due to the assumption that the mass fractions of the smog chamber SOA samples using these tracers are equal to those in the ambient atmosphere, there are presently limited other means available for estimating the SOA concentrations originating from individual SOA precursors. Among the tracer compounds observed in ambient $PM_{2.5}$ samples are two tracer compounds that have been identified in smog chamber aromatic SOA samples.[291] To date, these aromatic tracer compounds have been identified in the laboratory for toluene and *m*-xylene SOA. Additional work is underway by the EPA to determine whether these tracers are also formed by benzene and other alkylbenzenes (including *o*-xylene, *p*-xylene, 1,2,4-trimethylbenzene, and ethylbenzene).

One caveat regarding this work is that a large number of VOCs emitted into the atmosphere, which have the potential to form SOA, have not yet been studied in environmental smog chambers. These unstudied compounds could produce SOA species that are being used as tracers for other VOCs thus overestimating the amount of SOA formed in the atmosphere by the VOCs studied to date. This approach may also estimate entire hydrocarbon classes (e.g., all methylsubstituted-monoaromatics or all monoterpenes) and not individual precursor hydrocarbons. Thus the tracers could be broadly representative and not indicative of individual precursors. This is still unknown. Also, anthropogenic precursors play a role in formation of atmospheric radicals and aerosol acidity, and these factors influence SOA formation from biogenic hydrocarbons.[292,293] This anthropogenic and biogenic interaction, important to EPA and others, needs further study. The issue of SOA formation from aromatic precursors is an important one to which EPA and others are paying significant attention.

The aromatic tracer compounds and their mass fractions have been used to estimate monthly ambient aromatic SOA concentrations from March 2004 to February 2005 in five U.S. Midwestern cities.[294] The annual tracer-based SOA concentration estimates were 0.15, 0.18, 0.13, 0.15, and 0.19 μg carbon/m^3 for Bondville, IL, East St. Louis, IL, Northbrook, IL, Cincinnati, OH and Detroit, MI, respectively, with the highest concentrations occurring in the summer. On average, the aromatic SOA concentrations made up 17 percent of the total SOA concentration. Thus, this work suggests that we are finding ambient PM levels on an annual basis of about 0.15 μg/m^3 associated with present toluene levels in the ambient air in these Midwest cities. Based on preliminary analysis of recent laboratory experiments, it appears the toluene tracer could also be formed during photooxidation of some of the xylenes.[295]

Over the past decade a variety of modeling studies have been conducted to predict ambient SOA levels. While early studies focused on the contribution of biogenic monoterpenes, additional precursors, such as sesquiterpenes, isoprene, benzene, toluene, and xylene, have been implemented in atmospheric models such as GEOS-Chem, PMCAMx, and CMAQ.[296, 297, 298, 299, 300,301,302] Studies have indicated that ambient OC levels may be underestimated by current model parameterizations.[303] In general, modeling studies focus on comparing the sum of the POA and SOA concentrations with ambient OC or estimated OA concentrations. Without a method to attribute measured OC to different sources or precursors, identifying causes of the underestimates in modeled OC via model/measurement comparisons can be challenging. However, analysis of SOA concentrations in Pasadena and Bakersfield, California during 2010 indicate CMAQ-predicted SOA from toluene and xylene is underestimated despite overestimates of the VOC precursors.[304] In addition, CMAQ-predicted aromatic SOA was underestimated in the Midwest US despite reasonable predictions of primary organic aerosol tracers, implying underestimated SOA yields.[305]

6A1.6.3 Ozone

As mentioned above, the addition of ethanol to fuels has been shown to contribute to PAN formation and this is one way for it to contribute therefore to ground-level ozone formation downwind of NO_X sources. PAN is a reservoir and carrier of NO_X and is the product of acetyl radicals reacting with NO_2 in the atmosphere. One source of PAN is the photooxidation of acetaldehyde, but many VOCs have the potential for forming acetyl radicals and therefore PAN or a PAN-type compound.[LL] PAN can undergo thermal decomposition with a lifetime of approximately 1 hour at 298K or 148 days at 250K. [MM]

$$\mathbf{CH_3C(O)OONO_2} + M \rightarrow CH_3C(O)OO\cdot + \mathbf{NO_2} + M \qquad k = 3.3 \times 10^{-4}\ s^{-1}$$ [306]

The reaction above shows how NO_2 is released in the thermal decomposition of PAN, along with a peroxy radical which can oxidize NO to NO_2 and form other species that convert

[LL] Many aromatic hydrocarbons, particularly those present in high percentages in gasoline (toluene, m-, o-, p-xylene, and 1,3,5-, 1,2,4-trimethylbenzene), form methylglyoxal and biacetyl, which are also strong generators of acetyl radicals (Smith, D.F., T.E. Kleindienst, C.D. McIver (1999) Primary product distribution from the reaction of OH with m-, p-xylene and 1,2,4- and 1,3,5-Trimethylbenzene. J. Atmos. Chem., 34: 339- 364).
[MM] All rate coefficients are listed at 298 K and, if applicable, 1 bar of air.

NO to NO2 through photochemical reactions, as previously shown in Chapter 6.2.2.2.1. NO_2 further photolyzes to produce ozone (O_3).

$$\mathbf{NO_2} + h\nu \rightarrow NO + O(^3P) \qquad \lambda = 300\text{-}800 \text{ nm}$$ [307]

$$O(^3P) + O_2 + M \rightarrow \mathbf{O_3} + M$$

The temperature sensitivity of PAN allows it to be stable enough at low temperatures to be transported long distances before decomposing to release NO_2. NO_2 can then participate in ozone formation in regions remote from the original NO_X source.[308] A discussion of CB05 mechanisms for ozone formation can be found in Yarwood et al. (2005).[309]

Another important way that ethanol fuels contribute to ozone formation is by increasing the formation of new radicals through increases in formaldehyde and acetaldehyde. The photolysis of both aldehydes results in up to two molecules of either hydroperoxy radical or methylperoxy radical, both of which oxidize NO to NO_2 leading to ozone formation.

6A1.6.4 Uncertainties Associated with Chemical Mechanisms

A key source of uncertainty with respect to the air quality modeling results is the photochemical mechanisms in CMAQ. Pollutants such as ozone, PM, acetaldehyde, formaldehyde, and acrolein can be formed secondarily through atmospheric chemical processes. Since secondarily formed pollutants can result from many different reaction pathways, there are uncertainties associated with each pathway. Simplifications of chemistry must be made in order to handle reactions of thousands of chemicals in the atmosphere. Mechanisms for formation of ozone, PM, acetaldehyde and peroxyacetyl nitrate (PAN) are discussed in previous Chapters 6A.1.6.1 through 6A1.6.3.

For PM, there are a number of uncertainties associated with SOA formation that should be addressed explicitly. As mentioned in Chapter 6A.1.6.2, a large number of VOCs emitted into the atmosphere, which have the potential to form SOA, have not yet been studied in detail. Not only have known VOCs not been studied in detail, but unknown (or unmeasured) VOCs can also produce SOA. This makes reconciling SOA from combustion sources extremely difficult. In addition, the amount of ambient SOA that comes from benzene is uncertain. Simplifications to the SOA treatment in CMAQ have also been made in order to preserve computational efficiency. These simplifications are described in release notes for CMAQ 4.7 on the Community Modeling and Analysis System (CMAS) website.[310]

6A.2 Air Quality Modeling Results

6A2.1 Annual $PM_{2.5}$ Results

The air quality modeling indicates that for the majority of the country, annual $PM_{2.5}$ design values (DV) will decrease due to these standards. The decreases in annual $PM_{2.5}$ DV, less than 0.05 µg/m^3, are likely due to the projected reductions in upstream primary $PM_{2.5}$ emissions, and reductions in both upstream and downstream NO_X, SO_X and VOCs. As described in Chapter 5.5.2.3, the air quality modeling used inventories that do not reflect the new requirements for controlling $PM_{2.5}$ emissions from APUs installed in new tractors and therefore show increases in downstream $PM_{2.5}$ emissions. Although in most areas this direct $PM_{2.5}$ increase is outweighed by reductions in secondary $PM_{2.5}$, the air quality modeling does predict ambient $PM_{2.5}$ increases in a few places. EPA is adopting Phase 1 and Phase 2 requirements to control $PM_{2.5}$ emissions from APUs installed in new tractors, therefore we do not expect to actually see increases in $PM_{2.5}$ DV from the Phase 2 program. In addition, assumptions about the usage of diesel-powered APUs also differs between the air quality inventories and the final rule inventories. The air quality inventories assumed more widespread usage of diesel-powered APUs than was assumed for the final rule. The APU assumptions mean that the NO_X reductions assumed in the air quality inventories are larger than we expect to occur and reductions in ambient $PM_{2.5}$ due to secondary nitrate formation are over-estimated in the air quality modeling.

The magnitude of the reductions in $PM_{2.5}$ DV from the final rule inventories is difficult to estimate due to the differences in the air quality inventories, namely overestimation of nitrate reductions and underestimation of direct $PM_{2.5}$ reductions. However, EPA does expect reductions in ambient concentrations of $PM_{2.5}$ due to these final standards. Maps and summary tables of the projected impacts of the air quality inventories on $PM_{2.5}$ DV are presented below. Figure 6A-2 presents the changes in annual $PM_{2.5}$ design values in 2040.[NN]

[NN] An annual $PM_{2.5}$ design value is the concentration that determines whether a monitoring site meets the annual NAAQS for $PM_{2.5}$. The full details involved in calculating an annual $PM_{2.5}$ design value are given in appendix N of 40 CFR part 50.

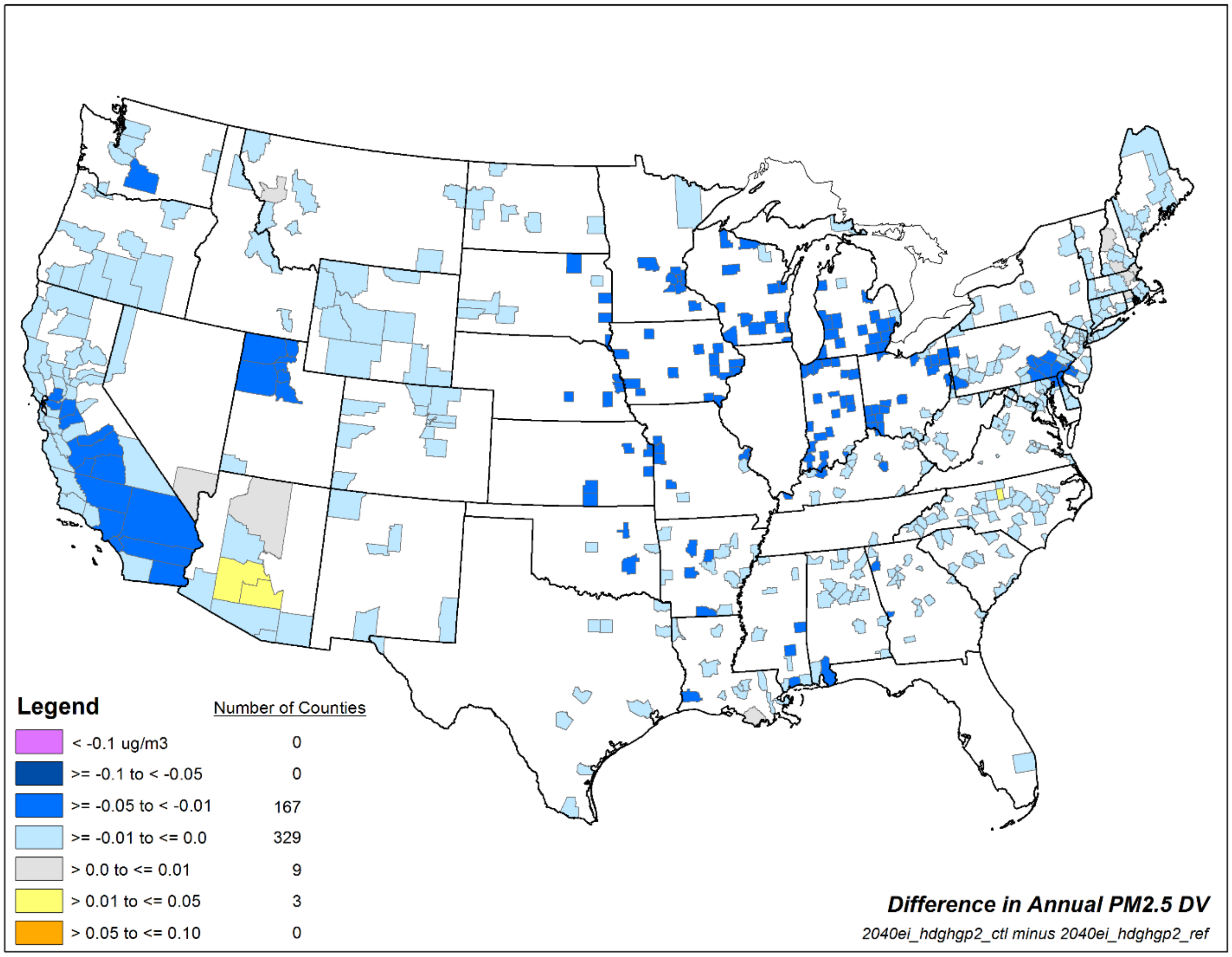

Figure 6A-2 Projected Change in 2040 Annual $PM_{2.5}$ Design Values Using Air Quality Inventories

Table 6A-1 presents the average change in 2040 annual $PM_{2.5}$ design values for: (1) all counties with 2011 baseline design values, (2) counties with 2011 baseline design values that exceeded the 2012 annual $PM_{2.5}$ standard, (3) counties with 2011 baseline design values that did not exceed the 2012 standard, but were within 10 percent of it, (4) counties with 2040 design values that exceeded the 2012 annual $PM_{2.5}$ standard, and (5) counties with 2040 design values that did not exceed the standard, but were within 10 percent of it. Counties within 10 percent of the standard are intended to reflect counties that although not violating the standards, will also be impacted by changes in $PM_{2.5}$ as they work to ensure long-term maintenance of the annual $PM_{2.5}$ NAAQS.

Table 6A-1 Average Change in 2040 Annual $PM_{2.5}$ Design Values using Air Quality Inventories

	Number of US Counties	2040 Population	Change in 2040 design value ($\mu g/m^3$)
All	508		-0.01
All, population-weighted		234,351,941	-0.01
Counties whose 2011 base year is violating the 2012 annual $PM_{2.5}$ standard	43		-0.02
Counties whose 2011 base year is violating the 2012 annual $PM_{2.5}$ standard, population-weighted		41,555,813	-0.02
Counties whose 2011 base year is within 10 percent of the 2012 annual $PM_{2.5}$ standard	77		-0.01
Counties whose 2011 base year is within 10 percent of the 2012 annual $PM_{2.5}$ standard, population-weighted		32,091,156	0.00
Counties whose 2040 control case is violating the 2012 annual $PM_{2.5}$ standard	9		-0.02
Counties whose 2040 control case is violating the 2012 annual $PM_{2.5}$ standard, population-weighted		8,575,947	-0.02
Counties whose 2040 control case is within 10% of the 2012 annual $PM_{2.5}$ standard	5		0.00
Counties whose 2040 control case is within 10% of the 2012 annual $PM_{2.5}$ standard, population-weighted		6,951,178	-0.01

Notes:
[a] Averages are over counties with 2011 modeled design values
[b] Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. (2011). 2012 Complete Economic and Demographic Data Source (CEDDS).

There are 9 counties, all in California, that are projected to have annual $PM_{2.5}$ design values above the NAAQS in 2040 without the Phase 2 standards or any other additional standards in place. Table 6A-2 below presents the changes in design values for these counties.

Table 6A-2 Change in Annual $PM_{2.5}$ Design Values (µg/m_3) using Air Quality Inventories for Counties Projected to be Above the Annual $PM_{2.5}$ NAAQS in 2040

County Name	Population in 2040[a]	Change in Annual $PM_{2.5}$ Design Value (µg/m_3)
Madera, California	173,045	-0.03
Imperial, California	228,454	-0.02
Kings, California	173,643	-0.02
Fresno, California	1,350,320	-0.02
Kern, California	1,100,054	-0.02
Stanislaus, California	732,713	-0.02
Tulare, California	509,803	-0.02
Merced, California	323,734	-0.01
Riverside, California	3,984,181	-0.02

Notes:
[a] Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. (2011). 2012 Complete Economic and Demographic Data Source (CEDDS).

6A2.2 24-hour $PM_{2.5}$ Results

The air quality modeling indicates that for the majority of the country, 24-hour $PM_{2.5}$ design values (DV) will decrease due to these standards. The decreases in 24-hour $PM_{2.5}$ DV, less than 0.6 µg/m^3, are likely due to the projected reductions in upstream primary $PM_{2.5}$ emissions, and reductions in both upstream and downstream NO_X, SO_X and VOCs. As described in Chapter 5.5.2.3, the air quality modeling used inventories that do not reflect the new requirements for controlling $PM_{2.5}$ emissions from APUs installed in new tractors and therefore show increases in downstream $PM_{2.5}$ emissions. Although in most areas this direct $PM_{2.5}$ increase is outweighed by reductions in secondary $PM_{2.5}$, the air quality modeling does predict ambient $PM_{2.5}$ increases in a few places. EPA is adopting Phase 1 and Phase 2 requirements to control $PM_{2.5}$ emissions from APUs installed in new tractors, therefore we do not expect to actually see increases in $PM_{2.5}$ DV from the Phase 2 program. In addition, assumptions about the usage of diesel-powered APUs also differs between the air quality inventories and the final rule inventories. The air quality inventories assumed more widespread usage of diesel-powered APUs than was assumed for the final rule. The APU assumptions mean that the NO_X reductions assumed in the air quality inventories are larger than we expect to occur and reductions in ambient $PM_{2.5}$ due to secondary nitrate formation are over-estimated in the air quality modeling.

The magnitude of the reductions in $PM_{2.5}$ DV from the final rule inventories is difficult to estimate due to the differences in the air quality inventories, namely overestimation of nitrate reductions and underestimation of direct $PM_{2.5}$ reductions. However, EPA does expect reductions in ambient concentrations of $PM_{2.5}$ due to these final standards. Maps and summary tables of the projected impacts of the air quality inventories on $PM_{2.5}$ DV are presented below. Figure 6A-3 presents the changes in 24-hour $PM_{2.5}$ design values in 2040.[OO]

[OO] An annual $PM_{2.5}$ design value is the concentration that determines whether a monitoring site meets the annual NAAQS for $PM_{2.5}$. The full details involved in calculating an annual $PM_{2.5}$ design value are given in appendix N of 40 CFR part 50.

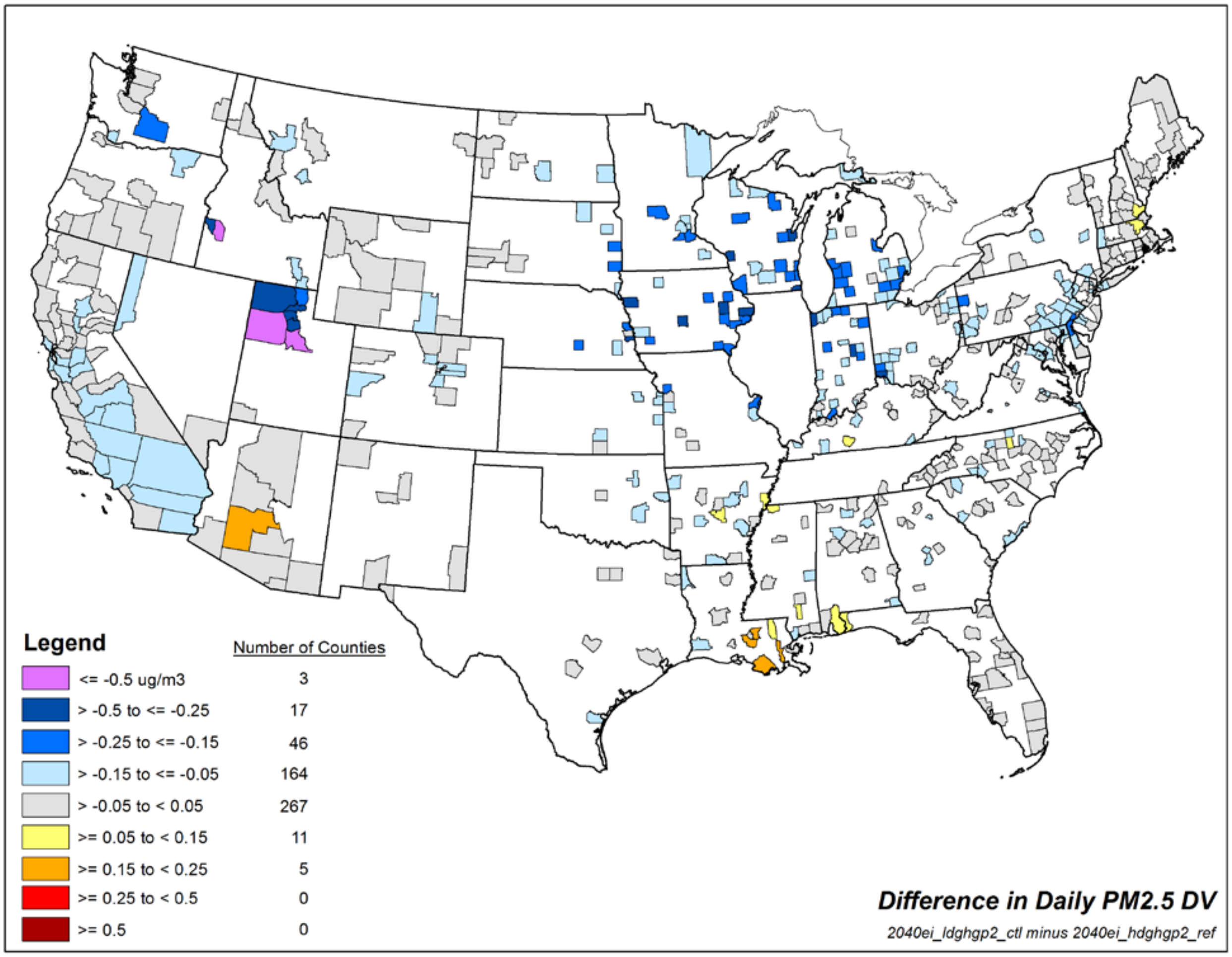

Figure 6A-3 Projected Change in 2040 Annual $PM_{2.5}$ Design Values Using Air Quality Inventories

Table 6A-3 presents the average change in 2040 24-hour $PM_{2.5}$ design values for: (1) all counties with 2011 baseline design values, (2) counties with 2011 baseline design values that exceeded the 2012 24-hour $PM_{2.5}$ standard, (3) counties with 2011 baseline design values that did not exceed the 2012 standard, but were within 10 percent of it, (4) counties with 2040 design values that exceeded the 2012 24-hour $PM_{2.5}$ standard, and (5) counties with 2040 design values that did not exceed the standard, but were within 10 percent of it. Counties within 10 percent of the standard are intended to reflect counties that although not violating the standards, will also be impacted by changes in $PM_{2.5}$ as they work to ensure long-term maintenance of the 24-hour $PM_{2.5}$ NAAQS.

Table 6A-3 Average Change in 2040 24-hour $PM_{2.5}$ Design Values using Air Quality Inventories

	Number of US Counties	2040 Population	Change in 2040 design value (µg/m^3)
All			-0.06
All, population-weighted	513	247,723,536	-0.05
Counties whose 2011 base year is violating the 2012 24-hour $PM_{2.5}$ standard			-0.15
Counties whose 2011 base year is violating the 2012 24-hour $PM_{2.5}$ standard, population-weighted	23	14,226,741	-0.18
Counties whose 2011 base year is within 10 percent of the 2012 24-hour $PM_{2.5}$ standard			-0.08
Counties whose 2011 base year is within 10 percent of the 2012 24-hour $PM_{2.5}$ standard, population-weighted	13	6,249,037	-0.10
Counties whose 2040 control case is violating the 2012 24-hour $PM_{2.5}$ standard			-0.05
Counties whose 2040 control case is violating the 2012 24-hour $PM_{2.5}$ standard, population-weighted	11	4,475,471	-0.09
Counties whose 2040 control case is within 10% of the 2012 24-hour $PM_{2.5}$ standard			-0.14
Counties whose 2040 control case is within 10% of the 2012 24-hour $PM_{2.5}$ standard, population-weighted	11	6,241,043	-0.23

Notes:
[a] Averages are over counties with 2011 modeled design values
[b] Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. (2011). 2012 Complete Economic and Demographic Data Source (CEDDS).

There are 11 counties, mainly in California, that are projected to have 24-hour $PM_{2.5}$ design values above the NAAQS in 2040 without the Phase 2 standards or any other additional standards in place.

Table 6A-4 below presents the changes in design values for these counties.

Table 6A-4 Change in 24-hour $PM_{2.5}$ Design Values ($\mu g/m^3$) using Air Quality Inventories for Counties Projected to be Above the 24-hour $PM_{2.5}$ NAAQS in 2040

County Name	Population in 2040[a]	Change in 24-hour $PM_{2.5}$ Design Value ($\mu g/m^3$)
Ravalli, Montana	53,253	0.0
Fresno, California	1,350,320	-0.1
Kings, California	173,643	-0.1
Kern, California	1,100,054	-0.1
Madera, California	173,045	0.0
Stanislaus, California	732,713	-0.1
Lake, Oregon	9,349	0.0
Tulare, California	509,803	-0.1
Shoshone, Idaho	10,981	0.0
Silver Bow, Montana	38,576	-0.1
Merced, California	323,734	0.0

Notes:
[a] Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. (2011). 2012 Complete Economic and Demographic Data Source (CEDDS).

6A2.3 Ozone Results

Air quality modeling results indicate that 8-hour ozone DV will be reduced across the country. The decreases in 8-hour ozone DV, max reduction of 1.7 ppb, are likely due to the projected reductions in both upstream and downstream NO_X and VOC emissions. As described in Chapter 5.5.2.3, assumptions about the usage of diesel-powered APUs differs between the air quality inventories and the final rule inventories. The air quality inventories assumed more widespread usage of diesel-powered APUs than was assumed for the final rule. The APU assumptions mean that the NO_X reductions assumed in the air quality inventories are larger than we expect to occur and reductions in 8-hour ozone are over-estimated in the air quality modeling.

The magnitude of the reductions in 8-hour ozone DV from the final rule inventories is difficult to estimate due to the complex, non-linear chemistry governing ozone formation. However, EPA does expect reductions in ambient ozone concentrations due to these final standards. Maps and summary tables of the projected impacts of the air quality inventories on 8-hour ozone DV are presented below. Figure 6A-4 presents the changes in 8-hour ozone design values in 2040.[PP]

[PP] An 8-hour ozone design value is the concentration that determines whether a monitoring site meets the NAAQS for ozone. The full details involved in calculating an 8-hour ozone design value are given in appendix I of 40 CFR part 50.

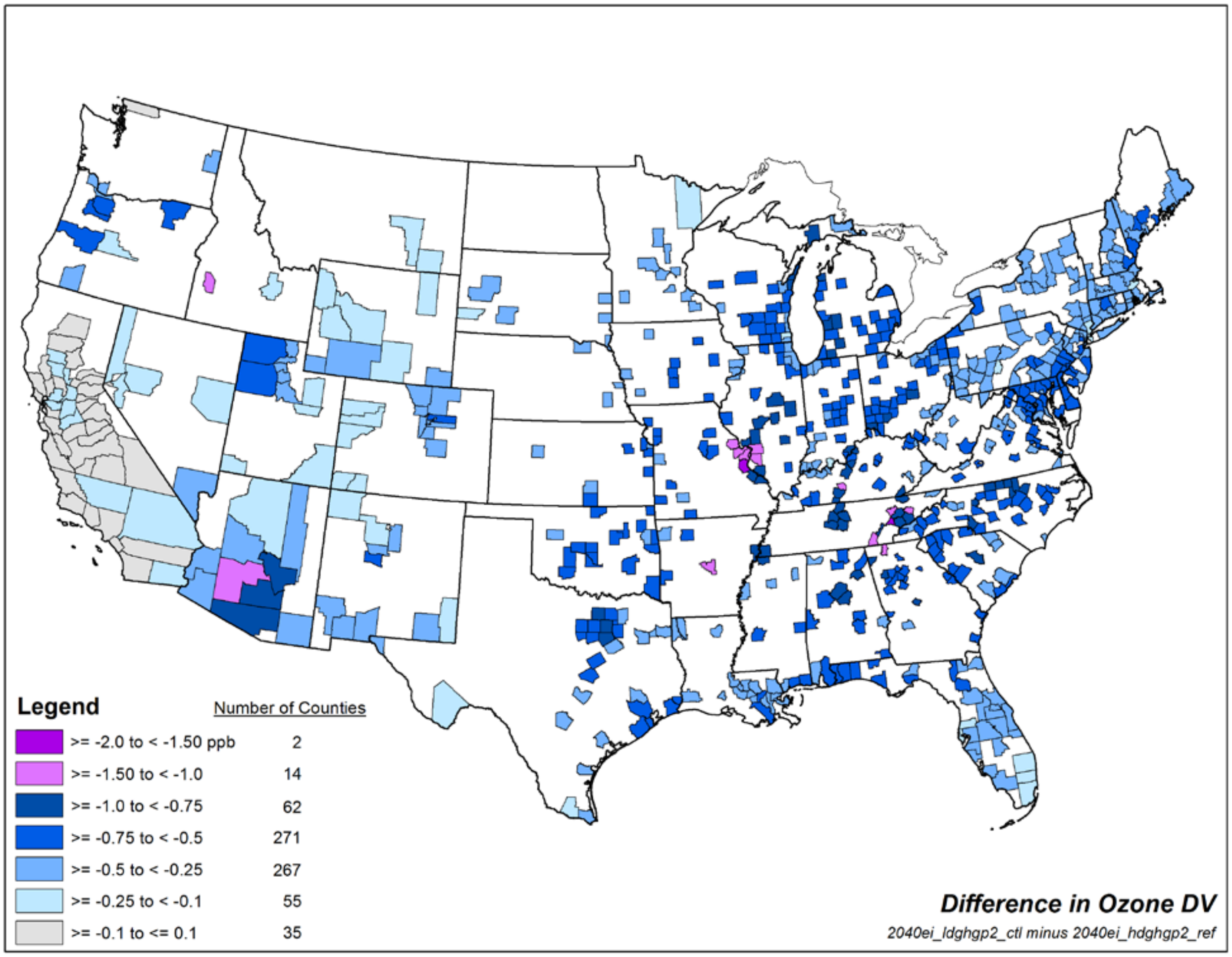

Figure 6A-4 Projected Change in 2040 8-hour Ozone Design Values Using Air Quality Inventories

Table 6A-5 presents the average change in 2040 8-hour ozone design values for: (1) all counties with 2011 baseline design values, (2) counties with 2011 baseline design values that exceeded the 2015 8-hour ozone standard, (3) counties with 2011 baseline design values that did not exceed the 2015 standard, but were within 10 percent of it, (4) counties with 2040 design values that exceeded the 2015 8-hour ozone standard, and (5) counties with 2040 design values that did not exceed the standard, but were within 10 percent of it. Counties within 10 percent of the standard are intended to reflect counties that although not violating the standards, will also be impacted by changes in ozone as they work to ensure long-term maintenance of the 8-hour ozone NAAQS.

Table 6A-5 Average Change in 2040 8-hour Ozone Design Values using Air Quality Inventories

	Number of US Counties	2040 Population	Change in 2040 design value (ppb)
All	706	286,828,135	-0.50
All, population-weighted			-0.46
Counties whose 2011 base year is violating the 2015 8-hour ozone standard	372		-0.54
Counties whose 2011 base year is violating the 2040 8-hour ozone standard, population-weighted		207,493,027	-0.47
Counties whose 2011 base year is within 10 percent of the 2015 8-hour ozone standard	239		-0.50
Counties whose 2011 base year is within 10 percent of the 2015 8-hour ozone standard, population-weighted		56,116,399	-0.48
Counties whose 2040 control case is violating the 2015 8-hour ozone standard	14		-0.19
Counties whose 2040 control case is violating the 2015 8-hour ozone standard, population-weighted		29,944,552	-0.14
Counties whose 2040 control case is within 10% of the 2015 8-hour ozone standard	37		-0.37
Counties whose 2040 control case is within 10% of the 2015 8-hour ozone standard, population-weighted		32,176,523	-0.45

Notes:
[a] Averages are over counties with 2011 modeled design values
[b] Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. (2011). 2012 Complete Economic and Demographic Data Source (CEDDS).

There are 16 counties that are projected to have 8-hour Ozone design values above the NAAQS in 2040 without the Phase 2 standards or any other additional standards in place. Table 6A-6 below presents the changes in design values for these counties.

Table 6A-6 Change in 8-hour Ozone Design Values (μg/m³) using Air Quality Inventories for Counties Projected to be Above the 8-hour Ozone NAAQS in 2040

County Name	Population in 2040[a]	Change in 8-hour Ozone Design Value (ppb)
San Bernardino, California	3,273,894	-0.11
Los Angeles, California	10,765,068	-0.08
Riverside, California	3,984,181	-0.10
Fairfield, Connecticut	1,019,651	-0.46
Queens, New York	2,462,190	-0.20
Fresno, California	1,350,320	-0.08
Westchester, New York	1,026,461	-0.23
Tulare, California	509,803	-0.07
Kern, California	1,100,054	-0.13
Richmond, New York	672,799	-0.38
Bronx, New York	1,643,295	-0.17
Suffolk, New York	1,889,102	-0.33
Imperial, California	228,455	-0.13
Sublette, Wyoming	19,279	-0.17
Larimer, Colorado	597,906	-0.39
Rio Blanco, Colorado	7,422	-0.20

Note:
[a] Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. (2011). 2012 Complete Economic and Demographic Data Source (CEDDS).

6A2.4 NO_2 Results

Air quality modeling results indicate that annual average NO_2 concentrations will be reduced across the country, see Figure 6A-5. However, the magnitude of the reductions that will actually result from the final standards is difficult to estimate because the air quality modeling inventories included larger NOx emission reductions than we now expect to occur. As described in Chapter 5.5.2.3, the air quality inventories and the final rule inventories make different assumptions about the usage of diesel-powered APUs. The air quality inventories assumed more widespread usage of diesel-powered APUs than was assumed for the final rule, and as a result the reductions in ambient NO_2 concentrations are overestimated in the air quality modeling.

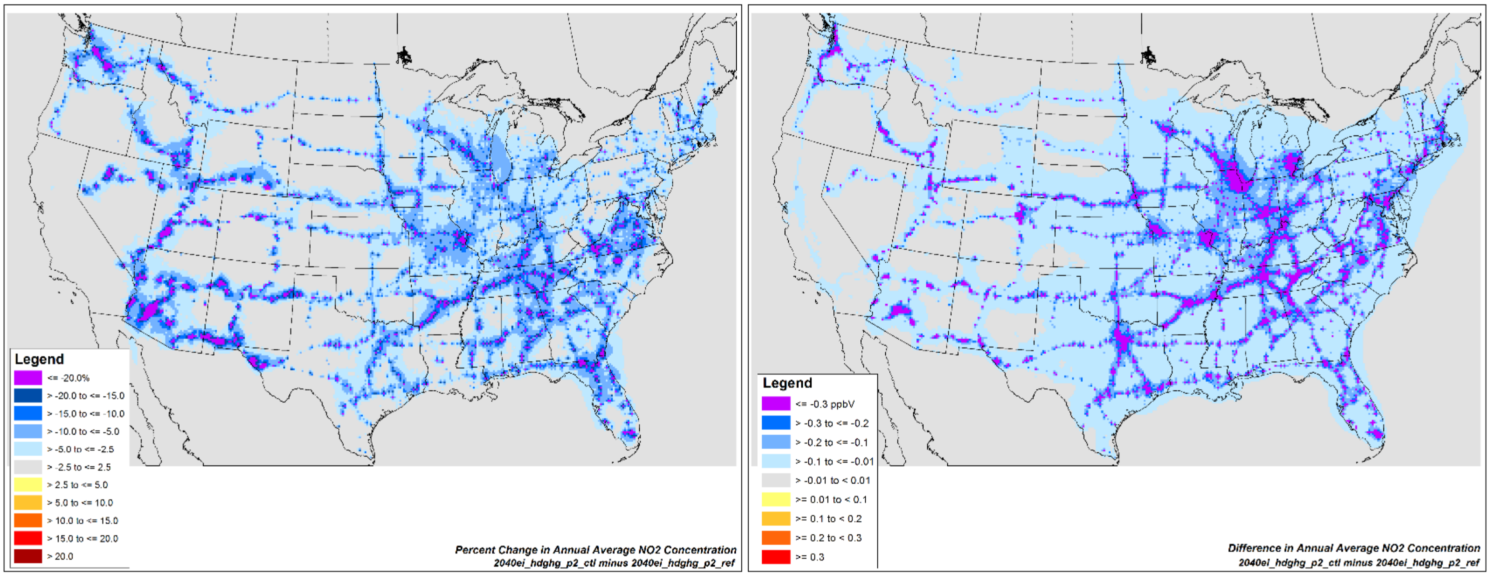

Figure 6A-5 Annual Changes in Ambient NO_2 Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in ppb (right)

6A2.5 Air Toxics Results

Our modeling indicates that the standards have relatively little impact on national average ambient concentrations of the modeled air toxics. Annual absolute changes in ambient concentrations are generally less than 0.2 µg/m^3 for benzene, formaldehyde, and acetaldehyde and less than 0.005 µg/m^3 for acrolein and 1,3-butadiene. Naphthalene changes are in the range of 0.005 µg/m^3 along major roadways and in urban areas. Air toxics concentration maps are presented below along with a table showing the percent of the population experiencing changes in ambient toxic concentrations.

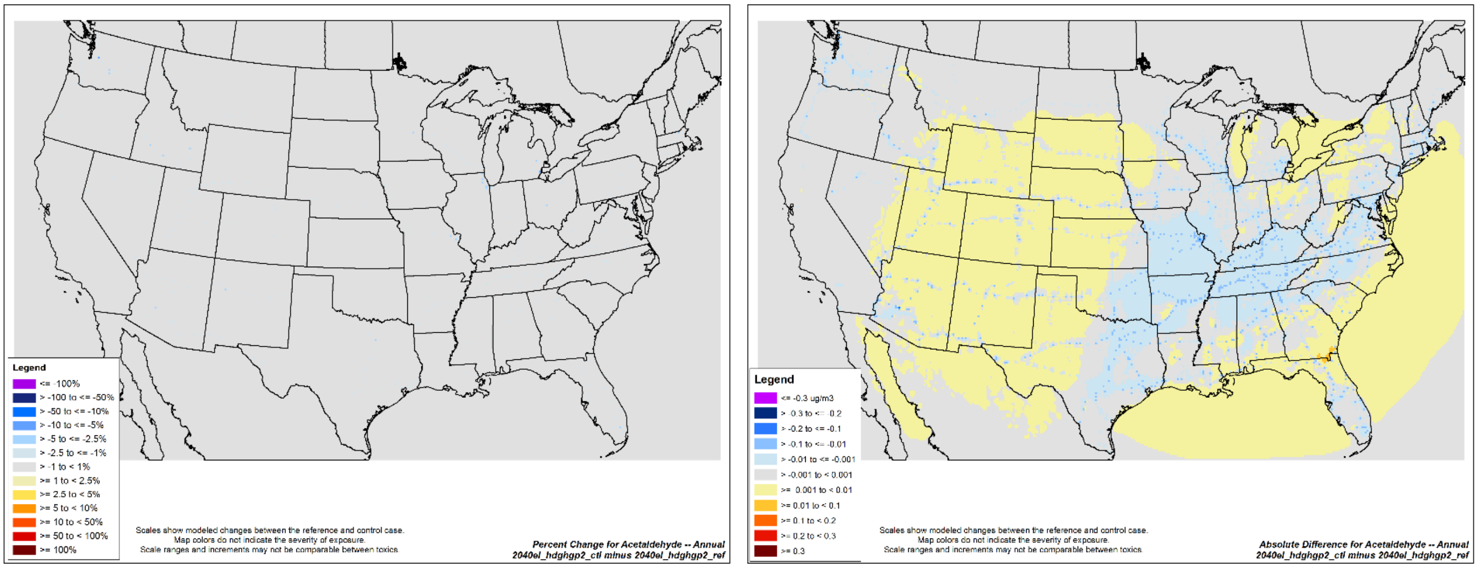

Figure 6A-6 Annual Changes in Acetaldehyde Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

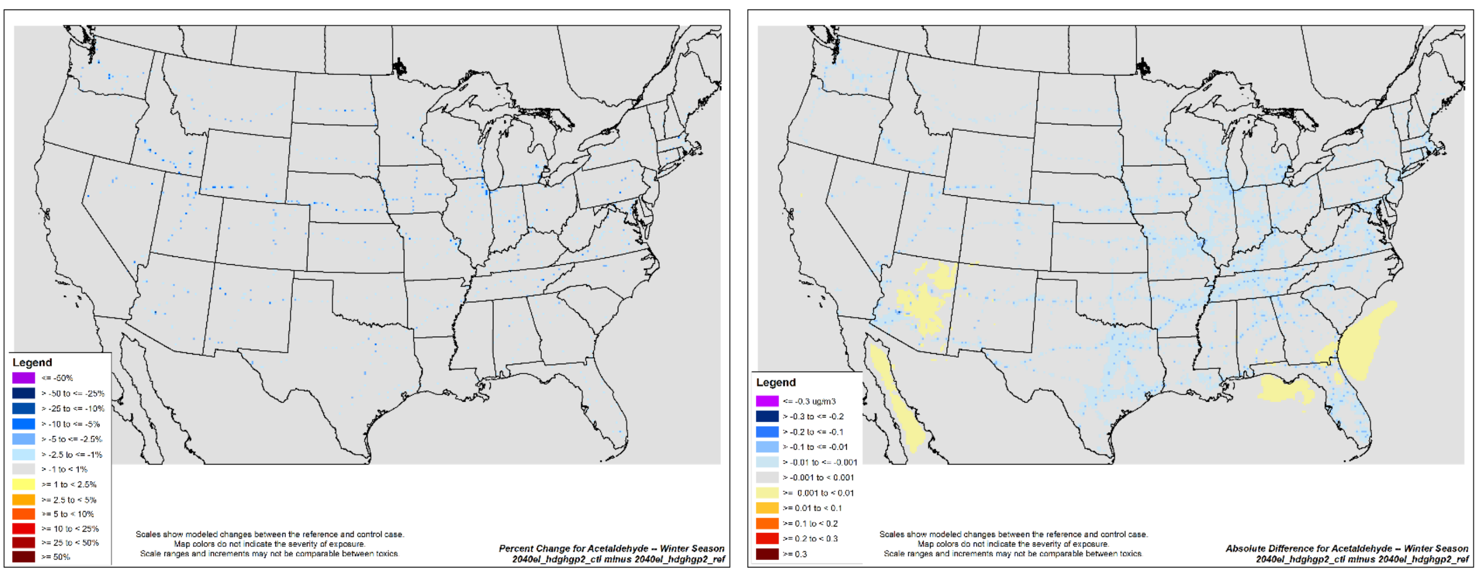

Figure 6A-7 Winter Changes in Acetaldehyde Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

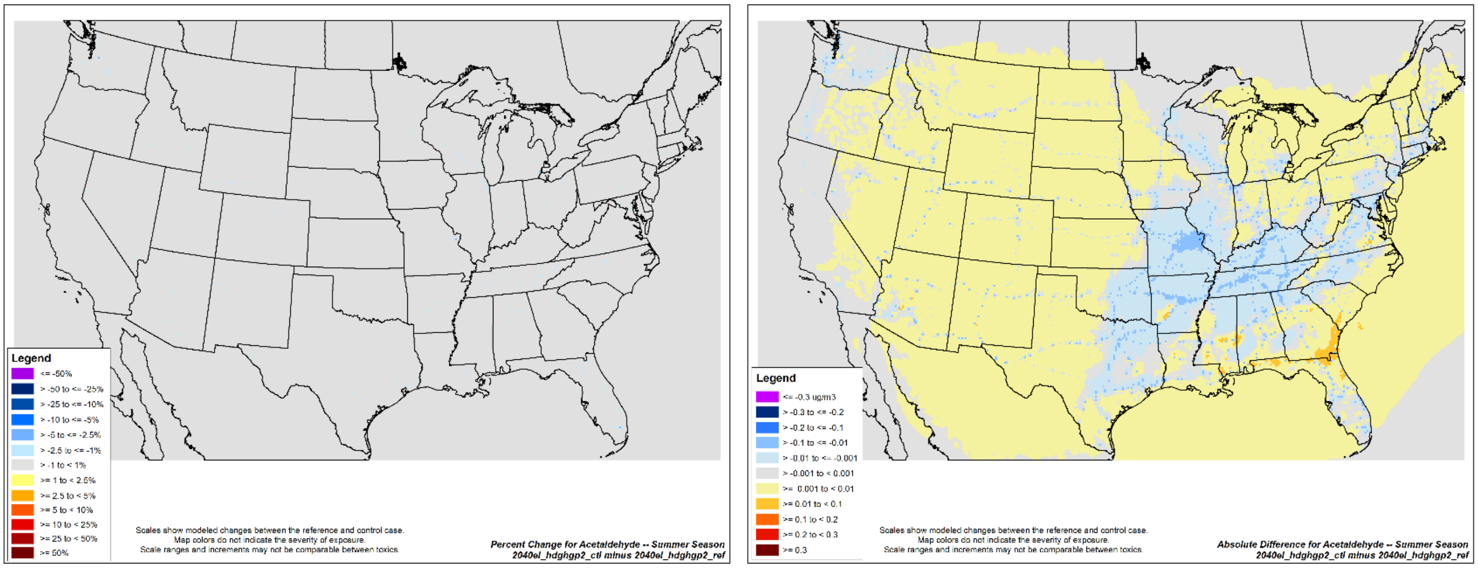

Figure 6A-8 Summer Changes in Acetaldehyde Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

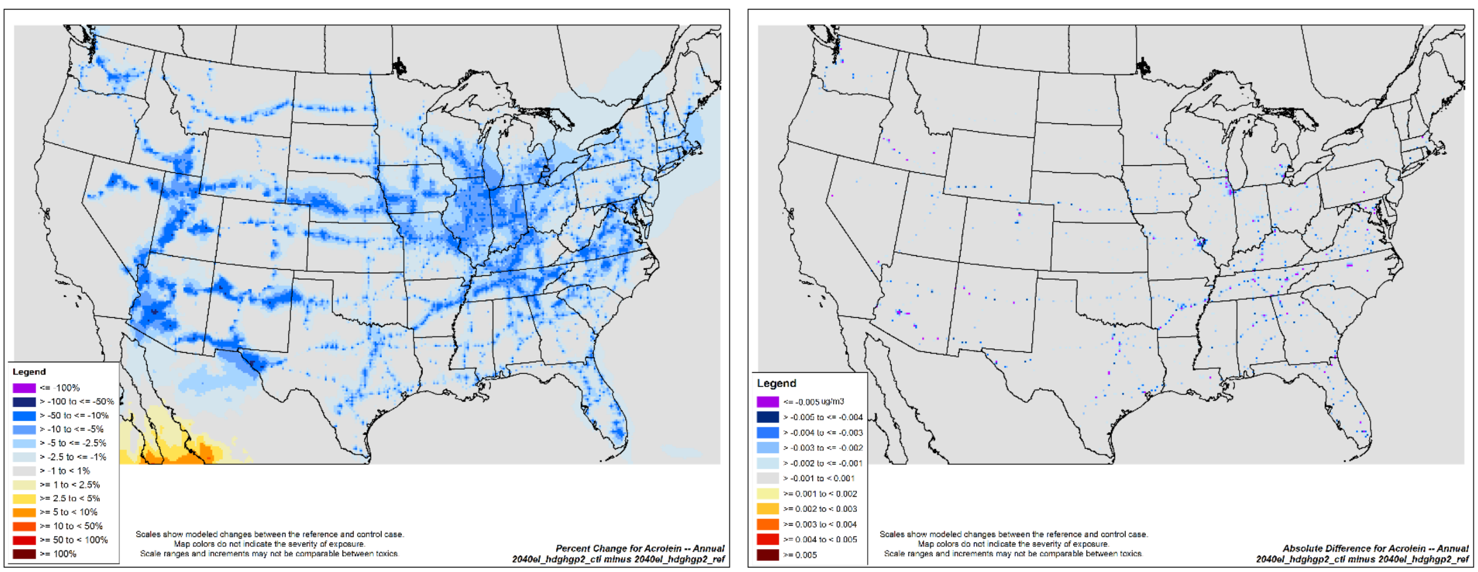

Figure 6A-9 Annual Changes in Acrolein Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

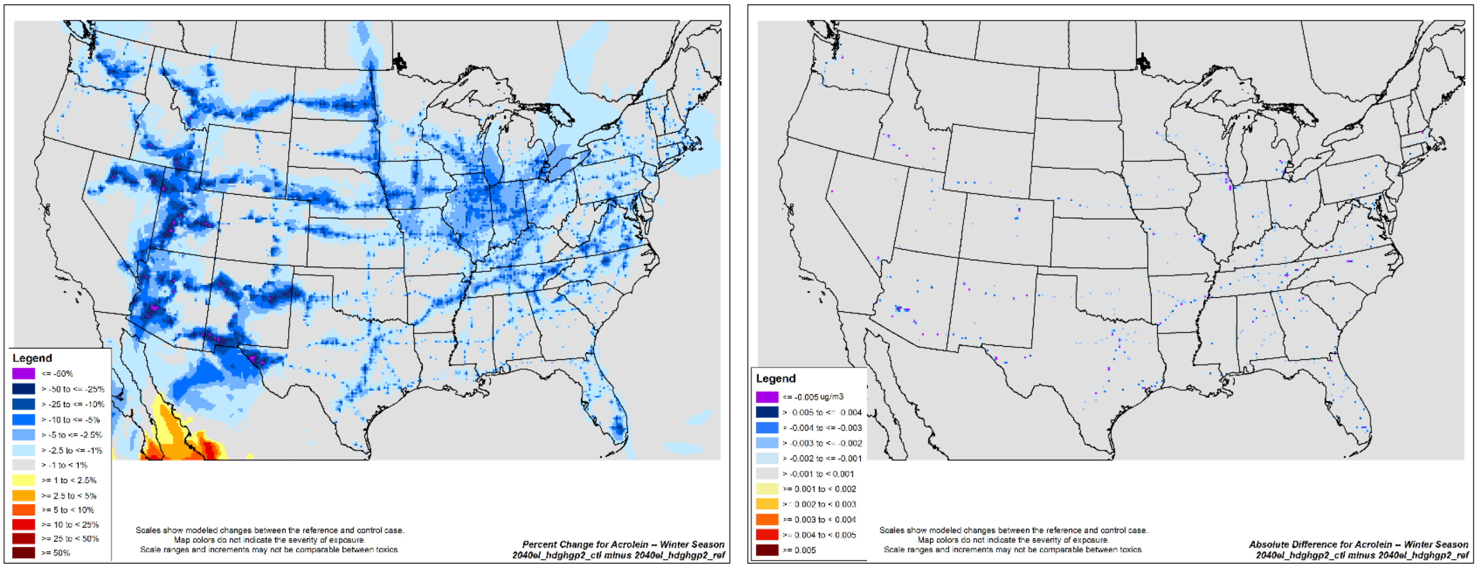

Figure 6A-10 Winter Changes in Acrolein Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in μg/m³ (right)

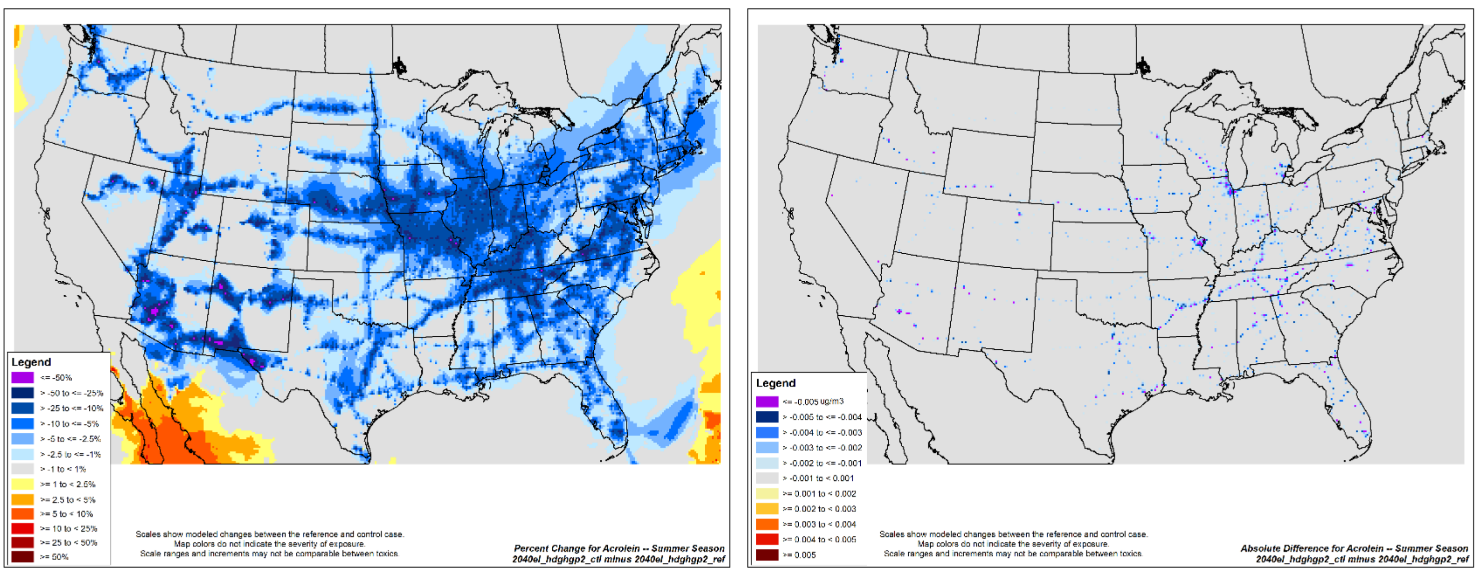

Figure 6A-11 Summer Changes in Acrolein Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in μg/m³ (right)

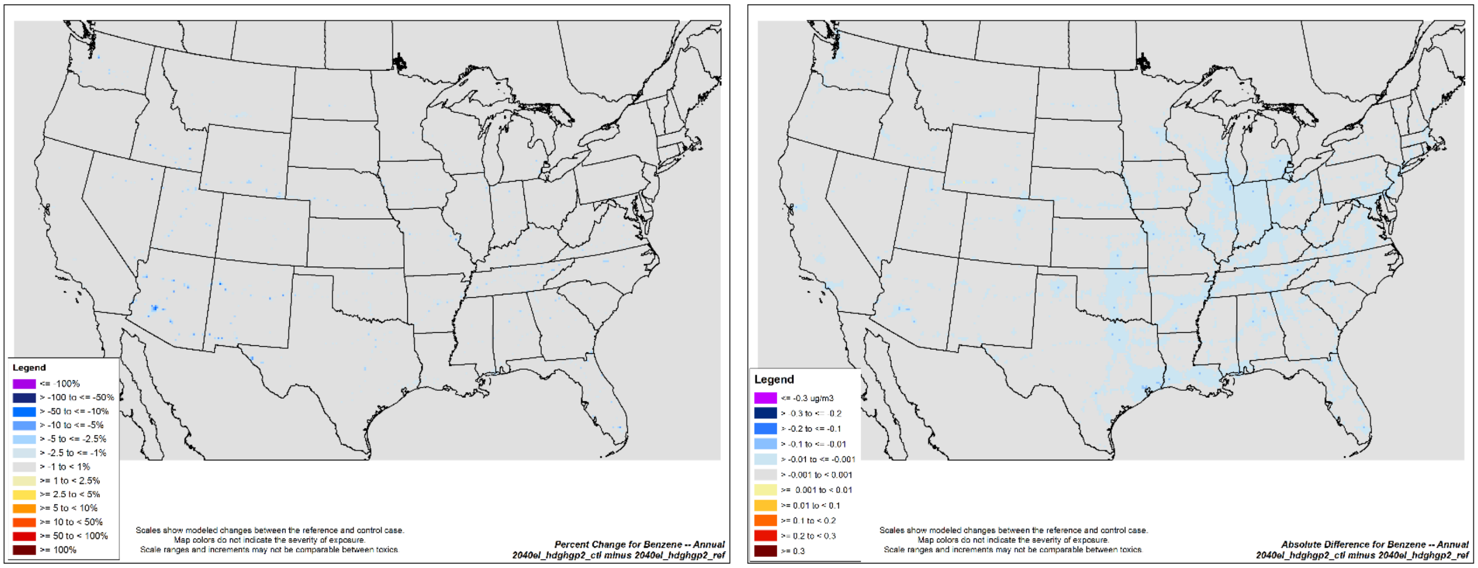

Figure 6A-12 Annual Changes in Benzene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

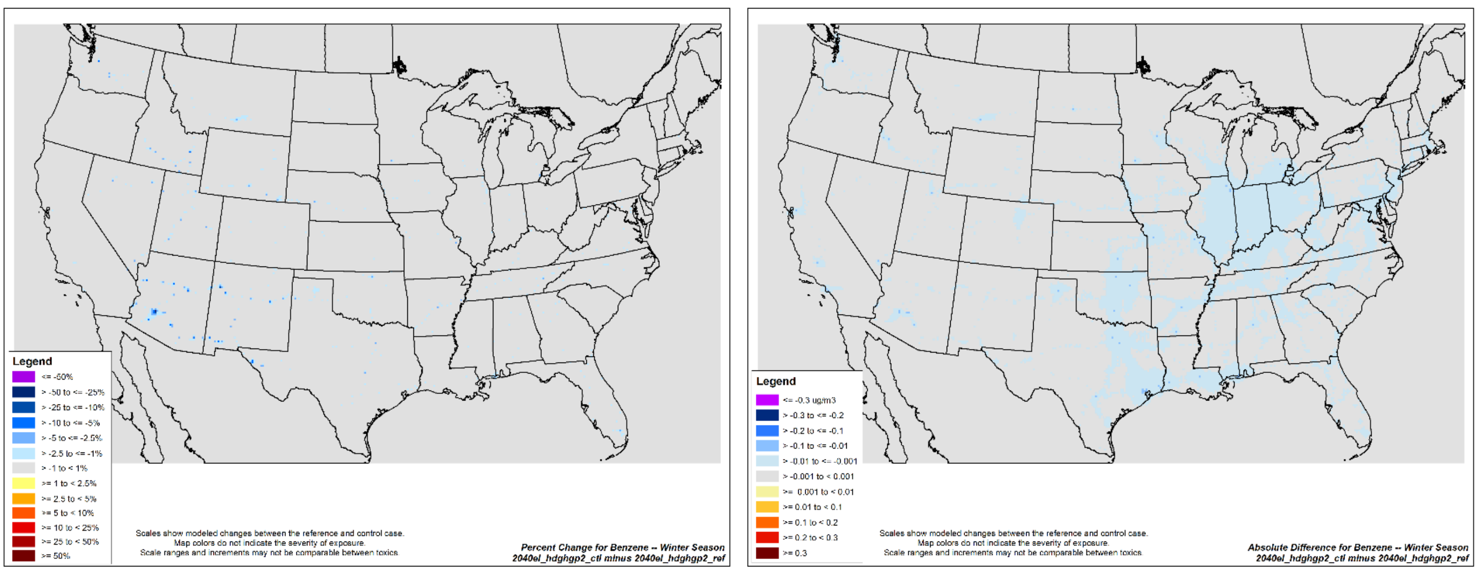

Figure 6A-13 Winter Changes in Benzene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

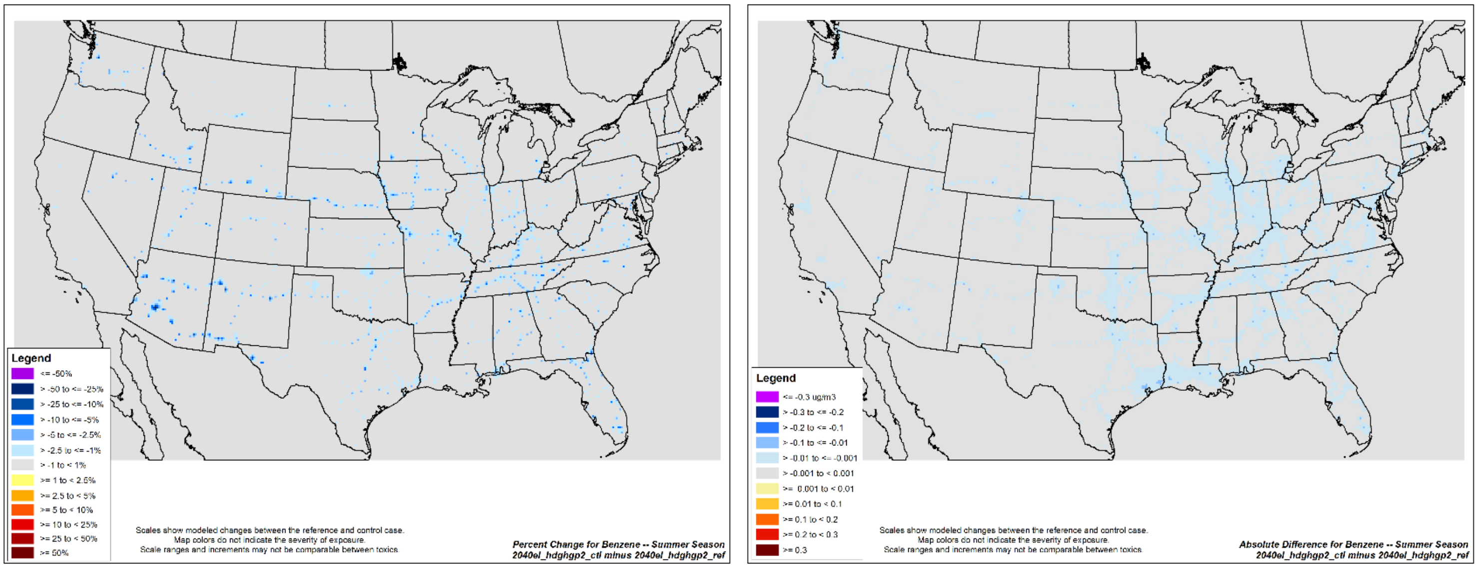

Figure 6A-14 Summer Changes in Benzene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in $\mu g/m^3$ (right)

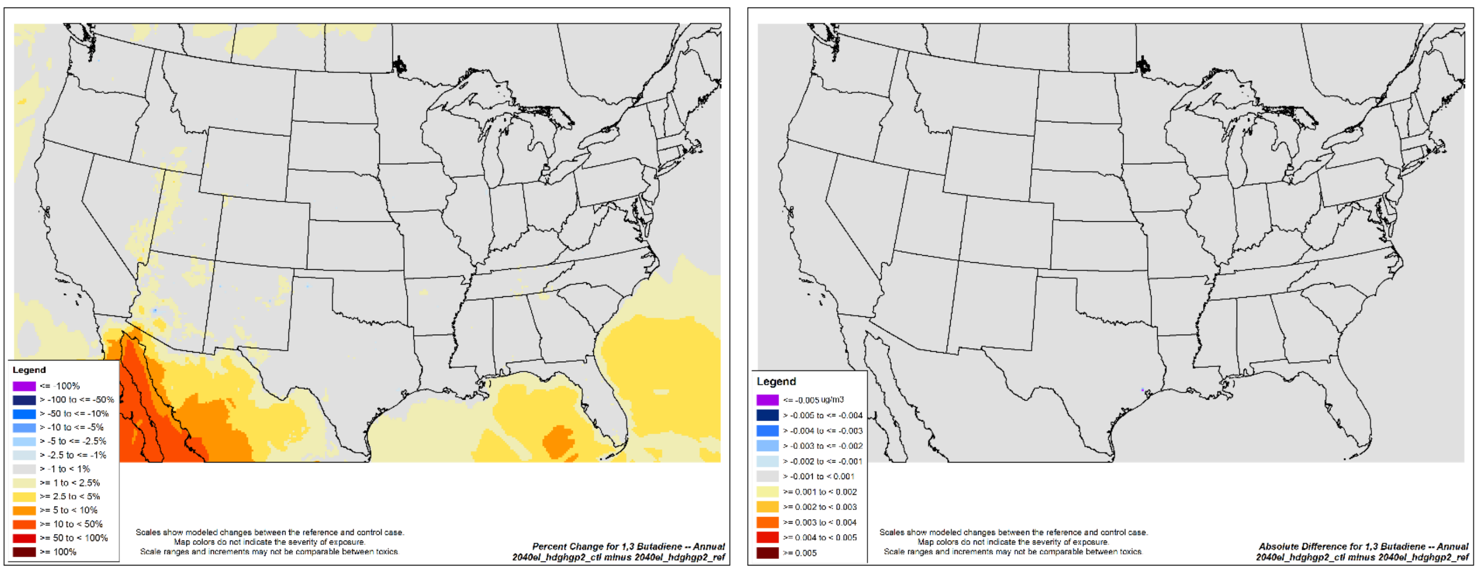

Figure 6A-15 Changes in 1,3-Butadiene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in $\mu g/m^3$ (right)

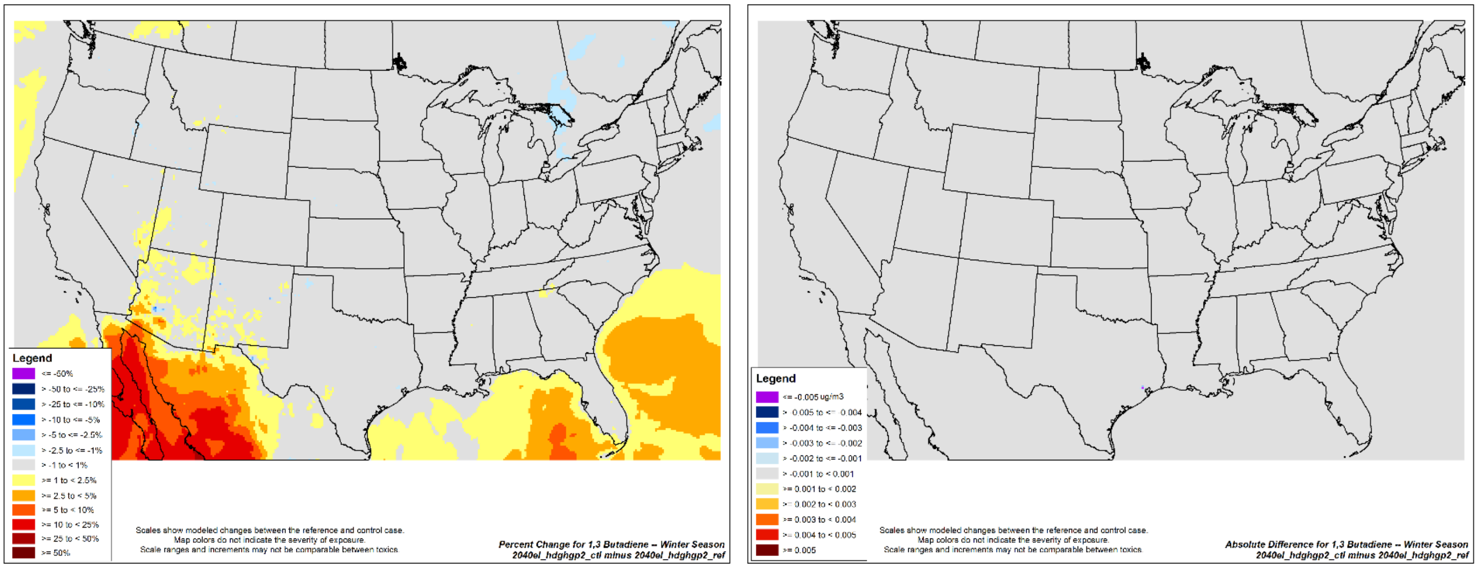

Figure 6A-16 Winter Changes in 1,3-Butadiene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in μg/m³ (right)

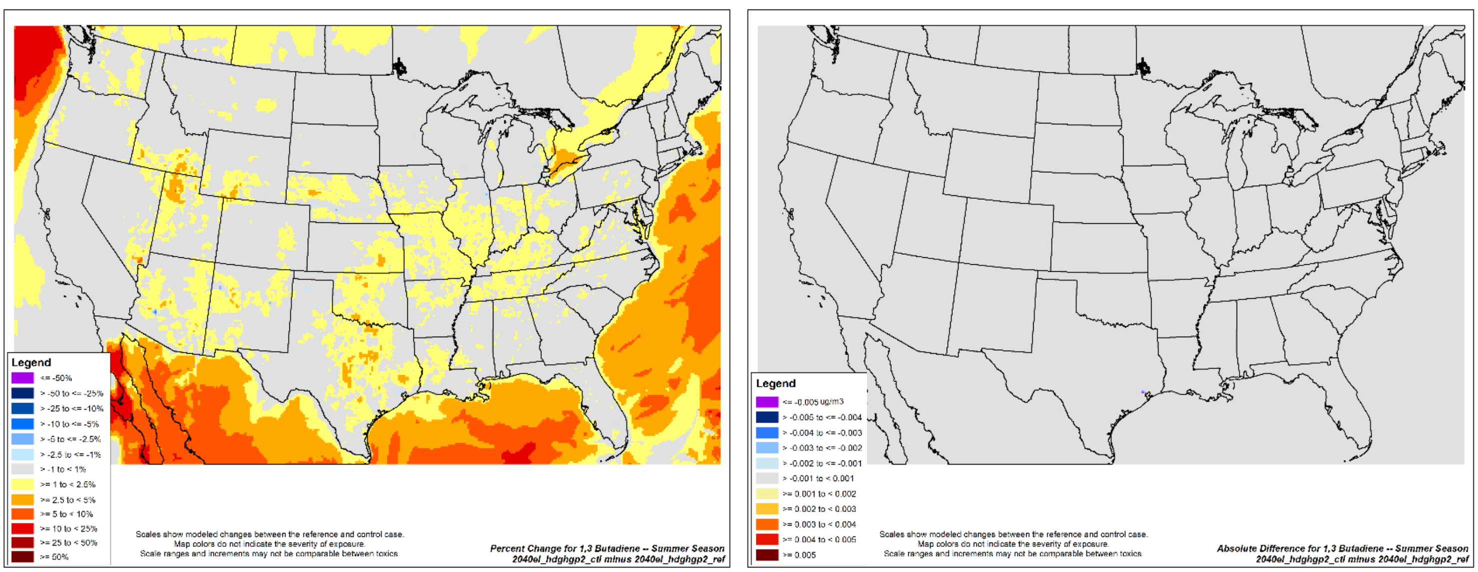

Figure 6A-17 Summer Changes in 1,3-Butadiene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in μg/m³ (right)

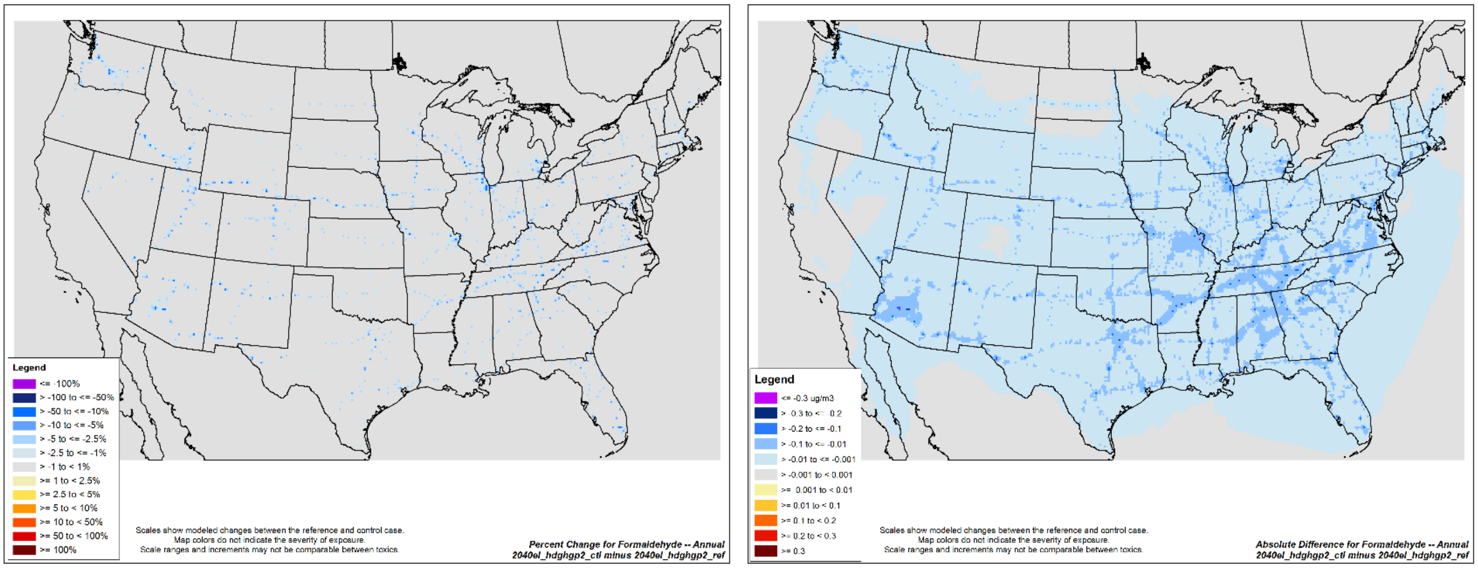

Figure 6A-18 Changes in Formaldehyde Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

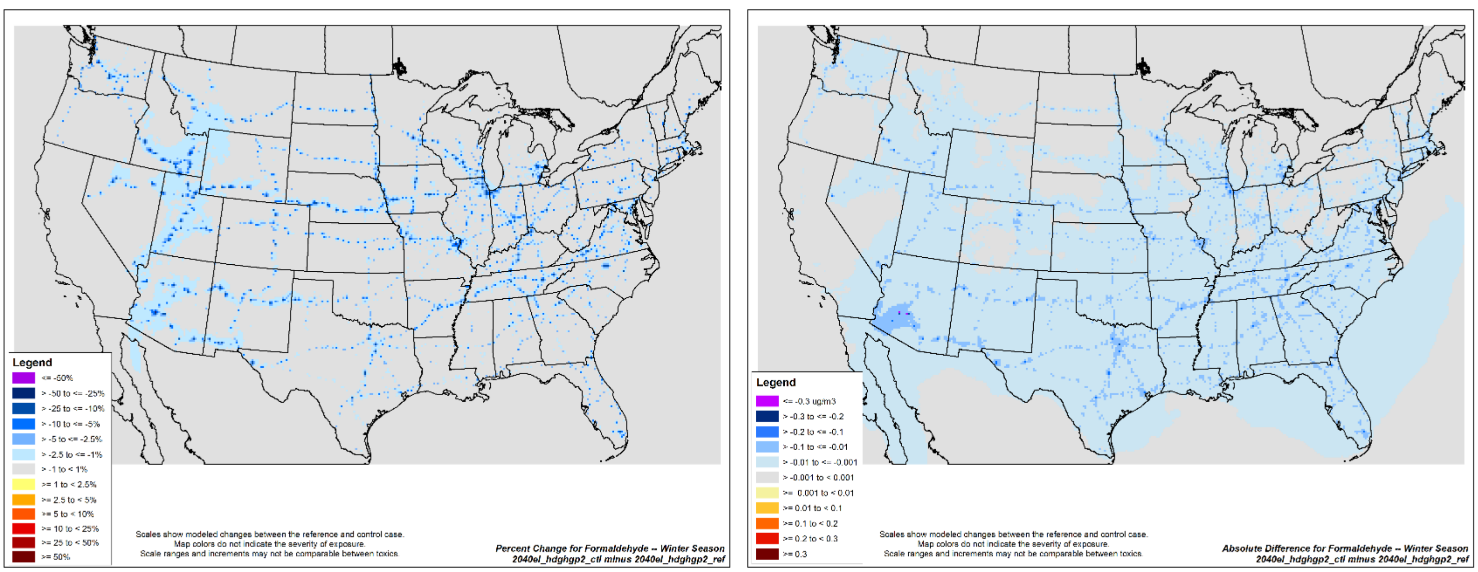

Figure 6A-19 Winter Changes in Formaldehyde Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

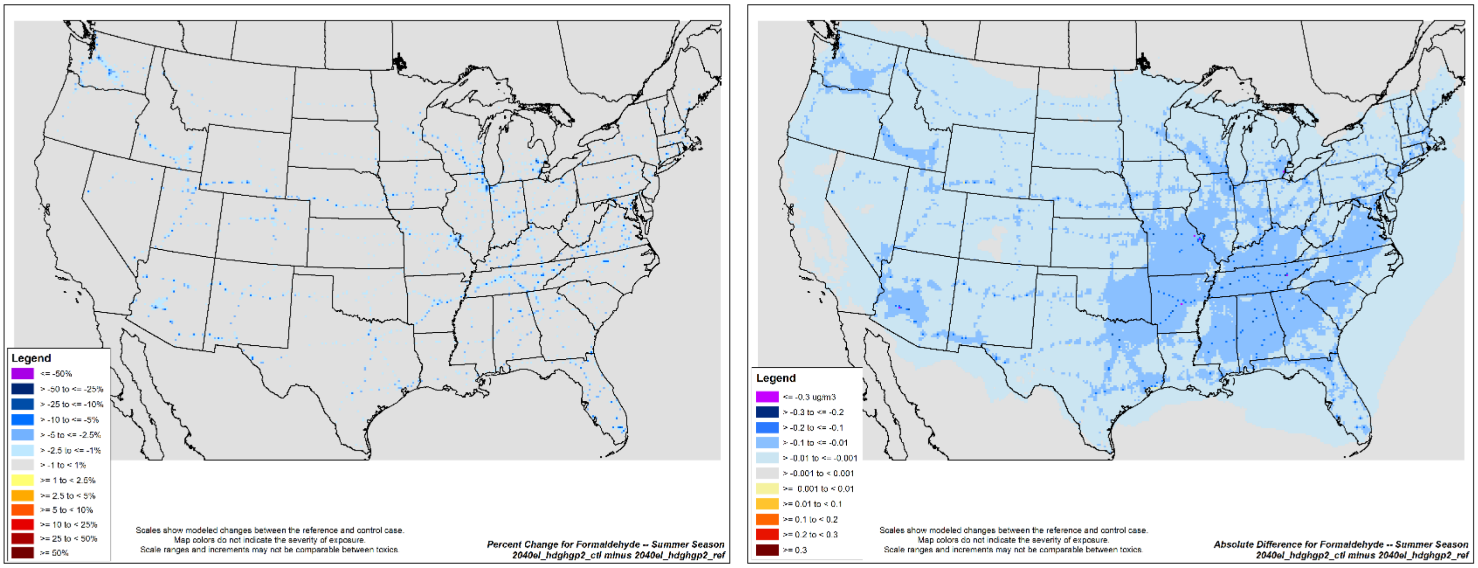

Figure 6A-20 Summer Changes in Formaldehyde Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

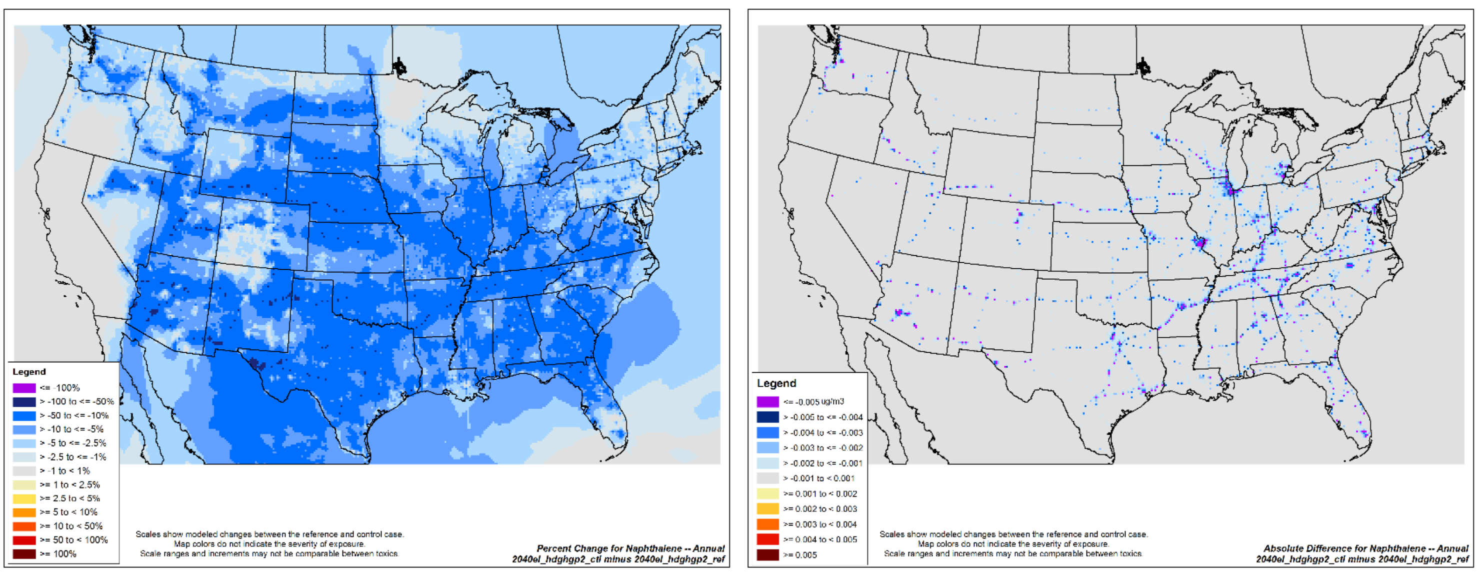

Figure 6A-21 Changes in Naphthalene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in µg/m³ (right)

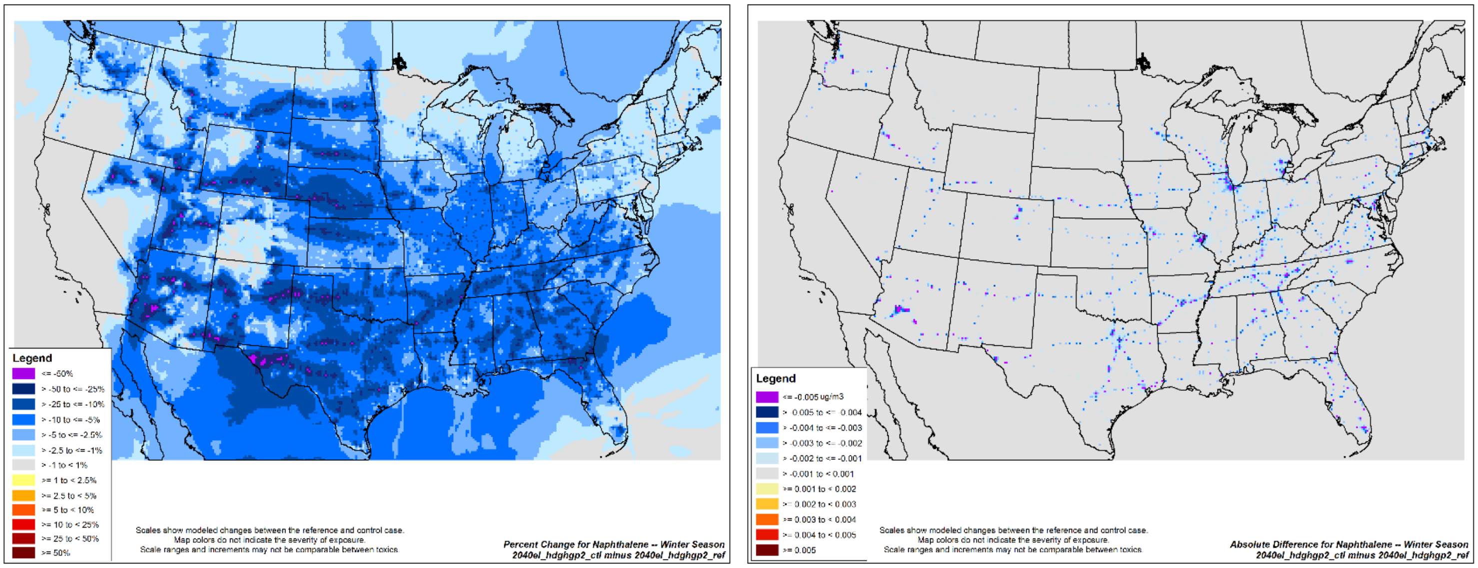

Figure 6A-22 Winter Changes in Naphthalene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in μg/m³ (right)

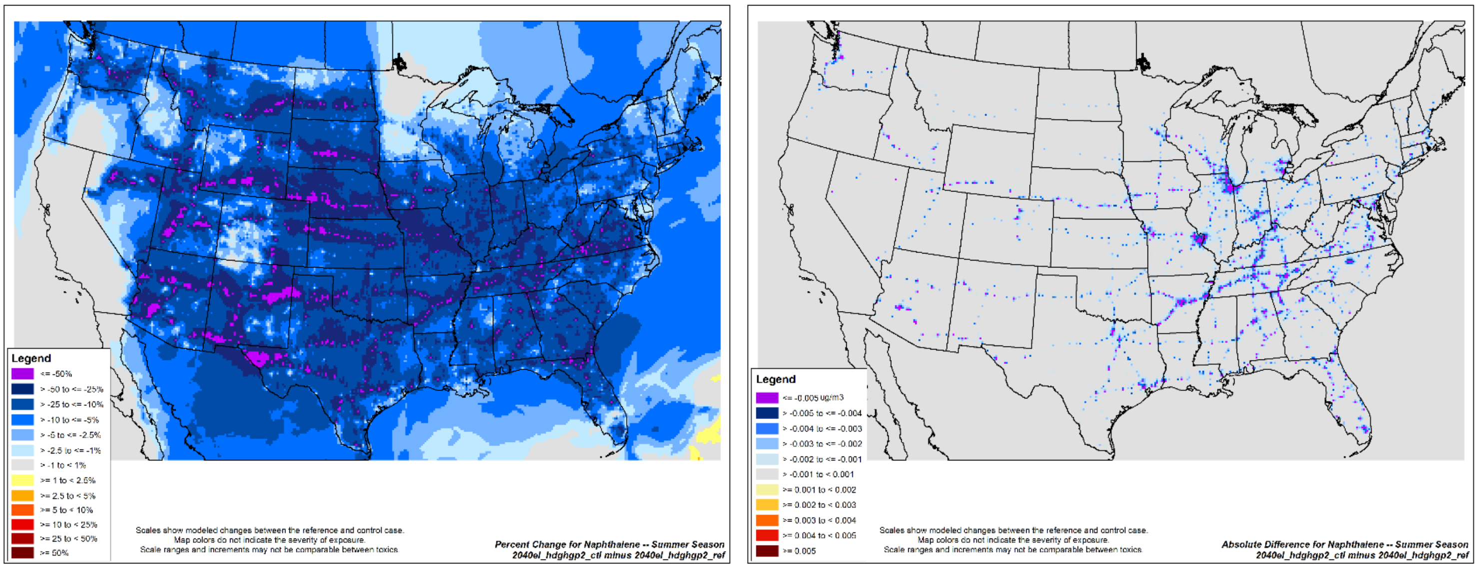

Figure 6A-23 Summer Changes in Naphthalene Ambient Concentrations between the Reference Case and the Control Case in 2040 Using Air Quality Inventories: Percent Changes (left) and Absolute Changes in μg/m³ (right)

Table 6A-7 Percent of Total Population Experiencing Changes in Annual Ambient Concentrations of Toxic Pollutants in 2040 as a Result of the Standards

Percent Change	Acetaldehyde	Acrolein	Benzene	1,3-Butadiene	Ethanol	Formaldehyde	Naphthalene
≤ -50		0%					0%
> -50 to ≤ -25		1%					4%
> -25 to ≤ -10		8%				1%	20%
> -10 to ≤ -5	0%	15%	0%			2%	24%
> -5 to ≤ -2.5	0%	25%	1%			5%	21%
> -2.5 to ≤ -1	3%	28%	5%	1%		18%	15%
> -1 to < 1	97%	23%	94%	99%	100%	74%	15%
≥ 1 to < 2.5				0%			
≥ 2.5 to < 5							
≥ 5 to < 10							
≥ 10 to < 25							
≥ 25 to < 50							
≥ 50							

6A2.6 Visibility Results

Table 6A-8 Visibility Levels (in Deciviews) for Mandatory Class I Federal Areas on the 20 Percent Worst Days Using Air Quality Inventories

Class 1 Area (20% worst days)	State	2011 Baseline Visibility	2040 Reference	2040 HDGHGP2 Control	Natural Background
Sipsey Wilderness	Alabama	22.93	18.16	18.07	10.99
Mazatzal Wilderness	Arizona	12.03	11.40	11.38	6.68
Pine Mountain Wilderness	Arizona	12.03	11.40	11.38	6.68
Superstition Wilderness	Arizona	12.72	11.82	11.80	6.54
Chiricahua NM	Arizona	12.08	11.54	11.53	7.20
Chiricahua Wilderness	Arizona	12.08	11.54	11.53	7.20
Galiuro Wilderness	Arizona	12.08	11.54	11.53	7.20
Grand Canyon NP	Arizona	10.92	10.53	10.52	7.04
Petrified Forest NP	Arizona	11.92	11.64	11.63	6.49
Sycamore Canyon Wilderness	Arizona	14.62	14.00	14.01	6.65
Caney Creek Wilderness	Arkansas	22.23	19.01	18.96	11.58
Upper Buffalo Wilderness	Arkansas	22.12	19.00	18.95	11.57
Joshua Tree NM	California	15.07	13.49	13.47	7.19
Kings Canyon NP	California	20.82	17.93	17.91	7.70
San Rafael Wilderness	California	16.46	14.51	14.49	7.57
San Gorgonio Wilderness	California	16.85	14.11	14.09	7.30

San Jacinto Wilderness	California	16.85	14.11	14.09	7.30
Sequoia NP	California	20.82	17.93	17.91	7.70
Agua Tibia Wilderness	California	18.44	15.66	15.65	7.64
Ansel Adams Wilderness (Minarets)	California	14.27	13.01	13.00	7.12
Desolation Wilderness	California	11.82	11.02	11.01	6.05
Dome Land Wilderness	California	17.23	15.93	15.92	7.46
Emigrant Wilderness	California	14.75	14.16	14.15	7.64
Hoover Wilderness	California	10.78	10.31	10.30	7.71
John Muir Wilderness	California	14.27	13.01	13.00	7.12
Kaiser Wilderness	California	14.27	13.01	13.00	7.12
Marble Mountain Wilderness	California	14.10	13.34	13.33	7.90
Mokelumne Wilderness	California	11.82	11.02	11.01	6.05
Pinnacles NM	California	16.15	14.42	14.41	7.99
Ventana Wilderness	California	16.15	14.42	14.41	7.99
Yolla Bolly Middle Eel Wilderness	California	14.10	13.34	13.33	7.90
Yosemite NP	California	14.75	14.16	14.15	7.64
Caribou Wilderness	California	13.49	12.83	12.83	7.31
Lava Beds NM	California	13.38	12.93	12.93	7.85
Lassen Volcanic NP	California	13.49	12.83	12.83	7.31
Point Reyes NS	California	20.98	19.93	19.93	15.77
Redwood NP	California	17.38	16.82	16.82	13.91
South Warner Wilderness	California	13.38	12.93	12.93	7.85
Thousand Lakes Wilderness	California	13.49	12.83	12.83	7.31
Rocky Mountain NP	Colorado	11.84	10.93	10.91	7.15
Black Canyon of the Gunnison NM	Colorado	9.88	9.71	9.70	6.21
La Garita Wilderness	Colorado	9.88	9.71	9.70	6.21
Weminuche Wilderness	Colorado	9.88	9.71	9.70	6.21
Eagles Nest Wilderness	Colorado	8.48	8.04	8.03	6.06
Flat Tops Wilderness	Colorado	8.48	8.04	8.03	6.06
Great Sand Dunes NM	Colorado	11.57	11.50	11.49	6.66
Maroon Bells-Snowmass Wilderness	Colorado	8.48	8.04	8.03	6.06
Mount Zirkel Wilderness	Colorado	9.11	8.70	8.69	6.08
Rawah Wilderness	Colorado	9.11	8.70	8.69	6.08
West Elk Wilderness	Colorado	8.48	8.04	8.03	6.06
Mesa Verde NP	Colorado	11.22	11.37	11.37	6.81
Chassahowitzka	Florida	21.34	18.21	18.17	11.03
St. Marks	Florida	22.23	18.74	18.70	11.67
Everglades NP	Florida	18.15	17.65	17.62	12.15
Cohutta Wilderness	Georgia	22.71	17.47	17.43	10.78
Okefenokee	Georgia	22.68	18.82	18.78	11.44
Wolf Island	Georgia	22.68	18.82	18.78	11.44
Craters of the Moon NM	Idaho	14.05	12.93	12.80	7.53
Sawtooth Wilderness	Idaho	15.64	15.44	15.44	6.42

Selway-Bitterroot Wilderness	Idaho	14.89	14.77	14.77	7.43
Mammoth Cave NP	Kentucky	25.09	19.83	19.75	11.08
Acadia NP	Maine	17.93	15.81	15.80	12.43
Moosehorn	Maine	16.83	15.27	15.26	12.01
Roosevelt Campobello International Park	Maine	16.83	15.27	15.26	12.01
Seney	Michigan	20.56	17.15	17.08	12.65
Isle Royale NP	Michigan	18.92	16.06	16.01	12.37
Boundary Waters Canoe Area	Minnesota	18.82	16.66	16.60	11.61
Hercules-Glades Wilderness	Missouri	22.89	19.57	19.51	11.30
Mingo	Missouri	24.31	20.91	20.86	11.62
Medicine Lake	Montana	17.98	17.07	17.06	7.89
Bob Marshall Wilderness	Montana	14.43	14.33	14.32	7.73
Cabinet Mountains Wilderness	Montana	12.73	12.24	12.23	7.52
Glacier NP	Montana	16.03	15.82	15.81	9.18
Mission Mountains Wilderness	Montana	14.43	14.33	14.32	7.73
Red Rock Lakes	Montana	11.98	11.73	11.72	6.44
Scapegoat Wilderness	Montana	14.43	14.33	14.32	7.73
UL Bend	Montana	14.11	13.77	13.76	8.16
Anaconda-Pintler Wilderness	Montana	14.89	14.77	14.77	7.43
Jarbidge Wilderness	Nevada	11.97	11.90	11.90	7.87
Great Gulf Wilderness	New Hampshire	16.66	13.61	13.60	11.99
Presidential Range-Dry River Wilderness	New Hampshire	16.66	13.61	13.60	11.99
Brigantine	New Jersey	23.75	19.64	19.61	12.24
Bosque del Apache	New Mexico	14.02	14.37	14.34	6.73
Salt Creek	New Mexico	17.42	18.32	18.30	6.81
Bandelier NM	New Mexico	11.92	12.22	12.21	6.26
Carlsbad Caverns NP	New Mexico	15.32	15.09	15.08	6.65
Pecos Wilderness	New Mexico	9.93	9.84	9.83	6.08
San Pedro Parks Wilderness	New Mexico	10.02	10.02	10.01	5.72
Wheeler Peak Wilderness	New Mexico	9.93	9.84	9.83	6.08
White Mountain Wilderness	New Mexico	14.19	14.56	14.56	6.80
Linville Gorge Wilderness	North Carolina	21.60	15.94	15.91	11.22
Swanquarter	North Carolina	21.77	16.75	16.73	11.55
Theodore Roosevelt NP	North Dakota	16.96	15.96	15.95	7.80
Wichita Mountains	Oklahoma	21.24	18.83	18.76	7.53
Hells Canyon Wilderness	Oregon	16.58	15.10	14.94	8.32
Eagle Cap Wilderness	Oregon	14.87	14.20	14.17	8.92
Strawberry Mountain Wilderness	Oregon	14.87	14.20	14.17	8.92
Kalmiopsis Wilderness	Oregon	15.01	14.52	14.51	9.44
Mount Hood Wilderness	Oregon	13.35	12.72	12.71	8.43
Mount Jefferson Wilderness	Oregon	15.77	15.52	15.51	8.79
Mount Washington Wilderness	Oregon	15.77	15.52	15.51	8.79
Three Sisters Wilderness	Oregon	15.77	15.52	15.51	8.79

Crater Lake NP	Oregon	11.64	11.33	11.33	7.62
Diamond Peak Wilderness	Oregon	11.64	11.33	11.33	7.62
Gearhart Mountain Wilderness	Oregon	11.64	11.33	11.33	7.62
Mountain Lakes Wilderness	Oregon	11.64	11.33	11.33	7.62
Cape Romain	South Carolina	23.17	19.02	18.99	12.12
Wind Cave NP	South Dakota	14.04	12.85	12.82	7.71
Badlands NP	South Dakota	15.67	14.32	14.30	8.06
Great Smoky Mountains NP	Tennessee	22.50	16.99	16.95	11.24
Joyce-Kilmer-Slickrock Wilderness	Tennessee	22.50	16.99	16.95	11.24
Guadalupe Mountains NP	Texas	15.32	15.09	15.08	6.65
Big Bend NP	Texas	16.30	16.54	16.54	7.16
Arches NP	Utah	10.83	10.53	10.50	6.43
Canyonlands NP	Utah	10.83	10.53	10.50	6.43
Capitol Reef NP	Utah	10.18	9.69	9.66	6.03
Bryce Canyon NP	Utah	10.61	10.21	10.19	6.80
Lye Brook Wilderness	Vermont	19.26	14.94	14.92	11.73
James River Face Wilderness	Virginia	22.55	17.28	17.24	11.13
Shenandoah NP	Virginia	21.82	15.20	15.16	11.35
Alpine Lake Wilderness	Washington	16.14	14.86	14.80	8.43
Mount Rainier NP	Washington	15.50	14.43	14.41	8.54
Olympic NP	Washington	14.10	13.50	13.48	8.44
Pasayten Wilderness	Washington	12.44	11.83	11.81	8.25
Glacier Peak Wilderness	Washington	13.51	12.82	12.81	8.39
Goat Rocks Wilderness	Washington	12.37	11.77	11.76	8.35
North Cascades NP	Washington	13.51	12.82	12.81	8.01
Mount Adams Wilderness	Washington	12.37	11.77	11.76	8.35
Dolly Sods Wilderness	West Virginia	22.40	16.06	16.03	10.39
Otter Creek Wilderness	West Virginia	22.40	16.06	16.03	10.39
Bridger Wilderness	Wyoming	10.25	9.91	9.90	6.45
Fitzpatrick Wilderness	Wyoming	10.25	9.91	9.90	6.45
Grand Teton NP	Wyoming	11.98	11.73	11.72	6.44
Teton Wilderness	Wyoming	11.98	11.73	11.72	6.44
Yellowstone NP	Wyoming	11.98	11.73	11.72	6.44

6A2.7 Deposition Results

Figure 6A-24 presents changes in projected nitrogen deposition in 2040 due to the standards and Figure 6A-25 presents changes in projected sulfur deposition due to the standards.

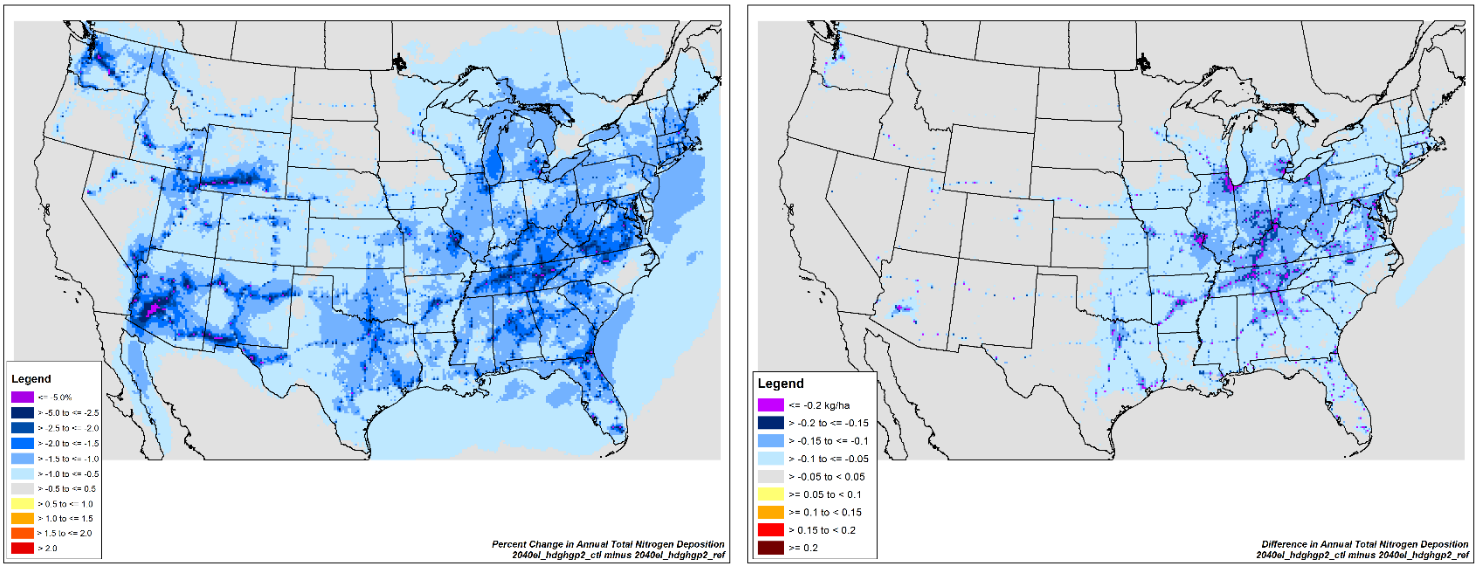

Figure 6A-24 Changes in Nitrogen Deposition between the Reference Case and the Control Case in 2040 using Air Quality Inventories: Percent Changes (left) and Absolute Changes in kg/ha (right)

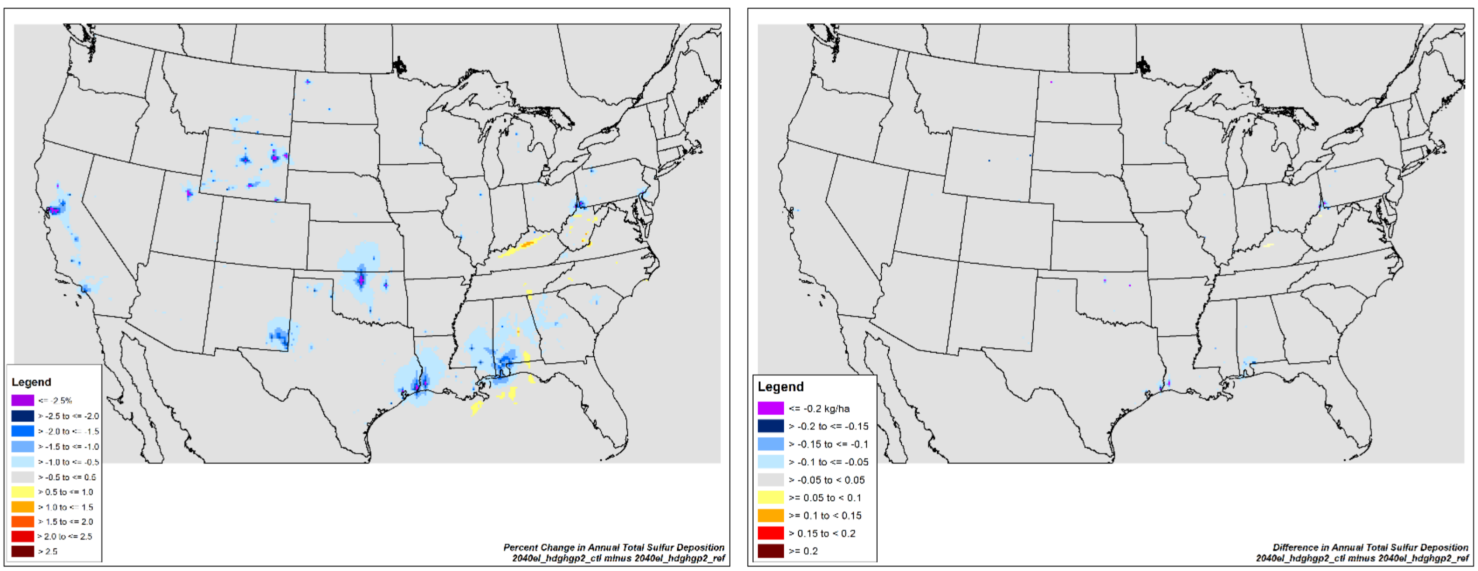

Figure 6A-25 Changes in Sulfur Deposition between the Reference Case and the Control Case in 2040 using Air Quality Inventories: Percent Changes (left) and Absolute Changes in kg/ha (right)

References

[1] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009.
[2] U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F.
[3] 78 FR 3086 (January 15, 2013) pages 3103-3104.
[4] 77 FR 38890 (June 29, 2012) pages 38906-38911.
[5] 78 FR 3086 (January 15, 2013) pages 3103-3104.
[6] U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, Chapter 6 (Section 6.5) and Chapter 7 (Section 7.6).
[7] 78 FR 3103 (January 15, 2013).
[8] 78 FR 3103 (January 15, 2013).
[9] 78 FR 3103-3104 (January 15, 2013).
[10] 78 FR 3104 (January 15, 2013).
[11] U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F. pg 2-13.
[12] U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F. pg 2-26.
[13] U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F. Section 2.3.4 and Table 2-6.
[14] 78 FR 3167-8 (January 15, 2013).
[15] 77 FR 38947-51 (June 29, 2012).
[16] U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F. Section 2.3.5 and Table 2-6.
[17] 78 FR 3121 (January 15, 2013).
[18] U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F. Chapter 8 and Chapter 2.
[19] 77 FR 38890, (June 29, 2012) page 38910.
[20] 78 FR 3086 (January 15, 2013) page 3104.
[21] U.S. EPA. (2011). Policy Assessment for the Review of the PM NAAQS. U.S. Environmental Protection Agency, Washington, DC, EPA/452/R-11-003. Section 2.2.1.
[22] U.S. EPA. (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F. Chapter 8 and Chapter 2 (Section 2.4.1).
[23] U.S. EPA. Integrated Science Assessment of Ozone and Related Photochemical Oxidants (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-10/076F, 2013. The ISA is available at http://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=247492#Download.
[24] U.S. EPA (2008). *Integrated Science Assessment (ISA) for Sulfur Oxides – Health Criteria* (Final Report). EPA/600/R-08/047F. Washington, DC, U.S. EPA. Retrieved on March 19, 2009 from http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=198843.
[25] U.S. EPA, (2010). Integrated Science Assessment for Carbon Monoxide (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/019F, 2010. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=218686. See Section 2.1.
[26] U.S. EPA, (2010). Integrated Science Assessment for Carbon Monoxide (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/019F, 2010. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=218686.
[27] U.S. EPA. (1999). *Guidelines for Carcinogen Risk Assessment*. Review Draft. NCEA-F-0644, July. Washington, DC: U.S. EPA. Retrieved on March 19, 2009 from http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=54932.
[28] U.S. EPA (2002). *Health Assessment Document for Diesel Engine Exhaust.* EPA/600/8-90/057F Office of research and Development, Washington DC. Retrieved on March 17, 2009 from http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=29060. pp. 1-1 1-2.

[29] Garshick, Eric, Francine Laden, Jaime E. Hart, Mary E. Davis, Ellen A. Eisen, and Thomas J. Smith. 2012. Lung cancer and elemental carbon exposure in trucking industry workers. Environmental Health Perspectives 120(9): 1301-1306.

[30] Silverman, D. T., Samanic, C. M., Lubin, J. H., Blair, A. E., Stewart, P. A., Vermeulen, R., & Attfield, M. D. (2012). The diesel exhaust in miners study: a nested case–control study of lung cancer and diesel exhaust. Journal of the National Cancer Institute.

[31] Olsson, Ann C., et al. "Exposure to diesel motor exhaust and lung cancer risk in a pooled analysis from case-control studies in Europe and Canada." American journal of respiratory and critical care medicine 183.7 (2011): 941-948.

[32] IARC [International Agency for Research on Cancer]. (2013). Diesel and gasoline engine exhausts and some nitroarenes. IARC Monographs Volume 105. [Online at http://monographs.iarc.fr/ENG/Monographs/vol105/index.php]

[33] U.S. EPA. (2015) Summary of Results for the 2011 National-Scale Assessment. http://www3.epa.gov/sites/production/files/2015-12/documents/2011-nata-summary-results.pdf.

[34] U.S. EPA (2015) 2011 National Air Toxics Assessment. http://www3.epa.gov/national-air-toxics-assessment/2011-national-air-toxics-assessment.

[35] U.S. EPA. (2000). Integrated Risk Information System File for Benzene. This material is available electronically at: http://www3.epa.gov/iris/subst/0276.htm.

[36] International Agency for Research on Cancer. (1982). IARC monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 29, Some industrial chemicals and dyestuffs, International Agency for Research on Cancer, World Health Organization, Lyon, France 1982.

[37] Irons, R.D.; Stillman, W.S.; Colagiovanni, D.B.; Henry, V.A. (1992). Synergistic action of the benzene metabolite hydroquinone on myelopoietic stimulating activity of granulocyte/macrophage colony-stimulating factor in vitro, Proc. Natl. Acad. Sci. 89:3691-3695.

[38] U.S. EPA. (2000). Integrated Risk Information System File for Benzene. This material is available electronically at: http://www3.epa.gov/iris/subst/0276.htm.

[39] International Agency for Research on Cancer (IARC). 1987. Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 29, Supplement 7, Some industrial chemicals and dyestuffs, World Health Organization, Lyon, France.

[40] NTP. (2014). 13th Report on Carcinogens. Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program.

[41] Aksoy, M. (1989). Hematotoxicity and carcinogenicity of benzene. Environ. Health Perspect. 82: 193-197. EPA-HQ-OAR-2011-0135.

[42] Goldstein, B.D. (1988). Benzene toxicity. Occupational medicine. State of the Art Reviews. 3: 541-554.

[43] Rothman, N., G.L. Li, M. Dosemeci, W.E. Bechtold, G.E. Marti, Y.Z. Wang, M. Linet, L.Q. Xi, W. Lu, M.T. Smith, N. Titenko-Holland, L.P. Zhang, W. Blot, S.N. Yin, and R.B. Hayes. (1996). Hematotoxicity among Chinese workers heavily exposed to benzene. Am. J. Ind. Med. 29: 236-246.

[44] U.S. EPA (2002). Toxicological Review of Benzene (Noncancer Effects). Environmental Protection Agency, Integrated Risk Information System (IRIS), Research and Development, National Center for Environmental Assessment, Washington DC. This material is available electronically at http://www3.epa.gov/iris/subst/0276.htm.

[45] Qu, O.; Shore, R.; Li, G.; Jin, X.; Chen, C.L.; Cohen, B.; Melikian, A.; Eastmond, D.; Rappaport, S.; Li, H.; Rupa, D.; Suramaya, R.; Songnian, W.; Huifant, Y.; Meng, M.; Winnik, M.; Kwok, E.; Li, Y.; Mu, R.; Xu, B.; Zhang, X.; Li, K. (2003). HEI Report 115, Validation & Evaluation of Biomarkers in Workers Exposed to Benzene in China.

[46] Qu, Q., R. Shore, G. Li, X. Jin, L.C. Chen, B. Cohen, et al. (2002). Hematological changes among Chinese workers with a broad range of benzene exposures. Am. J. Industr. Med. 42: 275-285.

[47] Lan, Qing, Zhang, L., Li, G., Vermeulen, R., et al. (2004). Hematotoxically in Workers Exposed to Low Levels of Benzene. Science 306: 1774-1776.

[48] Turtletaub, K.W. and Mani, C. (2003). Benzene metabolism in rodents at doses relevant to human exposure from Urban Air. Research Reports Health Effect Inst. Report No.113.

[49] U.S. Agency for Toxic Substances and Disease Registry (ATSDR). (2007). Toxicological profile for benzene. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. http://www.atsdr.cdc.gov/ToxProfiles/tp3.pdf.

[50] U.S. EPA. (2002). Health Assessment of 1,3-Butadiene. Office of Research and Development, National Center for Environmental Assessment, Washington Office, Washington, DC. Report No. EPA600-P-98-001F. This document is available electronically at http://www3.epa.gov/iris/supdocs/buta-sup.pdf.

[51] U.S. EPA. (2002) “Full IRIS Summary for 1,3-butadiene (CASRN 106-99-0)” Environmental Protection Agency, Integrated Risk Information System (IRIS), Research and Development, National Center for Environmental Assessment, Washington, DC http://www3.epa.gov/iris/subst/0139.htm.

[52] International Agency for Research on Cancer (IARC). (1999). Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 71, Re-evaluation of some organic chemicals, hydrazine and hydrogen peroxide and Volume 97 (in preparation), World Health Organization, Lyon, France.

[53] International Agency for Research on Cancer (IARC). (2008). Monographs on the evaluation of carcinogenic risk of chemicals to humans, 1,3-Butadiene, Ethylene Oxide and Vinyl Halides (Vinyl Fluoride, Vinyl Chloride and Vinyl Bromide) Volume 97, World Health Organization, Lyon, France.

[54] NTP. (2014). 13th Report on Carcinogens. Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program.

[55] U.S. EPA. (2002). “Full IRIS Summary for 1,3-butadiene (CASRN 106-99-0)” Environmental Protection Agency, Integrated Risk Information System (IRIS), Research and Development, National Center for Environmental Assessment, Washington, DC http://www3.epa.gov/iris/subst/0139.htm.

[56] Bevan, C.; Stadler, J.C.; Elliot, G.S.; et al. (1996). Subchronic toxicity of 4-vinylcyclohexene in rats and mice by inhalation. Fundam. Appl. Toxicol. 32:1-10.

[57] EPA. Integrated Risk Information System. Formaldehyde (CASRN 50-00-0) http://www3.epa.gov/iris/subst/0419/htm.

[58] NTP. (2014). 13th Report on Carcinogens. Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program.

[59] IARC Monographs on the Evaluation of Carcinogenic Risks to Humans Volume 88 (2006): Formaldehyde, 2-Butoxyethanol and 1-tert-Butoxypropan-2-ol.

[60] IARC Monographs on the Evaluation of Carcinogenic Risks to Humans Volume 100F (2012): Formaldehyde.

[61] Hauptmann, M.; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Blair, A. 2003. Mortality from lymphohematopoetic malignancies among workers in formaldehyde industries. Journal of the National Cancer Institute 95: 1615-1623.

[62] Hauptmann, M.; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Blair, A. 2004. Mortality from solid cancers among workers in formaldehyde industries. American Journal of Epidemiology 159: 1117-1130.

[63] Beane Freeman, L. E.; Blair, A.; Lubin, J. H.; Stewart, P. A.; Hayes, R. B.; Hoover, R. N.; Hauptmann, M. 2009. Mortality from lymphohematopoietic malignancies among workers in formaldehyde industries: The National Cancer Institute cohort. J. National Cancer Inst. 101: 751-761.

[64] Pinkerton, L. E. 2004. Mortality among a cohort of garment workers exposed to formaldehyde: an update. Occup. Environ. Med. 61: 193-200.

[65] Coggon, D, EC Harris, J Poole, KT Palmer. 2003. Extended follow-up of a cohort of British chemical workers exposed to formaldehyde. J National Cancer Inst. 95:1608-1615.

[66] Hauptmann, M,; Stewart P. A.; Lubin J. H.; Beane Freeman, L. E.; Hornung, R. W.; Herrick, R. F.; Hoover, R. N.; Fraumeni, J. F.; Hayes, R. B. 2009. Mortality from lymphohematopoietic malignancies and brain cancer among embalmers exposed to formaldehyde. Journal of the National Cancer Institute 101:1696-1708.

[67] ATSDR. 1999. Toxicological Profile for Formaldehyde, U.S. Department of Health and Human Services (HHS), July 1999.

[68] ATSDR. 2010. Addendum to the Toxicological Profile for Formaldehyde. U.S. Department of Health and Human Services (HHS), October 2010.

[69] IPCS. 2002. Concise International Chemical Assessment Document 40. Formaldehyde. World Health Organization.

[70] EPA (U.S. Environmental Protection Agency). 2010. Toxicological Review of Formaldehyde (CAS No. 50-00-0) – Inhalation Assessment: In Support of Summary Information on the Integrated Risk Information System (IRIS). External Review Draft. EPA/635/R-10/002A. U.S. Environmental Protection Agency, Washington DC [online]. Available: http://cfpub.epa.gov/ncea/irs_drats/recordisplay.cfm?deid=223614.

[71] NRC (National Research Council). 2011. Review of the Environmental Protection Agency’s Draft IRIS Assessment of Formaldehyde. Washington DC: National Academies Press. http://books.nap.edu/openbook.php?record_id=13142.

[72] U.S. EPA (1991). Integrated Risk Information System File of Acetaldehyde. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www3.epa.gov/iris/subst/0290.htm.

[73] U.S. EPA (1991). Integrated Risk Information System File of Acetaldehyde. This material is available electronically at http://www3.epa.gov/iris/subst/0290.htm.

[74] NTP. (2014). 13th Report on Carcinogens. Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program.
[75] International Agency for Research on Cancer (IARC). (1999). Re-evaluation of some organic chemicals, hydrazine, and hydrogen peroxide. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemical to Humans, Vol 71. Lyon, France.
[76] U.S. EPA (1991). Integrated Risk Information System File of Acetaldehyde. This material is available electronically at http://www3.epa.gov/iris/subst/0290.htm.
[77] U.S. EPA. (2003). Integrated Risk Information System File of Acrolein. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www3.epa.gov/iris/subst/0364.htm.
[78] Appleman, L.M., R.A. Woutersen, and V.J. Feron. (1982). Inhalation toxicity of acetaldehyde in rats. I. Acute and subacute studies. Toxicology. 23: 293-297.
[79] Myou, S.; Fujimura, M.; Nishi K.; Ohka, T.; and Matsuda, T. (1993). Aerosolized acetaldehyde induces histamine-mediated bronchoconstriction in asthmatics. Am. Rev. Respir.Dis.148(4 Pt 1): 940-943.
[80] U.S. EPA. (2003). Integrated Risk Information System File of Acrolein. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available at http://www3.epa.gov/iris/subst/0364.htm.
[81] International Agency for Research on Cancer (IARC). (1995). Monographs on the evaluation of carcinogenic risk of chemicals to humans, Volume 63. Dry cleaning, some chlorinated solvents and other industrial chemicals, World Health Organization, Lyon, France.
[82] U.S. EPA. (2003). Integrated Risk Information System File of Acrolein. Office of Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available at http://www3.epa.gov/iris/subst/0364.htm.
[83] U.S. EPA. (2003). Integrated Risk Information System File of Acrolein. Office of Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available at http://www3.epa.gov/iris/subst/0364.htm.
[84] U.S. EPA. (2003). Toxicological review of acrolein in support of summary information on Integrated Risk Information System (IRIS) National Center for Environmental Assessment, Washington, DC. EPA/635/R-03/003. p. 10. Available online at: http://www3.epa.gov/ncea/iris/toxreviews/0364tr.pdf.
[85] U.S. EPA. (2003). Toxicological review of acrolein in support of summary information on Integrated Risk Information System (IRIS) National Center for Environmental Assessment, Washington, DC. EPA/635/R-03/003. Available online at: http://www3.epa.gov/ncea/iris/toxreviews/0364tr.pdf.
[86] Morris JB, Symanowicz PT, Olsen JE, et al. (2003). Immediate sensory nerve-mediated respiratory responses to irritants in healthy and allergic airway-diseased mice. J Appl Physiol 94(4):1563-1571.
[87] U.S. EPA. (2009). Graphical Arrays of Chemical-Specific Health Effect Reference Values for Inhalation Exposures (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/061, 2009. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=211003.
[88] Agency for Toxic Substances and Disease Registry (ATSDR). (1995). Toxicological profile for Polycyclic Aromatic Hydrocarbons (PAHs). Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. Available electronically at http://www.atsdr.cdc.gov/ToxProfiles/TP.asp?id=122&tid=25.
[89] U.S. EPA (2002). *Health Assessment Document for Diesel Engine Exhaust*. EPA/600/8-90/057F Office of Research and Development, Washington DC. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=29060.
[90] International Agency for Research on Cancer (IARC). (2012). Monographs on the Evaluation of the Carcinogenic Risk of Chemicals for Humans, Chemical Agents and Related Occupations. Vol. 100F. Lyon, France.
[91] U.S. EPA (1997). Integrated Risk Information System File of indeno (1,2,3-cd)pyrene. Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www3.epa.gov/ncea/iris/subst/0457.htm.
[92] Perera, F.P.; Rauh, V.; Tsai, W-Y.; et al. (2002). Effect of transplacental exposure to environmental pollutants on birth outcomes in a multiethnic population. Environ Health Perspect. 111: 201-205.
[93] Perera, F.P.; Rauh, V.; Whyatt, R.M.; Tsai, W.Y.; Tang, D.; Diaz, D.; Hoepner, L.; Barr, D.; Tu, Y.H.; Camann, D.; Kinney, P. (2006). Effect of prenatal exposure to airborne polycyclic aromatic hydrocarbons on neurodevelopment in the first 3 years of life among inner-city children. Environ Health Perspect 114: 1287-1292.
[94] U. S. EPA. 1998. Toxicological Review of Naphthalene (Reassessment of the Inhalation Cancer Risk), Environmental Protection Agency, Integrated Risk Information System, Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www3.epa.gov/iris/subst/0436.htm.

[95] U. S. EPA. 1998. Toxicological Review of Naphthalene (Reassessment of the Inhalation Cancer Risk), Environmental Protection Agency, Integrated Risk Information System, Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www3.epa.gov/iris/subst/0436.htm.
[96] U. S. EPA. (1998). Toxicological Review of Naphthalene (Reassessment of the Inhalation Cancer Risk), Environmental Protection Agency, Integrated Risk Information System, Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www3.epa.gov/iris/subst/0436.htm.
[97] Oak Ridge Institute for Science and Education. (2004). External Peer Review for the IRIS Reassessment of the Inhalation Carcinogenicity of Naphthalene. August 2004. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=84403.
[98] NTP. (2014). 13th Report on Carcinogens. Research Triangle Park, NC: U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program.
[99] International Agency for Research on Cancer (IARC). (2002). Monographs on the Evaluation of the Carcinogenic Risk of Chemicals for Humans. Vol. 82. Lyon, France.
[100] U. S. EPA. (1998). Toxicological Review of Naphthalene, Environmental Protection Agency, Integrated Risk Information System, Research and Development, National Center for Environmental Assessment, Washington, DC. This material is available electronically at http://www3.epa.gov/iris/subst/0436.htm.
[101] U.S. EPA. (1998). Toxicological Review of Naphthalene. Environmental Protection Agency, Integrated Risk Information System (IRIS), Research and Development, National Center for Environmental Assessment, Washington, DC http://www3.epa.gov/iris/subst/0436.htm.
[102] U.S. EPA Integrated Risk Information System (IRIS) database is available at: www3.epa.gov/iris.
[103] Health Effects Institute Panel on the Health Effects of Traffic-Related Air Pollution. (2010). Traffic-related air pollution: a critical review of the literature on emissions, exposure, and health effects. HEI Special Report 17. [Online at http://www.healtheffects.org].
[104] Bureau of Labor Statistics. (2009). American Time Use Survey. [Online at http://www.bls.gov/tus].
[105] Bureau of Transportation Statistics. (2003). Highlights of the 2001 National Household Travel Survey. Report BTS03-05. [Online at http://www.bts.gov].
[106] Baja, E.S.; Schwartz, J.D.; Wellenius, G.A.; Coull, B.A.; Zanobetti, A.; Vokonas, P.S.; Suh, H.H. (2010). Traffic-related air pollution and QT interval: modification by diabetes, obesity, and oxidate stress gene polymorphisms in the Normative Aging Study. Environ Health Perspect 118: 840-846. doi:10.1289/ehp.0901396.
[107] Zanobettia, A.; Stone, P.H.; Speizer, F.E.; Schwarz, J.D.; Coull, B.A.; Suh, H.H.; Nearing, B.D.; Mittleman, M.A.; Verrier, R.L.; Gold, D.R. (2009). T-wave alternans, air pollution and traffic in high-risk subjects. Am J Cardiol 104: 665-670. doi:10.1016/j.amjcard.2009.04.046.
[108] Brook, R.D.; Rajagopalan, S.; Pope, C.A.; Brook, J.R.; Bhatnagar, A.; Diez-Rouz, A.V.; Holguin, F.; Hong, Y.; Luepker, R.V.; et la. (2010). Particulate matter air pollution and cardiovascular disease: An Update To The Scientific Statement From The American Heart Association. Circulation 121: 2331-2378. doi:10.1161/CIR.0b013e3181dbece1.
[109] Bastain, T.M.; Gilliland, F.D.; Li, Y.; Saxon, A.; Diaz-Sanchez, D. (2003) Intraindividual reproducibility of nazal allergic responses to diesel exhaust particles indicates a susceptible phenotype. Clinical Immunol 109: 130-136.
[110] Gilliland, F.D.; Li, Y.; Diaz-Sanchez, D. (2004) Effect of glutathione-S-transferase M1 and P1 genotypes on xenobiotic enhancement of allergic responses: randomized, placebo-controlled crossover study. Lancet 363:119-125.
[111] Svartengren, M., Strand, V.; Bylin, G. Järup, L.; Pershagen, G. (2000) Short-term exposure to air pollution in a road tunnel enhances the asthmatic response to allergen. Eur Respir J 15: 716-724.
[112] Vrijheid, M.; Martinez, D.; Manzanares, S.; Dadvand, P.; Schembari, A.; Rankin, F.; Nieuwenhuijsen, M. (2011). Ambient air pollution and risk of congenital anomalies: a systematic review and meta-analysis. Environ Health Perspect 119: 598-606. doi:10.1289/ehp.1002946.
[113] Boothe, VL.; Boehmer, T.K.; Wendel, A.M.; Yip, F.Y. (2014) Residential traffic exposure and childhood leukemia: a systematic review and meta-analysis. Am J Prev Med 46: 413-422.
[114] Sun, X.; Zhang, S.; Ma, X. (2014) No association between traffic density and risk of childhood leukemia: a meta-analysis. Asia Pac J Cancer Prev 15: 5229-5232.
[115] Raaschou-Nielsen, O.; Reynolds, P. (2006) Air pollution and childhood cancer: a review of the epidemiological literature. Int J Cancer 118: 2920-2929. Docket EPA-HQ-OAR-2010-0162.
[116] National Research Council, (1993). Protecting Visibility in National Parks and Wilderness Areas. National Academy of Sciences Committee on Haze in National Parks and Wilderness Areas. National Academy Press,

Washington, DC. This book can be viewed on the National Academy Press Website at http://www.nap.edu/books/0309048443/html/.
[117] Sisler, J.F. 1996. Spatial and seasonal patterns and long-term variability of the composition of the haze in the United States: an analysis of data from the IMPROVE network. CIRA Report, ISSN 0737-5352-32, Colorado State University.
[118] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009.
[119] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009.
[120] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009. *pg 9-19 through 9-23.*
[121] 73 FR 16486 (March 27, 2008).
[122] Chapter 9, Section 9.3.4 of U.S. EPA, 2013 Integrated Science Assessment for Ozone and Related Photochemical Oxidants. Office of Research and Development/National Center for Environmental Assessment. U.S. Environmental Protection Agency. EPA 600/R-10/076F.
[123] 73 FR 16492 (March 27, 2008).
[124] 73 FR 16493-16494 (March 27, 2008).
[125] 73 FR 16490/ 16497 (March 27, 2008).
[126] U.S. EPA. Integrated Science Assessment of Ozone and Related Photochemical Oxidants (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-10/076F, 2013. The ISA is available at http://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=247492#Download.
[127] U.S. EPA (2009). Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009.
[128] U.S. EPA. (2008). Integrated Science Assessment for Oxides of Nitrogen and Sulfur- Ecological Criteria (Final). U.S. EPA, Washington D.C., EPA/600/R-08/082F.
[129] U.S. EPA. (2008). Integrated Science Assessment for Oxides of Nitrogen and Sulfur- Ecological Criteria (Final). U.S. EPA, Washington D.C., EPA/600/R-08/082F.
[130] U.S. Environmental Protection Agency (U.S. EPA). 2008. Integrated Science Assessment for Oxides of Nitrogen and Sulfur—Ecological Criteria National (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485>.
[131] U.S. Environmental Protection Agency (U.S. EPA). 2008. Integrated Science Assessment for Oxides of Nitrogen and Sulfur—Ecological Criteria National (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485>.
[132] U.S. Environmental Protection Agency (U.S. EPA). 2008. Integrated Science Assessment for Oxides of Nitrogen and Sulfur—Ecological Criteria National (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485>.
[133] U.S. Environmental Protection Agency (U.S. EPA). 2008. Integrated Science Assessment for Oxides of Nitrogen and Sulfur—Ecological Criteria National (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485>.
[134] U.S. Environmental Protection Agency (U.S. EPA). 2008. Integrated Science Assessment for Oxides of Nitrogen and Sulfur—Ecological Criteria National (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485>.
[135] Hutchison, R., and C.E. Kraft. 1994. "Hmong Fishing Activity and Fish Consumption." Journal of Great Lakes Research 20(2):471–487.
[136] Peterson, D.E., M.S. Kanarek, M.A. Kuykendall, J.M. Diedrich, H.A. Anderson, P.L. Remington, and T.B. Sheffy. 1994. "Fish Consumption Patterns and Blood Mercury Levels in Wisconsin Chippewa Indians." Archives of Environmental Health 49(1):53–58.
[137] U.S. Environmental Protection Agency (U.S. EPA). 2008. Integrated Science Assessment for Oxides of Nitrogen and Sulfur—Ecological Criteria National (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485>.

[138] Joslin, J.D., Kelly, J.M., and van Miegroet, H. 1992. “Soil chemistry and nutrition of North American spruce-fir stands: evidence for recent change. “ Journal of Environmental Quality, 21, 12-30.
[139] U.S. Environmental Protection Agency (U.S. EPA). 2008. Integrated Science Assessment for Oxides of Nitrogen and Sulfur—Ecological Criteria National (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485>.
[140] DeHayes, D.H., P.G. Schaberg, G.J. Hawley, and G.R. Strimbeck. 1999. “Acid rain impacts on calcium nutrition and forest health.” Bioscience 49(10):789–800.
[141] Bricker, S., B. Longstaff, W. Dennison, A. Jones, K. Boicourt, C. Wicks, and J. Woerner. 2007. Effects of Nutrient Enrichment In the Nation’s Estuaries: A Decade of Change. NOAA Coastal Ocean Program Decision Analysis Series No. 26. National Centers for Coastal Ocean Science, Silver Spring, MD. 328 pp.
[142] Valigura, R.A., R.B. Alexander, M.S. Castro, T.P. Meyers, H.W. Paerl, P.E. Stacy, and R.E. Turner. 2001. Nitrogen Loading in Coastal Water Bodies: An Atmospheric Perspective. Washington, DC: American Geophysical Union.
[143] U.S. Environmental Protection Agency (U.S. EPA). 2008. Integrated Science Assessment for Oxides of Nitrogen and Sulfur—Ecological Criteria National (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485>.
[144] U.S. Environmental Protection Agency (U.S. EPA). 2008. Integrated Science Assessment for Oxides of Nitrogen and Sulfur—Ecological Criteria National (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485>.
[145] U.S. Environmental Protection Agency (U.S. EPA). 2008. Integrated Science Assessment for Oxides of Nitrogen and Sulfur—Ecological Criteria National (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485>.
[146] Hutchinson J; Maynard D; Geiser L. (1996). Air quality and lichens - a literature review emphasizing the Pacific Northwest, USA. Pacific Northwest Region Air Resource Management Program; U.S. Forest Service; U.S. Department of Agriculture (USDA).
[147] U.S. Environmental Protection Agency (U.S. EPA). 2008. Integrated Science Assessment for Oxides of Nitrogen and Sulfur—Ecological Criteria National (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485>.
[148] U.S. Environmental Protection Agency (U.S. EPA). 2008. Integrated Science Assessment for Oxides of Nitrogen and Sulfur—Ecological Criteria National (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485>.
[149] U.S. Environmental Protection Agency (U.S. EPA). 2009. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment—RTP Division. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.
[150] Grantz DA; Garner JHB; Johnson DW. 2003. “Ecological effects of particulate matter.” Environ Int, 29: 213-239.
[151] U.S. Environmental Protection Agency (U.S. EPA). 2009. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment—RTP Division. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.
[152] U.S. Environmental Protection Agency (U.S. EPA). 2009. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment—RTP Division. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.
[153] U.S. Environmental Protection Agency (U.S. EPA). 2009. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment—RTP Division. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.
[154] U.S. Environmental Protection Agency (U.S. EPA). 2009. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment—RTP Division. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.

[155] Chameides. W.L., Yu, H., Liu, S.C., Bergin, M., Zhou, X., Mearns, L., Wang, G., Kiang, C.S., Saylor, R.D., Luo, C. Huang, Y., Steiner, A., and Giorgi, F. 1999. "Case study of the effects of atmospheric aerosols and regional haze on agriculture: an opportunity to enhance crop yields in China through emission controls?" PNAS, 96: 13626-13633.

[156] U.S. Environmental Protection Agency (U.S. EPA). 2009. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment—RTP Division. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.

[157] U.S. Environmental Protection Agency (U.S. EPA). 2009. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment—RTP Division. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.

[158] Parrish ZD; White JC; Isleyen M; Gent MPN; Iannucci-Berger W; Eitzer BD; Kelsey JW; Mattina MI. 2006. "Accumulation of weathered polycyclic aromatic hydrocarbons (PAHs) by plant and earthworm species." Chemosphere, 64: 609-618.

[159] Simcik M.F., Eisenreich S.J., Lioy P.J. 1999. "Source apportionment and source/sink relationship of PAHs in the coastal atmosphere of Chicago and Lake Michigan." Atmospheric Environment, 33, 5071-5079.

[160] Simcik M.F., Eisenreich, S.J., Golden K.A., et al. 1996. "Atmospheric Loading of Polycyclic Aromatic Hydrocarbons to Lake Michigan as Recorded in the Sediments." Environmental Science and Technology, 30, 3039-3046.

[161] Arzavus K.M., Dickhut R.M., and Canuel E.A. 2001. "Fate of Atmospherically Deposited Polycyclic Aromatic Hydrocarbons (PAHs) in Chesapeake Bay." Environmental Science & Technology, 35, 2178-2183.

[162] Cotrufo, M.F., De Santo A.V., Alfani A., Bartoli G., De Cristofaro A. 1995. "Effects of urban heavy metal pollution on organic matter decomposition in Quercus ilex L. Woods." Environmental Pollution, 89(1), 81-87.

[163] Niklinska M., Laskowski R., Maryanski M. (1998). "Effect of heavy metals and storage time on two types of forest litter: basal respiration rate and exchangeable metals" Ecotoxicological Environmental Safety, 41, 8-18.

[164] U.S. Environmental Protection Agency (U.S. EPA). 2009. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment—RTP Division. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.

[165] U.S. Environmental Protection Agency (U.S. EPA). 2009. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment—RTP Division. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.

[166] U.S. Environmental Protection Agency (U.S. EPA). 2009. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment—RTP Division. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.

[167] U.S. Environmental Protection Agency (U.S. EPA). 2009. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment—RTP Division. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.

[168] Hageman KJ; Simonich SL; Campbell DH; Wilson GR; Landers DH. 2006. "Atmospheric deposition of current-use and historic-use pesticides in snow at national parks in the western United States." Environ Sci Technol, 40: 3174-3180.

[169] Landers DH; Simonich SL; Jaffe DA; Geiser LH; Campbell DH; Schwindt AR; Schreck CB; Kent ML; Hafner WD; Taylor HE; Hageman KJ; Usenko S; Ackerman LK; Schrlau JE; Rose NL; Blett TF; Erway MM. (2008). The Fate, Transport and Ecological Impacts of Airborne Contaminants in Western National Parks (USA). EPA/600/R-07/138. U.S. Environmental Protection Agency, Office of Research and Development, NHEERL, Western Ecology Division. Corvallis, Oregon.

[170] U.S. Environmental Protection Agency (U.S. EPA). 2009. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment—RTP Division. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.

[171] Irving, P.M., e.d. 1991. Acid Deposition: State of Science and Technology, Volume III, Terrestrial, Materials, Health, and Visibility Effects, The U.S. National Acid Precipitation Assessment Program, Chapter 24, page 24–76.

[172] U.S. EPA. (1991). Effects of organic chemicals in the atmosphere on terrestrial plants. EPA/600/3-91/001.

[173] Cape JN, ID Leith, J Binnie, J Content, M Donkin, M Skewes, DN Price AR Brown, AD Sharpe. (2003). Effects of VOCs on herbaceous plants in an open-top chamber experiment. Environ. Pollut. 124:341-343.

[174] Cape JN, ID Leith, J Binnie, J Content, M Donkin, M Skewes, DN Price AR Brown, AD Sharpe. (2003). Effects of VOCs on herbaceous plants in an open-top chamber experiment. Environ. Pollut. 124:341-343.

[175] Viskari E-L. (2000). Epicuticular wax of Norway spruce needles as indicator of traffic pollutant deposition. Water, Air, and Soil Pollut. 121:327-337.

[176] Ugrekhelidze D, F Korte, G Kvesitadze. (1997). Uptake and transformation of benzene and toluene by plant leaves. Ecotox. Environ. Safety 37:24-29.
[177] Kammerbauer H, H Selinger, R Rommelt, A Ziegler-Jons, D Knoppik, B Hock. (1987). Toxic components of motor vehicle emissions for the spruce Picea abies. Environ. Pollut. 48:235-243.
[178] U.S. EPA, 2011. Our Nation's Air: Status and Trends through 2010. EPA-454/R-12-001. February 2012. Available at: http://www3.epa.gov/airtrends/2011/.
[179] U.S. EPA. (2015) Summary of Results for the 2011 National-Scale Assessment. https://www3.epa.gov/sites/production/files/2015-12/documents/2011-nata-summary-results.pdf.
[180] Health Effects Institute Panel on the Health Effects of Traffic-Related Air Pollution. (2010) Traffic-related air pollution: a critical review of the literature on emissions, exposure, and health effects. HEI Special Report 17. Available at http://www.healtheffects.org].
[181] 70 FR 19844 (April 14, 2005).
[182] EPA 2014. Fact Sheet: Final Area Designations for the Annual Fine Particle Standard. https://www3.epa.gov/pmdesignations/2012standards/final/20141218fs.pdf.
[183] 74 FR 58688 (November 13, 2009) and 76 FR 6056 (February 3, 2011).
[184] 77FR 30088 (May 21, 2012) and 77 FR 34221 (June 11, 2012).
[185] https://www3.epa.gov/ozone-pollution/2015-ozone-naaqs-timelines.
[186] U.S. EPA. (2012). Fact Sheet – Air Quality Designations for the 2010 Primary Nitrogen Dioxide (NO_2) National Ambient Air Quality Standards. http://www3.epa.gov/airquality/nitrogenoxides/designations/pdfs/20120120FS.pdf.
[187] U.S. Environmental Protection Agency (2013). Revision to Ambient Nitrogen Dioxide Monitoring Requirements. March 7, 2013. http://www3.epa.gov/airquality/nitrogenoxides/pdfs/20130307fr.pdf.
[188] U.S. EPA (2015) 2011 National-Scale Air Toxics Assessment. https://www3.epa.gov/national-air-toxics-assessment/2011-nata-assessment-results#emissions.
[189] U.S. EPA (2015) 2011 National-Scale Air Toxics Assessment. https://www3.epa.gov/national-air-toxics-assessment/2011-nata-assessment-results#emissions.
[190] U.S. Environmental Protection Agency (2007). Control of Hazardous Air Pollutants from Mobile Sources; Final Rule. 72 FR 8434, February 26, 2007.
[191] U.S. EPA. (2015) 2011 NATA: Assessment Results https://www3.epa.gov/national-air-toxics-assessment/2011-nata-assessment-results.
[192] U.S. EPA. (2015) 2011 NATA: Assessment Results. https://www3.epa.gov/national-air-toxics-assessment/2011-nata-assessment-results.
[193] U.S. Environmental Protection Agency (EPA). 2009. Integrated Science Assessment for Particulate Matter. U.S. Environmental Protection Agency. Research Triangle Park. EPA/600/R-08/139F.
[194] EPA's Report on the Environment: Regional Haze. https://cfpub.epa.gov/roe/indicator.cfm?i=21
[195] Trijonis, J.C. et al. 1987. Preliminary extinction budget results from the RESOLVE program, pp. 872-883. In: P.J. Bhardwaja, et.. al.. Visibility Protection Research and Policy Aspects. Air Pollution Control Assoc., Pittsburgh, PA.
[196] Trijonis, J.C. et al. 1988. RESOLVE Project Final Report: Visibility conditions and Causes of Visibility Degradation in the Mojave Desert of California. NWC TP #6869. Naval Weapons Center, China Lake, CA.
[197] Irving, Patricia M., e.d., 1991. Acid Deposition: State of Science and Technology, Volume III, Terrestrial, Materials, Health, and Visibility Effects, The U.S. National Acid Precipitation Assessment Program, Chapter 24, page 24–76.
[198] EPA Report on the Environment. Accessed in 2016, https://cfpub.epa.gov/roe/indicator.cfm?i=1. Based on data from the NADP/National Trends Network (accessed 2014, http://nadp.sws.uiuc.edu) and the Clean Air Status and Trends Network (accessed 2014, https://www3.epa.gov/castnet.).
[199] "EPA's Denial of the Petitions to Reconsider the Endangerment and Cause or Contribute Findings for Greenhouse Gases under Section 202(a) of the Clean Air Act," 75 Fed. Reg. 49,556 (Aug. 13, 2010) ("Reconsideration Denial").
[200] Intergovernmental Panel on Climate Change (IPCC). 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA.
[201] Intergovernmental Panel on Climate Change (IPCC). 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Intergovernmental Panel on Climate Change (IPCC). 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability.

Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Intergovernmental Panel on Climate Change (IPCC). 2014. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[202] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds. 2014. Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program. Available at http://nca2014.globalchange.gov.

[203] National Research Council (NRC). 2010. Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean. National Academies Press. Washington, DC.

[204] National Research Council (NRC). 2011. Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia. National Academies Press, Washington, DC.

[205] National Research Council (NRC) 2011. National Security Implications of Climate Change for U.S. Naval Forces. National Academies Press. Washington, DC.

[206] National Research Council (NRC). 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. National Academies Press. Washington, DC.

[207] National Research Council (NRC). 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. National Academies Press. Washington, DC.

[208] National Research Council (NRC). 2013. Climate and Social Stress: Implications for Security Analysis. National Academies Press. Washington, DC.

[209] National Research Council (NRC). 2013. Abrupt Impacts of Climate Change: Anticipating Surprises. National Academies Press. Washington, DC.

[210] Brenkert A, S. Smith, S. Kim, and H. Pitcher, 2003: Model Documentation for the MiniCAM. PNNL-14337, Pacific Northwest National Laboratory, Richland, Washington.

[211] Wigley, T.M.L. and Raper, S.C.B. 1992. Implications for Climate And Sea-Level of Revised IPCC Emissions Scenarios Nature 357, 293-300. Raper, S.C.B., Wigley T.M.L. and Warrick R.A. 1996. in Sea-Level Rise and Coastal Subsidence: Causes, Consequences and Strategies J.D. Milliman, B.U. Haq, Eds., Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 11-45.

[212] Wigley, T.M.L. and Raper, S.C.B. 2002. Reasons for larger warming projections in the IPCC Third Assessment Report J. Climate 15, 2945-2952.

[213] Thompson AM, KV Calvin, SJ Smith, GP Kyle, A Volke, P Patel, S Delgado-Arias, B Bond-Lamberty, MA Wise, LE Clarke and JA Edmonds. 2010. "RCP4.5: A Pathway for Stabilization of Radiative Forcing by 2100." Climatic Change (in review).

[214] Clarke, L., J. Edmonds, H. Jacoby, H. Pitcher, J. Reilly, R. Richels, (2007) Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. Sub-report 2.1A of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research (Department of Energy, Office of Biological & Environmental Research, Washington, DC., USA, 154 pp.).

[215] Wigley, T.M.L. 2008. MAGICC 5.3.v2 User Manual. *UCAR* – Climate and Global Dynamics Division, Boulder, Colorado. http://www.cgd.ucar.edu/cas/wigley/magicc/.

[216] Meehl, G.A. et al. (2007) Global Climate Projections. In: *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[217] National Research Council, 2011. Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millenia. Washington, DC: National Academies Press.

[218] Lewis, E., and D. W. R. Wallace. 1998. Program Developed for CO_2 System Calculations. ORNL/CDIAC-105. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee.

[219] Pierrot, D. E. Lewis, and D. W. R. Wallace. 2006. MS Excel Program Developed for CO_2 System Calculations. ORNL/CDIAC-105a. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee. doi: 10.3334/CDIAC/otg.CO2SYS_XLS_CDIAC105a

[220] Mehrbach, C., C. H. Culberson, J. E. Hawley, and R. N. Pytkowicz. 1973. Measurement of the apparent dissociation constants of carbonic acid in seawater at atmospheric pressure. Limnology and Oceanography **18**:897-907.

[221] Dickson, A. G. and F. J. Millero. 1987. A comparison of the equilibrium constants for the dissociation of carbonic acid in seawater media. *Deep-Sea Res.* **34**, 1733-1743. (Corrigenda. *Deep-Sea Res.* **36**, 983).

[222] A. G. Dickson. 1990. Thermodynamics of the dissociation of boric acid in synthetic sea water from 273.15 to 318.15 K. *Deep-Sea Res.* **37**, 755-766.
[223] A. G. Dickson. 1990. Thermodynamics of the dissociation of boric acid in synthetic sea water from 273.15 to 318.15 K. *Deep-Sea Res.* **37**, 755-766.
[224] Dickson, A. G. 2003. Certificate of Analysis – Reference material for oceanic CO_2 measurements (Batch #62, bottled on August 21, 2003). Certified by Andrew Dickson, Scripps Institution of Oceanography. November 21, 2003.
Dickson, A. G. 2005. Certificate of Analysis – Reference material for oceanic CO_2 measurements (Batch #69, bottled on January 4, 2005). Certified by Andrew Dickson, Scripps Institution of Oceanography. July 12, 2005.
Dickson, A. G. 2009. Certificate of Analysis – Reference material for oceanic CO_2 measurements (Batch #100, bottled on November 13, 2009). Certified by Andrew Dickson, Scripps Institution of Oceanography. February 10, 2010.
[225] Byun, D.W., Ching, J. K.S. 1999. *Science algorithms of the EPA models-3 community multiscale air quality (CMAQ) modeling system*. Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development.
[226] Byun, D.W., Schere, K.L. (2006). Review of the Governing Equations, Computational Algorithms, and Other Components of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System. *Journal of Applied Mechanics Reviews, 59(2),* 51-77.
[227] Dennis, R.L., Byun, D.W., Novak, J.H., Galluppi, K.J., Coats, C.J., and Vouk, M.A. (1996). The next generation of integrated air quality modeling: EPA's Models-3, *Atmospheric Environment, 30,* 1925-1938.
[228] Brown, N., Allen, D., Amar, P., Kallos, G., McNider, R., Russell,, A., Stockwell, W. (September 2011). Final Report: Fourth Peer Review of the CMAQ Model, NERL/ORD/EPA. U.S. EPA, Research Triangle Park, NC., http://www3.epa.gov/asmdnerl/Reviews/2011_CMAQ_Review_FinalReport.pdf.
[229] Hogrefe, C., Biswas, J., Lynn, B., Civerolo, K., Ku, J.Y., Rosenthal, J., et al. (2004). Simulating regional-scale ozone climatology over the eastern United States: model evaluation results. *Atmospheric Environment, 38(17),* 2627-2638.
[230] Lin, M., Oki, T., Holloway, T., Streets, D.G., Bengtsson, M., Kanae, S. (2008). Long-range transport of acidifying substances in East Asia-Part I: Model evaluation and sensitivity studies. *Atmospheric Environment, 42(24),* 5939-5955.
[231] U.S. EPA, 2008. *Technical support document for the final locomotive/marine rule: Air quality modeling analyses.* Research Triangle Park, N.C.: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Air Quality Assessment Division.
[232] Community Modeling and Analysis System (CMAS) website: http://www.cmascenter.org., RELEASE_NOTES for CMAQv5.0 - February 2012.
[233] Community Modeling and Analysis System (CMAS) website: http://www.cmascenter.org., RELEASE_NOTES for CMAQv5.0.1 - July 2012.
[234] Community Modeling and Analysis System (CMAS) website: http://www.cmascenter.org. CMAQ version 5.0.2 (April 2014 release) Technical Documentation. - May 2014.
[235] Skamarock, W.C., Klemp, J.B., Dudhia, J., Gill, D.O., Barker, D.M., Duda, M.G., Huang, X., Wang, W., Powers, J.G., 2008. A Description of the Advanced Research WRF Version 3.
[236] Byun, D.W., Ching, J. K.S. (1999). *Science algorithms of EPA Models-3 Community Multiscale Air Quality (CMAQ) modeling system*, EPA/600/R-99/030, Office of Research and Development). Please also see: http://www.cmascenter.org/.
[237] Skamarock, W., Klemp, J., Dudhia, J., Gill, D., Barker, D., Dudha, M., Huang, X-Y., Wang, W., Powers, J., June 2008. A Description of the Advanced Research WRF Version 3, NCAR Technical Note, NCAR/TN-475+STR, Mesoscale and Microscale Meteorology Division, NCAR, Boulder, Colorado.
[238] Yantosca, R.M., Long, M.S., Payer, M., and Cooper, M. 2012: GEOS-Chem v9-01-03 Online User's Guide, available at: http://acmg.seas.harvard.edu/geos/doc/man/.
[239] Henderson, B.H., Akhtar, F., Pye, O.T., Napelenok, S.L., Hutzell, W.T. 2014. A database and tool for boundary conditions for regional air quality modeling: description and evaluation. Geosci. Model Dev., 7, 339-360.
[240] Karl, T. R. and Koss, W. J., 1984: "Regional and National Monthly, Seasonal, and Annual Temperature Weighted by Area, 1895-1983." Historical Climatology Series 4-3, National Climatic Data Center, Asheville, NC, 38 pp.
[241] U.S. EPA, 2004, Procedures for Estimating Future $PM_{2.5}$ Values for the CAIR Final Rule by Application of the (Revised) Speciated Modeled Attainment Test (SMAT)- Updated 11/8/04.
[242] U.S. EPA, 2011, Final Cross State Air Pollution Rule Air Quality Modeling TSD.

[243] U.S. EPA, 2007. Guidance on the Use of Models and Other Analyses For Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze; EPA-454/B-07-002; Research Triangle Park, NC; April 2007.
[244] Yarwood G, Rao S, Yocke M, Whitten GZ (2005) Updates to the Carbon Bond Chemical Mechanism: CB05. Final Report to the U.S. EPA, RT-0400675, December 8, 2005, http://www.camx.com/publ/pdfs/CB05_Final_Report_120805.pdf.
[245] U.S. EPA. 2014. Memorandum to Docket: Updates to MOVES for the Tier 3 FRM Analysis.
[246] Dodge, M.C., 2000. Chemical oxidant mechanisms for air quality modeling: critical review. Atmospheric Environment 34, 2103-2130.
[247] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html.
[248] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html.
[249] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html.
[250] Sander, S.P., Friedl, R.R., Golden, D.M., Kurylo, M.J., Huie, R.E., Orkin, V.L., Moortgat, G.K., Ravishankara, A.R., Kolb, C.E., Molina, M.J., Finlayson-Pitts, B.J. (2003) Chemical Kinetics and Photochemical Data for use in Atmospheric Studies, Evaluation Number 14. NASA Jet Propulsion Laboratory http://jpldataeval.jpl.nasa.gov/index.html.
[251] J.G. Calvert, A. Mellouki, J.J. Orlando, M.J. Pilling, and T.J. Wallington, 2011. The mechanisms of atmospheric oxidation of the oxygenates. Oxford University Press, New York/Oxford.
[252] Sander, S.P., Friedl, R.R., Golden, D.M., Kurylo, M.J., Huie, R.E., Orkin, V.L., Moortgat, G.K., Ravishankara, A.R., Kolb, C.E., Molina, M.J., Finlayson-Pitts, B.J. (2003) Chemical Kinetics and Photochemical Data for use in Atmospheric Studies, Evaluation Number 14. NASA Jet Propulsion Laboratory http://jpldataeval.jpl.nasa.gov/index.html.
[253] Yarwood, G., Rao, S., Yocke, M., Whitten, G.Z., 2005. Updates to the Carbon Bond Mechanism: CB05. Final Report to the U.S. EPA, RT-0400675. Yocke and Company, Novato, CA.
[254] Luecken, D.J., Phillips, S., Sarwar, G., Jang, C., 2008b. Effects of using the CB05 vs. SAPRC99 vs. CB4 chemical mechanism on model predictions: Ozone and gas-phase photochemical precursor concentrations. Atmospheric Environment 42, 5805-5820.
[255] Sander, S.P., Friedl, R.R., Golden, D.M., Kurylo, M.J., Huie, R.E., Orkin, V.L., Moortgat, G.K., Ravishankara, A.R., Kolb, C.E., Molina, M.J., Finlayson-Pitts, B.J., 2003. Chemical Kinetics and Photochemical Data for use in Atmospheric Studies, Evaluation Number 14. NASA Jet Propulsion Laboratory.
[256] Sander, S.P., Friedl, R.R., Golden, D.M., Kurylo, M.J., Huie, R.E., Orkin, V.L., Moortgat, G.K., Ravishankara, A.R., Kolb, C.E., Molina, M.J., Finlayson-Pitts, B.J., 2003. Chemical Kinetics and Photochemical Data for use in Atmospheric Studies, Evaluation Number 14. NASA Jet Propulsion Laboratory.
[257] Luecken, D.J., Hutzell, W.T., Strum, M., Pouliot, G., 2012. Regional sources of atmospheric formaldehyde and acetaldehyde, and implications for atmospheric modeling. *Atmospheric Environment*, 47, 477-490.
[258] Atkinson R, Arey J (2003) Atmospheric Degradation of Volatile Organic Compounds. Chem Rev 103: 4605-4638.
[259] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html.
[260] Lewandowski M, M Jaoui , JH Offenberg , TE Kleindienst, EO Edney, RJ Sheesley, JJ Schauer (2008) Primary and secondary contributions to ambient PM in the midwestern United States, Environ Sci Technol 42(9):3303-3309. http://pubs.acs.org/cgi-bin/article.cgi/esthag/2008/42/i09/html/es0720412.html.
[261] Kleindienst TE, M Jaoui, M Lewandowski, JH Offenberg, EO Edney (2007) Estimates of the contributions of biogenic and anthropogenic hydrocarbons to secondary organic aerosol at a southeastern U.S. location, Atmos Environ 41(37):8288-8300.
[262] Offenberg JH, CW Lewis, M Lewandowski, M Jaoui, TE Kleindienst, EO Edney (2007) Contributions of

Toluene and □pinene to SOA Formed in an Irradiated Toluene/ □pinene,NO_x/Air Mixture: Comparison of Results Using ^{14}C Content and SOA Organic Tracer Methods, Environ Sci Technol 41: 3972-3976.
[263] Pandis, S.N., Harley, R.A., Cass, G.R., Seinfeld, J.H. (1992) Secondary organic aerosol formation and transport. Atmos Environ 26, 2269–2282.
[264] Takekawa, H. Minoura, H. Yamazaki, S. (2003) Temperature dependence of secondary organic aerosol formation by photo-oxidation of hydrocarbons. Atmos Environ 37: 3413–3424.
[265] Kleeman, M.J., Ying, Q., Lu, J., Mysliwiec, M.J., Griffin, R.J., Chen, J., Clegg, S. (2007) Source apportionment of secondary organic aerosol during a severe photochemical smog episode. Atmos Environ 41: 576–591.
[266] Robinson, A. L.; Donahue, N. M.; Shrivastava, M.; Weitkamp, E. A.; Sage, A. M.; Grieshop, A. P.; Lane, T. E.; Pierce, J. R.; Pandis, S. N. (2007) Rethinking organic aerosol: Semivolatile emissions and photochemical aging. Science 315: 1259-1262.
[267] Griffin, R. J.; Cocker, D. R.; Seinfeld, J. H.; Dabdub, D. (1999) Estimate of global atmospheric organic aerosol from oxidation of biogenic hydrocarbons. Geophys Res Lett 26 (17) 2721– 2724.
[268] Lewis, C. W.; Klouda, G. A.; Ellenson, W. D. (2004) Radiocarbon measurement of the biogenic contribution to summertime PM-2.5 ambient aerosol in Nashville, TN. Atmos Environ 38 (35) 6053– 6061.
[269] Byun DW, Schere, KL (2006) Review of the Governing Equations, Computational Algorithms, and Other Components of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System, J Applied Mechanics Reviews 59: 51-76.
[270] Edney, E. O., T. E. Kleindienst, M. Lewandowski, and J. H. Offenberg, 2007. Updated SOA chemical mechanism for the Community Multi-Scale Air Quality model, EPA 600/X-07/025, U.S. EPA, Research Triangle Park, NC.
[271] Carlton, A.G., B. J. Turpin, K. Altieri, S. Seitzinger, R. Mathur, S. Roselle, R. J. Weber, (2008), CMAQ model performance enhanced when in-cloud SOA is included: comparisons of OC predictions with measurements, Environ. Sci. Technol. 42 (23), 8798–8802.
[272] Carlton, A. G., P. V. Bhave, S. L. Napelenok, E. O. Edney, G. Sarwar, R. W. Pinder, G. A. Pouliot, and M. Houyoux. Model Representation of Secondary Organic Aerosol in CMAQv4.7. Env. Sci. & Techno. 2010, 44 (22), 8553-8560.
[273] Simulating the Degree of Oxidation in Atmospheric Organic Particles. Simon, H and Bhave, Environ. Sci. Technol., 2012, 46 (1), pp 331–339.
[274] U.S. EPA, 2010. Our Nations Air, Status and Trends through 2008. EPA 454/R-09-002, February 2010. http://www3.epa.gov/airtrends/2010.
[275] Hildebrandt et al. 2009 ACP http://www.atmos-chem-phys.net/9/2973/2009/acp-9-2973-2009.html.
[276] Ng et al. 2007 ACP http://www.atmos-chem-phys.net/7/3909/2007/acp-7-3909-2007.html.
[277] U.S. EPA. 2015. 2011 NATA: Assessment Results. https://www3.epa.gov/national-air-toxics-assessment/2011-nata-assessment-results#modeled.
[278] U.S. EPA (2007) Regulatory Impact Analysis for the Control of Hazardous Air Pollutants from Mobile Sources Rule, Chapter 3, Air Quality and Resulting Health and Welfare Effects of Air Pollution from Mobile Sources. 72 FR 8428, February 26, 2007. http://www3.epa.gov/otaq/regs/toxics/420r07002.pdf.
[279] Ng et al. 2007 ACP http://www.atmos-chem-phys.net/7/3909/2007/acp-7-3909-2007.html.
[280] Lim, Y.B., Ziemann, P.J. (2009) Effects of Molecular Structure on Aerosol Yields from OH Radical-Initiated Reactions of Linear, Branched, and Cyclic Alkanes in the Presence of NO_X. Environ Sci Technol 43 (7): 2328-2334.
[281] Kleindienst, T.E. (2008) Hypothetical SOA Production from Ethanol Photooxidation. Memo to the Docket EPA-HQ-OAR-2005-0161.
[282] Turpin, B.J., Huntzicker, J.J., Larson, S.M., Cass, G.R. (1991) Los Angeles Summer Midday Particulate Carbon: Primary and Secondary Aerosol. Environ Sci Technol 25: 1788-1793.
[283] Turpin, B.J., Huntzicker, J.J. (1995) Identification of Secondary Organic Aerosol Episodes and Quantitation of Primary and Secondary Organic Aerosol Concentrations During SCAQS. Atmos Environ 29(23): 3527-3544.
[284] Bae M-S, Schauer JJ, Turner JR (2006) Estimation of the Monthly Average Ratios of Organic Mass to Organic Carbon for Fine Particulate Matter at an Urban Site, Aerosol Sci Technol 40(12): 1123-1139. http://dx.doi.org/10.1080/02786820601004085.
[285] Kleindienst TE, M Jaoui, M Lewandowski, JH Offenberg, EO Edney (2007) Estimates of the contributions of biogenic and anthropogenic hydrocarbons to secondary organic aerosol at a southeastern U.S. location. Atmos Environ 41(37):8288-8300.
[286] Offenberg JH, CW Lewis, M Lewandowski, M Jaoui, TE Kleindienst, EO Edney (2007) Contributions of Toluene and □pinene to SOA Formed in an Irradiated Toluene/ □pinene,NO_x/Air Mixture: Comparison of Results Using ^{14}C Content and SOA Organic Tracer Methods, Environ Sci Technol 41: 3972-3976.

[287] Claeys M, R Szmigielski, I Kourtchev, P Van der Veken, R Vermeylen, W Maenhaut, M Jaoui, TE Kleindienst, M Lewandowski, JH Offenberg, EO Edney (2007) Hydroxydicarboxylic acids: Markers for secondary organic aerosol from the photooxidation of -pinene. Environ Sci Technol 41(5): 1628-1634.

[288] Edney EO, TE Kleindienst, M Jaoui, M Lewandowski, JH Offenberg, W Wang, M Claeys (2005) Formation of 2-methyl tetrols and 2-methylglyceric acid in secondary organic aerosol from laboratory irradiated isoprene/NO_X/SO_2/air mixtures and their detection in ambient $PM_{2.5}$ samples collected in the Eastern United States. Atmos Environ 39: 5281-5289.

[289] Jaoui M, TE Kleindienst, M Lewandowski, JH Offenberg, EO Edney (2005) Identification and quantification of aerosol polar oxygenated compounds bearing carboxylic or hydroxyl groups. 2. Organic tracer compounds from monoterpenes. Environ Sci Technol 39: 5661-5673.

[290] Kleindienst TE, TS Conver, CD McIver, EO Edney (2004) Determination of secondary organic aerosol products from the photooxidation of toluene and their implications in ambient $PM_{2.5}$. J Atmos Chem 47: 70-100.

[291] Kleindienst TE, TS Conver, CD McIver, EO Edney (2004) Determination of secondary organic aerosol products from the photooxidation of toluene and their implication in ambient $PM_{2.5}$, J Atmos Chem 47: 70-100.

[292] Pye et al. 2013 ES&T Epoxide pathways improve model predictions of isoprene markers and reveal key role of acidity in aerosol formation, http://pubs.acs.org/doi/abs/10.1021/es402106h.

[293] Carlton et al. 2010 ES&T Can biogenic SOA be controlled? http://pubs.acs.org/doi/full/10.1021/es903506b

[294] Lewandowski M, M Jaoui , JH Offenberg , TE Kleindienst, EO Edney, RJ Sheesley, JJ Schauer (2008) Primary and secondary contributions to ambient PM in the midwestern United States, Environ Sci Technol 42(9):3303-3309. http://pubs.acs.org/cgi-bin/article.cgi/esthag/2008/42/i09/html/es0720412.html.

[295] Kleindienst TE, M Jaoui, M Lewandowski, JH Offenberg, EO Edney (2007) Estimates of the contributions of biogenic and anthropogenic hydrocarbons to secondary organic aerosol at a southeastern U.S. location. Atmos Environ 41(37):8288-8300.

[296] Henze DK, JH Seinfeld (2006) Global secondary organic aerosol from isoprene oxidation. Geophys Res Lett 33: L09812. doi:10.1029/2006GL025976.

[297] Hildebrandt, L., Donahue1, N. M, Pandis1, S. N. (2009) High formation of secondary organic aerosol from the photo-oxidation of toluene. Atmos Chem Phys 9: 2973-2986. Docket EPA-HQ-OAR-2011-0135.

[298] Ng, N. L., Kroll, J. H., Chan, A. W. H., Chabra, P. S., Flagan, R. C., Seinfield, J. H., Secondary organic aerosol formation from *m*-xylene, toluene, and benzene, Atmospheric Chemistry and Physics Discussion, 7, 3909-3922, 2007. Docket EPA-HQ-OAR-2011-0135.

[299] Henze, D. K., Seinfeld, J. H., Ng, N. L., Kroll, J. H., Fu, T.-M., Jacob, D. J., and Heald, C. L. (2008) Global modeling of secondary organic aerosol formation from aromatic hydrocarbons: high- vs. low-yield pathways, Atmos. Chem. Phys., 8, 2405-2420, doi:10.5194/acp-8-2405-2008.

[300] Lane, T. E., Donahue, N.M. and Pandis, S.N. (2008) Simulating secondary organic aerosol formation using the volatility basis-set approach in a chemical transport model, Atmos. Environ., 42, 7439-7451, doi: 10.1016/j.atmosenv.2008.06.026.

[301] Carlton, A.G., Bhave, P.V., Napelenok, S.L., Edney, E.O., Sarwar, g., Pinder, R.W., Pouliot, G.A., Houyoux, M., (2010). Model Representation of Secondary Organic Aerosol in CMAQv4.7. Environ Sci Technol 44(22), 8553-8560.

[302] Parikh, H.M., Carlton, A.G., Vizuete, W., and Kamen, R.M. (2011) Modeling secondary organic aerosol using a dynamic partitioning approach incorporating particle aqueous-phase chemistry, Atmospheric Environment, 45, 1126-1137.

[303] Volkamer, R., J.L. Jimenez, F. SanMartini,K.Dzepina,Q. Zhang,D. Salcedo,L. T. Molina, D. R.Worsnop, and M. J. Molina (2006), Secondary organic aerosol formation from anthropogenic air pollution: Rapid and higher than expected, Geophys. Res. Lett., 33, L17811, doi:10.1029/2006GL026899.

[304] Baker, K. R., Carlton, A. G., Kleindienst, T. E., Offenberg, J. H., Beaver, M. R., Gentner, D. R., Goldstein, A. H., Hayes, P. L., Jimenez, J. L., Gilman, J. B., de Gouw, J. A., Woody, M. C., Pye, H. O. T., Kelly, J. T., Lewandowski, M., Jaoui, M., Stevens, P. S., Brune, W. H., Lin, Y.-H., Rubitschun, C. L., and Surratt, J. D.: Gas and aerosol carbon in California: comparison of measurements and model predictions in Pasadena and Bakersfield, Atmos. Chem. Phys., 15, 5243-5258, doi:10.5194/acp-15-5243-2015, 2015.

[305] Napelenok, S. L., H. Simon, P. Bhave, H. O. T. Pye, G. A. Pouliot, R. J. Sheesley, J. J. Schauer, Diagnostic air quality model evaluation of source specific primary and secondary fine particulate carbon, Environ. Sci. Technol., doi: 10.1021/es4033024w, 2014.

[306] Atkinson, R., Baulch, D.L., Cox, R.A., Crowley, J.N., Hampson, R.F. Jr., Hynes, R.G., Jenkin, M.E., Kerr, J.A., Rossi, M.J., Troe, J. (2005) Evaluated Kinetic and Photochemical Data for Atmospheric Chemistry - IUPAC

Subcommittee on Gas Kinetic Data Evaluation for Atmospheric Chemistry. July 2005 web version. http://www.iupac-kinetic.ch.cam.ac.uk/index.html. Docket EPA-HQ-OAR-2011-0135.

[307] Sander, S.P., Friedl, R.R., Golden, D.M., Kurylo, M.J., Huie, R.E., Orkin, V.L., Moortgat, G.K., Ravishankara, A.R., Kolb, C.E., Molina, M.J., Finlayson-Pitts, B.J. (2003) Chemical Kinetics and Photochemical Data for use in Atmospheric Studies, Evaluation Number 14. NASA Jet Propulsion Laboratory. http://jpldataeval.jpl.nasa.gov/index.html. Docket EPA-HQ-OAR-2011-0135.

[308] Finlayson-Pitts BJ, Pitts JN Jr. (1986) Atmospheric Chemistry: Fundamentals and Experimental Techniques, Wiley, New York.

[309] Yarwood G, Rao S, Yocke M, Whitten GZ (2005) Updates to the Carbon Bond Chemical Mechanism: CB05. Final Report to the U.S. EPA, RT-0400675, December 8, 2005. http://www.camx.com/publ/pdfs/CB05_Final_Report_120805.pdf. Docket EPA-HQ-OAR-2011-0135,

[310] http://www.cmascenter.org/help/model_docs/cmaq/4.7/RELEASE_NOTES.txt.

Chapter 7: Vehicle-Related Costs, Fuel Savings & Maintenance Costs

In this chapter, the agencies present estimates of the vehicle -related costs associated with the standards along with corresponding fuel savings and maintenance costs. For this final rule, the agencies used two analytical methods for the heavy-duty pick up and van segment by employing both DOT's CAFE model and EPA's MOVES model. The agencies used EPA's MOVES model to estimate fuel consumption and emissions impacts for tractor-trailers (including the engine that powers the tractor), and vocational vehicles (including the engine that powers the vehicle). Additional calculations were performed to determine corresponding monetized program costs and benefits. For heavy-duty pickups and vans, the agencies performed separate analyses, which we refer to as "Method A" and "Method B." In Method A, the CAFE model was used to project a pathway the industry could use to comply with each regulatory alternative and the estimated effects on fuel consumption, emissions, benefits and costs. In Method B, the CAFE model was used to project a pathway the industry could use to comply with each regulatory alternative, along with resultant impacts on per-vehicle costs, and the MOVES model was used to calculate corresponding changes in total fuel consumption and annual emissions. Additional calculations were performed to determine corresponding monetized program costs and benefits. NHTSA considered Method A as its central analysis and Method B as a supplemental analysis. EPA considered the results of Method B. The agencies concluded that both methods led the agencies to the same conclusions and the same selection of the standards. Throughout this chapter and in later chapters presenting program-related costs and benefits, engine costs are included along with vehicle-related costs.

7.1 Vehicle Costs, Fuel Savings and Maintenance Costs vs. the Dynamic Baseline and Using Method A

NHTSA's analysis of the potential costs of the standards combines DOT CAFE model calculations of HD pickup and van costs with EPA MOVES modeling of vocational vehicle, tractor and trailer fuel consumption along with EPA analysis of vocational vehicle, tractor and trailer costs. The analysis includes costs for fuel-saving technology that manufacturers could add in response to the standards, EPA estimates of the additional compliance and R&D costs for vocational vehicles and combination tractor trailers, and some additional maintenance costs.

7.1.1 Vehicle Program Costs

In this section, NHTSA presents its estimate of the vehicle- -related costs associated with the program versus Alternative 1b using the CAFE model analysis of HD pickups and vans. The presentation here summarizes the costs associated with new technology the agencies estimate manufacturers could add to meet the GHG and fuel consumption standards. The analysis summarized here provides our estimate of incremental costs on a per vehicle basis and on a MY lifetime basis. In Chapter 7.2, where EPA presents the Method B analysis, the analogous information is presented along with costs on an annual, or calendar year, basis for all segments. For details behind the cost estimates associated with individual technologies, the reader is directed to Sections III through VI of the Preamble and to Chapter 2 of the RIA.

Note that all discounted costs presented in this chapter, whether in the Calendar Year (or annual) analysis or the Model Year Lifetime analysis, are discounted back to 2015 at the discount rate shown in the table(s).

7.1.1.1 Technology Costs

For the HD pickup trucks and vans, the Method A analysis used technology costs consistent with that used for our recent 2017-2025 light-duty joint rulemaking since most of the technologies expected for HD pickup trucks and vans are consistent with those expected for the larger light-duty trucks. The cost estimates presented in the recent light-duty joint rulemaking were then scaled upward to account for the larger weight, towing capacity, and work demands of the trucks in these heavier classes. For details on that scaling process and the resultant costs for individual technologies, the reader is directed to Chapter 2.6 and 2.12 of this RIA. Note also that all cost estimates have been updated to 2013 dollars for this analysis while the 2017-2025 light-duty joint rulemaking was presented in 2010 dollars.[1] To mark-up the technology costs to consider indirect costs the agencies use two different methodologies: NHTSA uses the retail price equivalent (RPE) multiplier, and EPA uses the indirect cost multiplier (ICM). For more details on these two methodologies see Chapter 2.11.1.2 and Chapter 10 in the RIA and Section VI.C in the Preamble.

For vocational vehicles, tractors and trailers, consistent with the Phase 1 rule, the agencies have estimated costs using a different methodology than that employed in the recent light-duty joint rulemaking establishing fuel economy and GHG standards. In the recent light-duty joint rulemaking, all fixed costs were included in the hardware costs via ICM's. As such, the hardware costs presented in that analysis included both the actual hardware and the associated fixed costs. For the vocational, tractor and trailer segments in this analysis, some of the fixed costs are estimated separately and are presented separately from the technology costs. As noted above, all costs are presented in 2013 dollars.

The estimates of vehicle costs are generated relative to two unique "no action" baselines. The first of these (alternative 1a, presented below in Chapter 7.2) representing generally flat fuel consumption improvements, or a fleet of vehicles meeting the Phase 1 heavy-duty requirements. The second of these (alternative 1b and presented here) representing dynamic fuel consumption improvements, or a fleet of vehicles with some improvement in fuel consumption even without additional regulatory action. See Section X of the Preamble and Chapter 11 of this RIA for more detail on these two baselines. As such, costs to comply with the Phase 1 standards are not included in the estimates here. In fact, in the methodology used for vocational vehicles, tractors and trailers, there are cases where Phase 1 technologies are being removed in favor of Phase 2 technologies – that is, the technology basis for the Phase 2 standards involves removing certain of the Phase 1 technologies. In those cases, savings are associated with the removal of the Phase 1 technology. The details of which technologies and where such savings occur are presented in Chapter 2.11 of the RIA.

For HD pickups and vans, as described in Chapter 2 of this RIA, the agencies used NHTSA's CAFE model to estimate the cost per vehicle associated with the standards (and possible alternative).[A] That model has the capability to look ahead at future standards when making determinations of how vehicles should be changed to comply. It does this because redesign cycles do not always line up well with regulatory implementation schedules, so a manufacturer may choose to redesign a vehicle in MY2018 in preparation for upcoming MY2021-2027 standards if that particular vehicle is not scheduled for another redesign until, say, MY2026. The result being new technology costs in years prior to implementation of the standards. The CAFE model's output would show such costs occurring in years prior to MY2021. On the other hand, the CAFE model also estimates the potential that credits generated in earlier model years might be carried forward (i.e., "banked") and then used in later model years, potentially reducing costs in some model years covered by the analysis.

Table 7-1 presents the average incremental technology costs per vehicle for the program relative to alternative 1b. These tables include both engine and vehicle technologies. For HD pickups and vans, costs begin with new standards in MY2018, as technology is utilized in vehicles with early redesign cycles. The costs jump in MY2021 as more complex technologies are utilized, then generally increase through the remainder of the analysis period. For vocational vehicles, the costs begin in MY2021, then decrease slightly through MY2023, with an increase in MY2024, decreasing slightly through MY2026, and followed by a large increase in costs from MY2027 until the end of the analysis period. The decreasing costs from MY2021 through MY 2023 and MY2024 through MY2026 are due to technology learning, whereby manufacturers can produce the same technologies at a lower cost. For tractor/trailers, the costs begin in MY2018 as trailers begin adding new technology to meet the 2018 trailer standards. Costs then increase in MY2021 as the tractor standards begin through 2027. After 2027, costs begin to decrease due to learning effects. All costs shown in the table represent the weighted average cost of all vehicles within the category shown in the heading.

[A] The CAFE model also provides a full benefit-cost analysis associated with standards, and NHTSA has used this analysis as part of Method A to provide estimates of the costs and benefits of today's standards. The full benefit-cost analysis for Method A is presented in Chapters 9 and 10 of this RIA. The full benefit-cost analysis for Method B is presented in Chapter 8 of this RIA.

Table 7-1 Estimated Technology Costs per Vehicle for the Final Program versus the Dynamic Baseline and using Method A (2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS
2018	$235	$0	$639
2019	$468	$0	$573
2020	$441	$0	$482
2021	$752	$1,110	$7,248
2022	$774	$1,088	$7,120
2023	$779	$1,027	$6,624
2024	$762	$2,022	$10,925
2025	$950	$1,986	$10,660
2026	$1,347	$1,927	$10,447
2027	$1,335	$2,662	$13,226
2028	$1,468	$2,616	$12,906
2029	$1,486	$2,586	$12,768

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1
As noted in the text, MYs 2018-2020 include costs for trailers only, and in MYs 2021 and later the costs include both tractor and trailer costs. Detailed technology and package costs for all segments can be found in Chapter 2 of this RIA (notably, see Sections 2.12 and 2.13).

Table 7-2 presents the model year lifetime costs for new technology discounted at 3 percent using Method A. And Table 7-3 presents the model year lifetime costs for new technology discounted at 7 percent using Method A.

Table 7-2 Discounted MY Lifetime New Technology Costs of the Final Program Vs. the Dynamic Baseline and using Method A (3% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$174	$0	$91	$265
2019	$335	$0	$79	$414
2020	$308	$0	$72	$380
2021	$503	$471	$897	$1,871
2022	$498	$450	$862	$1,810
2023	$486	$414	$781	$1,681
2024	$464	$801	$1,283	$2,548
2025	$570	$778	$1,233	$2,581
2026	$795	$744	$1,183	$2,722
2027	$775	$1,009	$1,465	$3,249
2028	$837	$977	$1,403	$3,217
2029	$833	$952	$1,372	$3,157
Sum	$6,578	$6,597	$10,722	$23,897

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-3 Discounted MY Lifetime New Technology Costs of the Final Program Vs. the Dynamic Baseline and using Method A (7% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$162	$0	$81	$243
2019	$299	$0	$68	$367
2020	$264	$0	$59	$323
2021	$416	$375	$714	$1,505
2022	$397	$345	$660	$1,402
2023	$373	$305	$576	$1,254
2024	$342	$568	$910	$1,820
2025	$404	$532	$842	$1,778
2026	$543	$489	$778	$1,810
2027	$510	$639	$928	$2,077
2028	$530	$595	$855	$1,980
2029	$507	$558	$805	$1,870
Sum	$4,746	$4,407	$7,277	$16,430

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.1.1.2 Compliance Costs

As noted above, for vocational vehicles and tractor trailers, some fixed costs were estimated separately from the hardware costs. As such, not all fixed costs are included in the tables presented in Chapter 7.1.1.1. The agencies have estimated additional and/or new compliance costs associated with the standards. Normally, compliance program costs would be considered part of the indirect costs and, therefore, would be accounted for via the markup applied to direct manufacturing costs. However, since the agencies are proposing new compliance elements that were not present during development of the indirect cost markups used in this analysis, additional compliance program costs are being accounted for via a separate "line-item" here. Note, for HD pickups and vans, the RPE methodology used for Method A already accounts for these costs. Again, see Chapter 10 of this RIA or Section VI.C of the Preamble for more on NHTSA's decision to use RPE in Method A.

There are three elements to the compliance costs estimated in this analysis. The first is for construction of new, or upgrades to existing, test facilities for conducting powertrain testing. The second costs are for conducting the powertrain tests themselves. And the third is for reporting of compliance data to EPA and NHTSA. We estimated these latter costs in the Phase 1 rule as $0.24 million, $0.9 million and $1.1 million for HD pickups and vans, vocational and tractors, respectively, for a total of $2.3 million per year (2009$).[2] All of these are industry-wide, annual costs.

We have estimated reporting costs in this Phase 2 final rule associated with new powertrain testing within the vocational vehicle program, the increased level of reporting in the tractor program and an all new compliance program where none has existed to date within the trailer program. We have estimated those costs, inclusive of the Phase 1 costs, such that the new GHG program reporting costs are estimated at $1.1 million and $1.2 million for vocational and tractor programs both in 2013$. All of these are industry-wide, annual costs.

For powertrain testing facility upgrades and construction, we have estimated that 6 manufacturers would upgrade and 5 would construct new facilities at an upgrade cost of $1.2 million and a new construction cost of $1.9 million, all in 2013$. The result being an industry-wide (but vocational program only) cost of $16.8 million (2013$). This cost would occur once which we have attributed to CY2020, one year prior to the first year of the Phase 2 vocational standards.

Lastly, the vocational program is also estimated to incur costs associated with conducting powertrain testing. We have estimated the cost of testing at $40,000 per test (2013$) and expect 10 tests/year for a total of $400,000/year. We have also estimated that the vocational program will incur costs associated with conducting transmission efficiency testing at a cost of $24,600 per test (2013$). We have estimated 11 tests per year for a total annual cost of $270,600. We have also estimated that the vocational program will incur costs associated with conducting axle efficiency testing at a cost of $12,600 per test (2013$). We have estimated that 9 tests would be done per year for a total annual cost of $113,400. We have also estimated an annual cost of $8,700 in tire testing will be incurring by the vocational program.

In the tractor program, we have used the same per test costs noted above for vocational and have estimated one transmission efficiency test per year for a total annual cost of $24,600 (2013$) and 15 axle efficiency tests per year for a total annual cost of $189,000 (2013$). To those costs, we have also added $300,000 (2013$) per year in aero-related testing and $5,400 (2013$) per year in tire testing. For the trailer program, we have estimated an annual compliance program cost of $7 million (2013$) to cover reporting, testing and capital costs.

Table 7-4 and Table 7-5 present the MY lifetime costs for new compliance program elements at 3 percent and 7 percent, respectively.

Table 7-4 Discounted MY Lifetime Compliance Costs of the Final Program Vs. The Dynamic Baseline and using Method A (3% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	0	0	0
2019	0	0	0
2020	14.5	0	14.5
2021	1.6	7.3	8.9
2022	1.5	7.1	8.6
2023	1.5	6.9	8.4
2024	1.4	6.7	8.1
2025	1.4	6.5	7.9
2026	1.3	6.3	7.6
2027	1.3	6.1	7.4
2028	1.3	5.9	7.2
2029	1.2	5.8	7.0
Sum	27.0	58.6	85.6

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-5 Discounted MY Lifetime Compliance Costs of the Final Program Vs. The Dynamic Baseline and using Method A (7% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	0	0	0.0
2019	0	0	0.0
2020	12.0	0	12.0
2021	1.2	5.8	7.0
2022	1.2	5.4	6.6
2023	1.1	5.1	6.2
2024	1.0	4.7	5.7
2025	0.9	4.4	5.3
2026	0.9	4.1	5.0
2027	0.8	3.9	4.7
2028	0.8	3.6	4.4
2029	0.7	3.4	4.1
Sum	20.6	40.4	62.0

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.1.1.3 Research & Development Costs

Much like the compliance program costs described above, Method A estimates additional engine, vocational vehicle and tractor R&D associated with the standards that is not accounted for via the indirect cost markups used in this analysis for those segments. The necessary R&D for HD pickups and vans is covered by the indirect costs included as part of the technology costs described above. In the Phase 1 rule, the agencies estimated the engine R&D costs at $6.8 million (2009$) per engine class per manufacturer per year for five years. In this Phase 2 analysis, both the Method A and Method B analyses estimate this same level of R&D and has assumed 12 heavy-heavy and 12 medium-heavy HD engine R&D programs would be conducted for a total of $218 million/year (2013$). In both methods, the agencies assume those costs would occur annually for 4 years, MYs 2021-2024. The total being $873 million (2013$) over 4 years (by comparison, the Phase 1 rule estimated a total of $852 million (2009$) over 5 years). To this, the agencies have estimated an additional $20 million/year spent by vocational vehicle manufacturers and $20 million/year spent by tractor manufacturers. In the end, the agencies are estimating a total of over $1 billion in R&D spending above and beyond the level included in the markups used to estimate indirect costs for these segments. The agencies have not included any *additional* R&D would be spent by trailer manufacturers since our trailer technology cost estimates include R&D conducted by trailer parts suppliers which are subsequently included in the prices charged by those suppliers to the trailer manufacturer. Additionally, the markups we have applied to cover indirect costs (see Chapter 2.12 of this RIA) include costs associated with R&D incurred by the trailer manufacturer.

Table 7-6 and Table 7-7 present the annual costs for R&D spending along with net present values at 3 percent and 7 percent, and the model year lifetime R&D costs discounted at 3 percent and 7 percent, respectively.

Table 7-6 Discounted MY Lifetime R&D Costs of the Final Program Vs. The Dynamic Baseline and using Method A (3% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	0	0	0
2019	0	0	0
2020	0	0	0
2021	108	108	216
2022	105	105	210
2023	102	102	204
2024	99	99	198
2025	0	0	0
2026	0	0	0
2027	0	0	0
2028	0	0	0
2029	0	0	0
Sum	415	415	830

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-7 Discounted MY Lifetime R&D Costs of the Final Program Vs. The Dynamic Baseline and using Method A (7% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	0	0	0
2019	0	0	0
2020	0	0	0
2021	86	86	172
2022	81	81	161
2023	75	75	151
2024	70	70	141
2025	0	0	0
2026	0	0	0
2027	0	0	0
2028	0	0	0
2029	0	0	0
Sum	313	313	625

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.1.1.4 Summary of Vehicle-Related Costs of the Program using Method A

Table 7-8 presents the model year lifetime costs associated with the final program discounted at 3 percent relative to the dynamic baseline and using Method A. Table 7-9 presents the model year lifetime costs associated with the final program discounted at 7 percent relative to the dynamic baseline and using Method A.

Table 7-8 Discounted MY Lifetime Vehicle-Related Costs of the Final Program Vs. The Dynamic Baseline and using Method A (3% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$174	$0	$91	$265
2019	$335	$0	$79	$414
2020	$308	$15	$72	$395
2021	$503	$581	$1,012	$2,096
2022	$498	$557	$974	$2,029
2023	$486	$518	$890	$1,893
2024	$464	$901	$1,389	$2,754
2025	$570	$779	$1,240	$2,589
2026	$795	$745	$1,189	$2,730
2027	$775	$1,010	$1,471	$3,256
2028	$837	$978	$1,409	$3,224
2029	$833	$953	$1,378	$3,164
Sum	$6,578	$7,039	$11,196	$24,813

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-9 Discounted MY Lifetime Vehicle-Related Costs of the Final Program Vs. The Dynamic Baseline and using Method A (7% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$162	$0	$81	$243
2019	$299	$0	$68	$367
2020	$264	$12	$59	$335
2021	$416	$484	$828	$1,728
2022	$397	$451	$770	$1,619
2023	$373	$408	$683	$1,464
2024	$342	$668	$1,014	$2,024
2025	$404	$533	$846	$1,783
2026	$543	$490	$782	$1,815
2027	$510	$640	$932	$2,082
2028	$530	$596	$859	$1,984
2029	$507	$559	$808	$1,874
Sum	$4,746	$4,843	$7,732	$17,322

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.1.2 Changes in Fuel Consumption and Savings

7.1.2.1 Changes in Fuel Consumption

The standards would result in significant improvements in the fuel efficiency of affected vehicles. Drivers of those vehicles would see corresponding savings associated with reduced fuel expenditures. The agencies have estimated the impacts on fuel consumption for the standards. More detail behind these changes in fuel consumption is presented in Chapter 5 and Chapter 10 of this RIA. The expected impacts on fuel consumption are shown in Table 7-10 as reductions from the dynamic baseline reference case (i.e., positive values represent fewer gallons consumed) and using Method A. The gallons shown in this table include any increased consumption resulting from the rebound effect.

Table 7-10 MY Lifetime Fuel Consumption Reductions due to the Final Program Vs. The Dynamic Baseline and using Method A (Million Gallons) [a]

	GASOLINE REDUCTIONS [b]				DIESEL REDUCTIONS			
MODEL YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	162	0	0	162	137	0	302	439
2019	262	0	0	262	217	0	191	408
2020	251	0	0	251	211	0	114	325
2021	432	186	0	618	208	701	3622	4531
2022	451	185	0	636	205	697	3509	4411
2023	464	184	0	648	200	693	3409	4302
2024	463	263	0	726	204	1097	5564	6865
2025	559	265	0	824	247	1108	5524	6879
2026	696	267	0	963	303	1114	5483	6900
2027	724	368	0	1092	319	1481	7384	9184
2028	756	371	0	1127	341	1492	7260	9093
2029	771	374	0	1145	353	1504	7337	9194

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] Gasoline reductions include reductions in Ethanol85.

7.1.2.2 Changes in Fuel Expenditures

Using the fuel consumption reductions presented above, NHTSA has calculated the fuel expenditure changes associated with the standards, subcategory by subcategory. To do this, reduced fuel consumption is multiplied in each year by the corresponding estimated average fuel price in that year, using the reference case fuel prices from AEO 2015 final release. As the AEO fuel price projections go through 2040 and not beyond, fuel prices beyond 2040 were set equal to the 2040 values. These estimates do not account for the significant uncertainty in future fuel prices; the monetized fuel savings would be understated if actual fuel prices are higher (or overstated if fuel prices are lower) than estimated. The Annual Energy Outlook (AEO) is a standard reference used by NHTSA and EPA and many other government agencies to estimate the projected price of fuel. This has been done using both the pre-tax and post-tax fuel prices. Since the post-tax fuel prices are the prices paid at fuel pumps, the fuel expenditure changes calculated using these prices represent the changes fuel purchasers would see. The pre-tax fuel savings are those that society would see. Assuming no change in fuel tax rates, the difference between these two columns represents the reduction in fuel tax revenues that would be received by state and federal governments. The MY lifetime fuel savings for the final program relative to the dynamic baseline and using Method A are shown in Table 7-11 using a 3 percent discount rate and in Table 7-12 using a 7 percent discount rate. Note that in Chapters 8 and 11 of this RIA, the overall benefits and costs of the rulemaking are presented and only the pre-tax fuel expenditure impacts are presented there.

Table 7-11 Discounted MY Lifetime Reductions in Fuel Expenditures of the Final Program Vs. The Dynamic Baseline and using Method A (3% Discount Rate, Billions of 2013$) [a]

	REDUCED FUEL EXPENDITURES – RETAIL				REDUCED FUEL EXPENDITURES – UNTAXED			
MODEL YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	0.9	0.0	0.8	1.7	0.8	0.0	0.7	1.5
2019	1.4	0.0	0.5	1.9	1.2	0.0	0.4	1.6
2020	1.3	0.0	0.3	1.6	1.2	0.0	0.3	1.5
2021	1.8	2.2	9.1	13.1	1.6	1.9	8.0	11.5
2022	1.8	2.1	8.7	12.6	1.6	1.9	7.7	11.2
2023	1.8	2.1	8.4	12.3	1.6	1.9	7.5	11.0
2024	1.8	3.2	13.5	18.5	1.6	2.9	12.1	16.6
2025	2.1	3.2	13.3	18.6	1.9	2.9	11.9	16.7
2026	2.6	3.2	13.0	18.8	2.3	2.8	11.7	16.8
2027	2.7	4.2	17.3	24.2	2.4	3.8	15.6	21.8
2028	2.8	4.2	16.8	23.8	2.5	3.8	15.2	21.5
2029	2.8	4.2	16.8	23.8	2.5	3.8	15.2	21.5
Sum	23.9	28.5	118.6	171.0	21.2	25.5	106.2	152.9

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-12 Discounted MY Lifetime Reductions in Fuel Expenditures of the Final Program Vs. The Dynamic Baseline and using Method A (7% Discount Rate, Billions of 2013$) [a]

	REDUCED FUEL EXPENDITURES – RETAIL				REDUCED FUEL EXPENDITURES – UNTAXED			
MODEL YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	0.8	0.0	0.6	1.4	0.7	0.0	0.5	1.2
2019	1.3	0.0	0.4	1.7	1.1	0.0	0.3	1.4
2020	1.2	0.0	0.2	1.4	1.0	0.0	0.2	1.2
2021	1.5	1.4	5.7	8.6	1.3	1.2	5.0	7.5
2022	1.4	1.3	5.2	7.9	1.3	1.1	4.6	7.0
2023	1.4	1.2	4.9	7.5	1.2	1.1	4.3	6.6
2024	1.3	1.8	7.5	10.6	1.2	1.6	6.7	9.5
2025	1.5	1.7	7.1	10.3	1.3	1.5	6.4	9.2
2026	1.8	1.7	6.8	10.3	1.6	1.5	6.0	9.1
2027	1.8	2.1	8.7	12.6	1.6	1.9	7.8	11.3
2028	1.8	2.0	8.1	11.9	1.6	1.8	7.3	10.7
2029	1.7	1.9	7.8	11.4	1.5	1.7	7.0	10.2
Sum	17.4	15.1	62.9	95.4	15.4	13.4	56.1	84.9

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.1.3 Maintenance Costs

The agencies have estimated increased maintenance costs associated with installation of lower rolling resistance tires. We expect that, when replaced, the lower rolling resistance tires would be replaced by equivalent performing tires throughout the vehicle lifetime. As such, the incremental increases in costs for lower rolling resistance tires would be incurred throughout the vehicle lifetime at intervals consistent with current tire replacement intervals. Those intervals are difficult to quantify given the variety of vehicles and operating modes within the HD industry. For HD pickups and vans, we have chosen a tire replacement interval of 40,000 miles. We have done the same for all vocational vehicles which is probably overly conservative as more frequent intervals results in higher maintenance costs. For tractors and trailers, we have used a maintenance interval of 200,000 miles. The presence of tire inflation management systems, and the increased use of those systems expected due to this final rule, should serve to improve tire maintenance intervals.

In evaluating maintenance costs associated with the rule relative to Alternative 1b, NHTSA has used, for HD pickups and vans, the integrated analysis performed using the CAFE modeling system, which includes additional miles from an estimated rebound effect of 10 percent (the rebound effect is the demand response of VMT when the cost-per-mile travel becomes less expensive). For vocational vehicles, tractors and trailers, NHTSA has used the MOVES-based approach outlined above. The results of NHTSA's analysis are reported as "Method A."

Table 7-13 presents the model year lifetime in-use maintenance costs—versus the dynamic baseline and using Method A— discounted at 3 percent. Table 7-14 presents the model year lifetime in-use maintenance costs—versus the dynamic baseline and using Method A—discounted at 7 percent.

Table 7-13 Discounted MY Lifetime Maintenance Costs of the Final Program Vs. The Dynamic Baseline and using Method A (3% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	0	6.7	6.7
2019	0	6.5	6.5
2020	0	6.5	6.5
2021	19.0	130.6	149.6
2022	17.8	126.2	144
2023	20.3	121.9	142.2
2024	53.6	97.6	151.2
2025	52.3	95.1	147.4
2026	42.5	93.4	135.9
2027	89.9	186.8	276.7
2028	86.1	181.4	267.5
2029	83.7	176.7	260.4
Sum	465.1	1229.5	1694.6

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-14 Discounted MY Lifetime Maintenance Costs of the Final Program Vs. The Dynamic Baseline and using Method A (7% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	0.0	4.7	4.7
2019	0.0	4.4	4.4
2020	0.0	4.2	4.2
2021	12.3	82.9	95.2
2022	11.1	77.1	88.2
2023	12.1	71.8	83.9
2024	30.8	55.6	86.4
2025	28.9	52.1	81
2026	22.7	49.3	72
2027	46.2	94.9	141.1
2028	42.6	88.8	131.4
2029	39.9	83.3	123.2
Sum	246.7	669.1	915.8

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.1.4 Analysis of Payback Periods

An important metric to vehicle purchasers is the payback period that can be expected on any new purchase. In other words, there is greater willingness to pay for new technology if that new technology "pays back" within an acceptable period of time. We make no effort to define the acceptable period of time here, but seek to estimate the payback period for others to make the decision themselves. We define the payback period as the point at which reduced fuel expenditures outpace increased vehicle costs. For example, a new MY2027 HD pickup truck is estimated to cost roughly $1,300 more (on average, in 2013$, and relative to the reference case vehicle) due to the addition of new fuel consumption improving and GHG reducing technology. This new technology would result in lower fuel consumption and, therefore, reduced fuel expenditures. But how many months or years would pass before the reduced fuel expenditures would surpass the increased costs?

To estimate the costs, we have considered not only the cost of the new technology, but also the taxes paid on the incrementally higher purchase expense, the slightly higher insurance expenses on the slightly higher value vehicle, the increased finance cost, and the increased maintenance costs associated with the new technology. Taxes and fees paid were estimated as 5.46 percent of the final MSRP. Financing was estimated to be 15.32 percent of final MSRP, and for insurance costs, the model uses an estimate of 19.23 percent of the final MSRP of a vehicle as the cost of insurance. These calculations do not represent specific vehicle classes or specific use cases so should not be seen as being applicable to any particular individual's situation. However, the payback periods do provide a general sense, on average, of what sort of payback periods are likely at a national, societal perspective.

Table 7-15 presents the discounted annual increased vehicle costs and fuel expenditure impacts associated with owning a new MY2027 HD pickup or van using both 3 percent and 7 percent discount rates. The results in this table use Method A. As shown in the table, the payback for HD pickups and vans occurs late in the 3rd year of ownership (the year in which cumulative expenditures become negative) using a 3 percent discount rate and in the early part of the 4th year using a 7 percent discount rate. For other classes of vehicles, including vehicle types such as refuse trucks and transit buses, refer to the Method B analysis of payback periods presented in Chapter 7.2.4.

Table 7-15 Discounted Owner Expenditures & Payback Period for MY2027 HD Pickups & Vans under the Final Program Vs. The Dynamic Baseline and using Method A 3% and 7% Discount Rates (2013$) [a]

Age	3% Discount Rate			7% Discount Rate		
	Technology cost, taxes, insurance [b]	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Fuel expenditures [c]	Cumulative expenditures
1	1296	-554	742	1248	-534	714
2	0	-494	248	0	-457	257
3	0	-424	-176	0	-378	-121
4	0	-357	-533	0	-306	-427
5	0	-284	-817	0	-235	-662
6	0	-214	-1031	0	-170	-832
7	0	-208	-1239	0	-160	-992
8	0	-175	-1414	0	-129	-1121

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2015 final release, reference case estimates.

7.2 Vehicle Costs, Fuel Savings and Maintenance Costs vs. the Flat Baseline and using Method B

As noted in the introduction to Chapter 7.1, the Method B analysis of the potential costs of the standards combines EPA MOVES modeling of vocational vehicle, tractor and trailer fuel consumption, EPA analysis of vocational vehicle, tractor and trailer costs, along with DOT CAFE model calculations of HD pickup and van costs per vehicle. The analysis includes costs for fuel-saving technology that manufacturers could add in response to the standards, EPA estimates of the additional compliance and R&D costs for vocational vehicles and combination tractor trailers, and some additional maintenance costs.[3]

7.2.1 Vehicle Program Costs

This section presents the Method B estimate of the vehicle-related costs associated with the final program versus the flat baseline (Alternative 1a) using the MOVES analysis of HD pickups and vans as well as vocational vehicle, tractors and trailers. The presentation here summarizes the costs associated with new technology the agencies estimate manufacturers could add to meet the GHG and fuel consumption standards. The analysis summarized here provides our estimate of incremental costs on a per vehicle basis, on a MY lifetime basis and on an annual basis. For details behind the cost estimates associated with individual technologies, the reader is directed to Sections III through VI of the Preamble and to Chapter 2 of the RIA. The analysis here also includes a look at payback periods—the time at which cumulative fuel savings outweigh increased costs associated with new, more fuel efficient vehicles. And finally, the analysis here includes a look at the cost per ton of GHG emissions reduced by the addition of new technology.

Note that all discounted costs presented in this chapter, whether in the Calendar Year (or annual) analysis or the Model Year Lifetime analysis, are discounted back to 2015 at the discount rate shown in the table(s).

7.2.1.1 Technology Costs

For the HD pickups and vans, Method B used the same technology costs as used in the proposal, except that those costs have been updated to 2013 dollars using a factor of 1.016 applied to the 2012$-based NPRM costs. As in the proposal, we have used a methodology consistent with that used for our recent 2017-2025 light-duty joint rulemaking since most of the technologies expected for HD pickups and vans are consistent with those expected for the larger light-duty trucks. The cost estimates presented in the recent light-duty joint rulemaking were then scaled upward to account for the larger weight, towing capacity, and work demands of the trucks in these heavier classes. For details on that scaling process and the resultant costs for individual technologies, the reader is directed to Chapter 2.12 of this RIA.

For vocational vehicles, tractors and trailers, consistent with the Phase 1 rule, the agencies have estimated costs using a different methodology than that employed in the recent light-duty joint rulemaking establishing fuel economy and GHG standards. In the recent light-duty joint rulemaking, all fixed costs were included in the hardware costs via an indirect cost multiplier. As such, the hardware costs presented in that analysis included both the actual hardware and the associated fixed costs. For the vocational, tractor and trailer segments in this analysis, some of the fixed costs are estimated separately and are presented separately from the technology costs. As noted above, all costs are presented in 2013 dollars.

The estimates of vehicle costs are generated relative to two unique "no action" baselines. The first of these (alternative 1a, presented here) representing generally flat or flat fuel consumption improvements, or a fleet of vehicles meeting the Phase 1 heavy-duty requirements. The second of these (alternative 1b and presented in detail in Chapter 7.1) representing dynamic fuel consumption improvements, or a fleet of vehicles with improving fuel consumption despite the lack of regulatory drivers. See Section X of the Preamble and Chapter 11 of this RIA for more detail on these two baselines. As such, costs to comply with the Phase 1 standards are not included in the estimates here. In fact, in the methodology used for vocational vehicles, tractors and trailers, there are cases where Phase 1 technologies are being removed in favor of Phase 2 technologies – that is, the technology basis for the Phase 2 standards involves removing certain of the Phase 1 technologies. In those cases, savings are associated with the removal of the Phase 1 technology. The details of which technologies and where such savings occur are presented in Chapter 2.12 of the RIA.

For HD pickups and vans, as described in Chapter 2 of this RIA, Method B uses NHTSA's CAFE model to estimate the cost per vehicle associated with the preferred and possible alternative standards.[B] That model has the capability to look ahead at future standards

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[B] The CAFE model also provides a full benefit-cost analysis associated with the HD pickup and van portion of the standards. The full benefit-cost analysis for Method A is presented in Chapters 9 and 10 of this RIA. The full benefit-cost analysis for Method B is presented in Chapter 8 of this RIA.

when making determinations of how vehicles should be changed to comply. It does this because redesign cycles do not always line up well with regulatory implementation schedules, so a manufacturer may choose to redesign a vehicle in MY2018 in preparation for upcoming MY2021 and later standards if that particular vehicle is not scheduled for another redesign until after the timeframe covered by the upcoming standards. The result being new technology costs in years prior to implementation of the standards. The CAFE model's output would show such costs occurring in years prior to MY2021. On the other hand, the CAFE model also estimates the potential that credits generated in earlier model years might be carried forward (i.e., "banked") and then used in later model years, potentially reducing costs in some model years covered by the analysis.

Table 7-16 presents the average incremental technology costs per vehicle for the final program relative to the flat baseline and using Method B (the MOVES analysis for all vehicle categories). These tables include both engine and vehicle technologies. For HD pickups and vans, costs begin before the MY2021 implementation as the CAFE model projects that manufacturers will start adding technology in anticipation of the standards. For vocational vehicles, costs begin in MY2021, then decrease slightly due to learning effects, then increase again in MY2024 and 2027 as the more stringent standards take effect. The story is similar for tractor-trailers where costs begin in MY2018 on trailers then follow a pattern similar to vocational vehicles as the MY2021, 2024 and 2027 standards take effect on tractors. Costs then decrease beyond MY2027 for each category due to learning effects. All costs shown in the table represent the weighted average cost of all vehicles within the category shown in the heading.

Table 7-16 Estimated Technology Costs per Vehicle for the Final Program versus the Flat Baseline and using Method B (2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS
2018	$114	$0	$568
2019	$105	$0	$548
2020	$108	$0	$535
2021	$524	$1,110	$7,352
2022	$516	$1,088	$7,269
2023	$804	$1,027	$6,799
2024	$963	$2,022	$11,134
2025	$1,180	$1,986	$10,901
2026	$1,244	$1,927	$10,712
2027	$1,364	$2,662	$13,550
2028	$1,354	$2,616	$13,229
2029	$1,355	$2,586	$13,089

Notes:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1
As noted in the text, MYs 2018-2020 include costs for trailers only, and in MYs 2021 and later the costs include both tractor and trailer costs, inclusive of engine-related costs. Detailed technology and package costs for all segments can be found in Chapter 2 of this RIA (notably, see Sections 2.12 and 2.13). Also, for HD pickups and vans, EPA has taken early costs and spread them over the years 2021 through 2026 so that those costs can be fully realized while showing them occurring during the expected years of implementation.

Table 7-17 presents the annual costs—versus the flat baseline and using Method B—for new engine- and vehicle-related technology along with net present values at 3 percent and 7 percent. Table 7-18 presents the model year lifetime costs—versus the flat baseline and using Method B—for new technology discounted at 3 percent. Table 7-19 presents the model year lifetime costs—versus the flat baseline and using Method B—for new technology discounted at 7 percent.

Table 7-17 Annual Technology Costs and Net Present Values Associated with the Final Program vs. the Flat Baseline and using Method B ($Millions of 2013$) [a]

CALENDAR YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$137	$0	$90	$227
2019	$126	$0	$89	$215
2020	$129	$0	$91	$220
2021	$621	$563	$1,087	$2,270
2022	$607	$553	$1,082	$2,243
2023	$944	$525	$1,016	$2,485
2024	$1,140	$1,045	$1,706	$3,890
2025	$1,406	$1,046	$1,695	$4,146
2026	$1,494	$1,030	$1,679	$4,203
2027	$1,639	$1,439	$2,141	$5,219
2028	$1,628	$1,435	$2,113	$5,176
2029	$1,627	$1,440	$2,128	$5,195
2030	$1,610	$1,449	$2,159	$5,219
2035	$1,625	$1,585	$2,432	$5,642
2040	$1,671	$1,776	$2,798	$6,245
2050	$1,755	$2,145	$3,369	$7,270
NPV, 3%	$25,007	$23,932	$37,841	$86,780
NPV, 7%	$12,239	$11,120	$17,789	$41,148

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-18 Discounted MY Lifetime New Technology Costs of the Final Program Vs. the Flat Baseline and using Method B (3% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$124	$0	$81	$205
2019	$110	$0	$78	$188
2020	$110	$0	$77	$187
2021	$512	$465	$897	$1,873
2022	$487	$443	$867	$1,797
2023	$735	$408	$790	$1,933
2024	$861	$789	$1,288	$2,938
2025	$1,031	$767	$1,242	$3,040
2026	$1,064	$733	$1,195	$2,992
2027	$1,133	$995	$1,479	$3,607
2028	$1,092	$963	$1,418	$3,473
2029	$1,060	$938	$1,386	$3,384
Sum	$8,316	$6,500	$10,800	$25,617

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-19 Discounted MY Lifetime New Technology Costs of the Final Program Vs. the Flat Baseline and using Method B (7% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$108	$0	$71	$179
2019	$93	$0	$66	$159
2020	$89	$0	$63	$152
2021	$400	$363	$700	$1,462
2022	$366	$333	$652	$1,350
2023	$531	$295	$572	$1,398
2024	$599	$549	$897	$2,046
2025	$691	$514	$833	$2,038
2026	$686	$473	$771	$1,930
2027	$704	$618	$919	$2,240
2028	$653	$576	$848	$2,076
2029	$610	$540	$798	$1,948
Sum	$5,530	$4,260	$7,188	$16,978

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

7.2.1.2 Compliance Costs

As noted above, some fixed costs were estimated separately from the hardware costs. As such, not all fixed costs are included in the tables presented in Chapter 7.2.1.1. The agencies have estimated additional and/or new compliance costs associated with the standards. Normally, compliance program costs would be considered part of the indirect costs and, therefore, would be accounted for via the markup applied to direct manufacturing costs. However, since the agencies are requiring new compliance elements that were not present during development of the indirect cost markups used in this analysis, additional compliance program costs are being accounted for via a separate "line-item" here. Note that, for HD pickups and vans, compliance elements were present during development of the indirect cost markups used; as such, these costs are already included as part of the technology costs described above.

There are three elements to the compliance costs estimated in this analysis. The first is for construction of new, or upgrades to existing, test facilities for conducting powertrain testing. The second costs are for conducting the powertrain tests themselves. And the third is for reporting of compliance data to EPA and NHTSA. We estimated these latter costs in the Phase 1 rule as $0.24 million, $0.9 million and $1.1 million for HD pickups and vans, vocational and tractors, respectively, for a total of $2.3 million per year (2009$).[4] All of these are industry-wide, annual costs.

We have estimated reporting costs in this Phase 2 final rule associated with new powertrain testing within the vocational vehicle program, the increased level of reporting in the tractor program and an all new compliance program where none has existed to date within the trailer program. We have estimated those costs, inclusive of the Phase 1 costs, such that the new GHG program reporting costs are estimated at $1.1 million and $1.2 million for vocational and tractor programs both in 2013$. All of these are industry-wide, annual costs.

For powertrain testing facility upgrades and construction, we have estimated that 6 manufacturers would upgrade and 5 would construct new facilities at an upgrade cost of $1.2 million and a new construction cost of $1.9 million, all in 2013$. The result being an industry-wide (but vocational program only) cost of $16.8 million (2013$). This cost would occur once which we have attributed to CY2020, one year prior to the first year of the Phase 2 vocational standards.

Lastly, the vocational program is also estimated to incur costs associated with conducting powertrain testing. We have estimated the cost of testing at $40,000 per test (2013$) and expect 10 tests/year for a total of $400,000/year. We have also estimated that the vocational program will incur costs associated with conducting transmission efficiency testing at a cost of $24,600 per test (2013$). We have estimated 11 tests per year for a total annual cost of $270,600. We have also estimated that the vocational program will incur costs associated with conducting axle efficiency testing at a cost of $12,600 per test (2013$). We have estimated that 9 tests would be done per year for a total annual cost of $113,400. We have also estimated an annual cost of $8,700 in tire testing will be incurring by the vocational program.

In the tractor program, we have used the same per test costs noted above for vocational and have estimated one transmission efficiency test per year for a total annual cost of $24,600

(2013$) and 15 axle efficiency tests per year for a total annual cost of $189,000 (2013$). To those costs, we have also added $300,000 (2013$) per year in aero-related testing and $5,400 (2013$) per year in tire testing.

For the trailer program, we have estimated an annual compliance program cost of $7 million (2013$) to cover reporting, testing and capital costs.

Table 7-20 through Table 7-22 present the annual costs for new compliance program elements along with net present values at 3 percent and 7 percent, and the model year lifetime compliance costs discounted at 3 percent and 7 percent, respectively.

Table 7-20 Annual Compliance Costs and Net Present Values Associated with the Final Program Vs. The Flat Baseline and using Method B ($Millions of 2013$) [a]

CALENDAR YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$0	$0
2019	$0	$0	$0	$0
2020	$0	$17	$0	$17
2021	$0	$1.9	$8.7	$11
2022	$0	$1.9	$8.7	$11
2023	$0	$1.9	$8.7	$11
2024	$0	$1.9	$8.7	$11
2025	$0	$1.9	$8.7	$11
2026	$0	$1.9	$8.7	$11
2027	$0	$1.9	$8.7	$11
2028	$0	$1.9	$8.7	$11
2029	$0	$1.9	$8.7	$11
2030	$0	$1.9	$8.7	$11
2035	$0	$1.9	$8.7	$11
2040	$0	$1.9	$8.7	$11
2050	$0	$1.9	$8.7	$11
NPV, 3%	$0	$45	$145	$191
NPV, 7%	$0	$27	$75	$102

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-21 Discounted MY Lifetime Compliance Costs of the Final Program Vs. The Flat Baseline and using Method B (3% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$0	$0
2019	$0	$0	$0	$0
2020	$0	$14	$0	$14
2021	$0	$1.5	$7.2	$8.7
2022	$0	$1.5	$7.0	$8.5
2023	$0	$1.4	$6.8	$8.2
2024	$0	$1.4	$6.6	$8.0
2025	$0	$1.4	$6.4	$7.8
2026	$0	$1.3	$6.2	$7.5
2027	$0	$1.3	$6.0	$7.3
2028	$0	$1.2	$5.9	$7.1
2029	$0	$1.2	$5.7	$6.9
Sum	$0	$27	$58	$84

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-22 Discounted MY Lifetime Compliance Costs of the Final Program Vs. The Flat Baseline and using Method B (7% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$0	$0
2019	$0	$0	$0	$0
2020	$0	$12	$0	$12
2021	$0	$1.2	$5.6	$6.8
2022	$0	$1.1	$5.3	$6.4
2023	$0	$1.0	$4.9	$6.0
2024	$0	$1.0	$4.6	$5.6
2025	$0	$0.9	$4.3	$5.2
2026	$0	$0.9	$4.0	$4.9
2027	$0	$0.8	$3.7	$4.5
2028	$0	$0.7	$3.5	$4.2
2029	$0	$0.7	$3.3	$4.0
Sum	$0	$20	$39	$59

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

7.2.1.3 Research & Development Costs

Much like the compliance program costs described above, EPA has estimated additional engine, vocational vehicle and tractor R&D associated with the standards that is not accounted for via the indirect cost markups used in this analysis for those segments. The necessary R&D for HD pickups and vans is covered by the indirect costs included as part of the technology costs described above. In the Phase 1 rule, the agencies estimated the engine R&D costs at $6.8 million (2009$) per engine class per manufacturer per year for five years. In this Phase 2 analysis, EPA has estimated this same level of R&D and has assumed 12 heavy-heavy and 12 medium-heavy HD engine R&D programs would be conducted for a total of $218 million/year (2013$). In this analysis, EPA has assumed those costs would occur annually for 4 years, MYs 2021-2024. The total being $873 million (2013$) over 4 years (by comparison, the Phase 1 rule estimated a total of $852 million (2009$) over 5 years). To this, EPA has estimated an additional $20 million/year spent by vocational vehicle manufacturers and $20 million/year spent by tractor manufacturers. In the end, EPA is estimating a total of over $1 billion in R&D spending above and beyond the level included in the markups used to estimate indirect costs for these segments. EPA has not included any *additional* R&D would be spent by trailer manufacturers since our trailer technology cost estimates include R&D conducted by trailer parts suppliers which are subsequently included in the prices charged by those suppliers to the trailer manufacturer. Additionally, the markups we have applied to cover indirect costs (see Chapter 2.12 of this RIA) include costs associated with R&D incurred by the trailer manufacturer.

Table 7-23 through Table 7-25 present the annual costs for R&D spending along with net present values at 3 percent and 7 percent, and the model year lifetime R&D costs discounted at 3 percent and 7 percent, respectively.

Table 7-23 Additional Annual R&D Costs, Not Covered by Indirect Cost Markups), and Net Present Values Associated with the Final Program Vs. The Flat Baseline and using Method B ($Millions of 2013$) [a]

CALENDAR YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$0	$0
2019	$0	$0	$0	$0
2020	$0	$0	$0	$0
2021	$0	$129	$129	$259
2022	$0	$129	$129	$259
2023	$0	$129	$129	$259
2024	$0	$129	$129	$259
2025	$0	$0	$0	$0
2026	$0	$0	$0	$0
2027	$0	$0	$0	$0
2028	$0	$0	$0	$0
2029	$0	$0	$0	$0
2030	$0	$0	$0	$0
2035	$0	$0	$0	$0
2040	$0	$0	$0	$0
2050	$0	$0	$0	$0
NPV, 3%	$0	$409	$409	$818
NPV, 7%	$0	$302	$302	$604

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-24 Discounted MY Lifetime R&D Costs, Not Covered by Indirect Cost Markups), of the Final Program Vs. The Flat Baseline and using Method B (3% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$0	$0
2019	$0	$0	$0	$0
2020	$0	$0	$0	$0
2021	$0	$107	$107	$214
2022	$0	$104	$104	$207
2023	$0	$101	$101	$201
2024	$0	$98	$98	$195
2025	$0	$0	$0	$0
2026	$0	$0	$0	$0
2027	$0	$0	$0	$0
2028	$0	$0	$0	$0
2029	$0	$0	$0	$0
Sum	$0	$409	$409	$818

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-25 Discounted MY Lifetime R&D Costs, Not Covered by Indirect Cost Markups), of the Final Program Vs. The Flat Baseline and using Method B (7% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$0	$0
2019	$0	$0	$0	$0
2020	$0	$0	$0	$0
2021	$0	$83	$83	$167
2022	$0	$78	$78	$156
2023	$0	$73	$73	$146
2024	$0	$68	$68	$136
2025	$0	$0	$0	$0
2026	$0	$0	$0	$0
2027	$0	$0	$0	$0
2028	$0	$0	$0	$0
2029	$0	$0	$0	$0
Sum	$0	$302	$302	$604

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

7.2.1.4 Summary of Vehicle-Related Costs of the Program using Method B

Table 7-26 presents the annual new vehicle costs (including engine-related costs) associated with the final program for HD pickups and vans, vocational vehicles, and tractor and trailer programs along with net present values at 3 percent and 7 percent. This table presents costs relative to the flat baseline and using the MOVES analysis of all vehicle categories (Method B). Table 7-27 presents the model year lifetime costs associated with the final program discounted at 3 percent relative to the flat baseline and using Method B. Table 7-28 presents the model year lifetime costs associated with the final program discounted at 7 percent relative to the flat baseline and using Method B.

Table 7-26 Annual Vehicle-Related Costs and Net Present Values Associated with the Final Program Vs. The Flat Baseline and using Method B ($Millions of 2013$) [a]

CALENDAR YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$137	$0	$90	$227
2019	$126	$0	$89	$215
2020	$129	$17	$91	$237
2021	$621	$694	$1,225	$2,540
2022	$607	$685	$1,220	$2,512
2023	$944	$656	$1,154	$2,755
2024	$1,140	$1,176	$1,844	$4,160
2025	$1,406	$1,048	$1,703	$4,157
2026	$1,494	$1,032	$1,687	$4,213
2027	$1,639	$1,441	$2,149	$5,230
2028	$1,628	$1,437	$2,122	$5,186
2029	$1,627	$1,442	$2,137	$5,206
2030	$1,610	$1,451	$2,168	$5,229
2035	$1,625	$1,587	$2,441	$5,653
2040	$1,671	$1,778	$2,807	$6,255
2050	$1,755	$2,147	$3,378	$7,280
NPV, 3%	$25,007	$24,386	$38,395	$87,788
NPV, 7%	$12,239	$11,449	$18,166	$41,854

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-27 Discounted MY Lifetime Vehicle-Related Costs of the Final Program Vs. The Flat Baseline and using Method B (3% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$124	$0	$81	$205
2019	$110	$0	$78	$188
2020	$110	$14	$77	$201
2021	$512	$573	$1,011	$2,096
2022	$487	$549	$978	$2,013
2023	$735	$510	$898	$2,143
2024	$861	$888	$1,393	$3,141
2025	$1,031	$768	$1,249	$3,048
2026	$1,064	$734	$1,201	$2,999
2027	$1,133	$996	$1,485	$3,614
2028	$1,092	$964	$1,424	$3,480
2029	$1,060	$939	$1,392	$3,391
Sum	$8,316	$6,935	$11,267	$26,519

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-28 Discounted MY Lifetime Vehicle-Related Costs of the Final Program Vs. The Flat Baseline and using Method B (7% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$108	$0	$71	$179
2019	$93	$0	$66	$159
2020	$89	$12	$63	$163
2021	$400	$447	$789	$1,636
2022	$366	$412	$735	$1,513
2023	$531	$369	$649	$1,550
2024	$599	$618	$970	$2,187
2025	$691	$515	$837	$2,043
2026	$686	$474	$775	$1,935
2027	$704	$619	$923	$2,245
2028	$653	$576	$851	$2,080
2029	$610	$541	$801	$1,952
Sum	$5,530	$4,583	$7,530	$17,642

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

7.2.2 Changes in Fuel Consumption and Savings

7.2.2.1 Changes in Fuel Consumption

The standards will result in significant improvements in the fuel efficiency of affected vehicles. Drivers of those vehicles will see corresponding savings associated with reduced fuel expenditures. The agencies have estimated the impacts on fuel consumption for the standards. More detail behind these changes in fuel consumption is presented in Chapter 5 of this RIA. The expected impacts on fuel consumption are shown in Table 7-29 as reductions from the flat baseline reference case (i.e., positive values represent fewer gallons consumed) and using the MOVES analysis of all vehicle categories (Method B). The gallons shown in this table include any increased consumption resulting from the rebound effect.

Table 7-29 Annual Fuel Consumption Reductions due to the Final Program Vs. The Flat Baseline and using Method B (Million Gallons) [a]

	GASOLINE REDUCTIONS				DIESEL REDUCTIONS			
CALENDAR YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	0	0	0	0	0	0	37	37
2019	0	0	0	0	0	0	76	76
2020	0	0	0	0	0	0	117	117
2021	11	17	0	28	8	57	363	428
2022	41	33	0	74	29	113	670	812
2023	89	50	0	138	62	169	980	1,211
2024	153	73	0	226	107	258	1,470	1,835
2025	235	95	0	330	164	344	1,949	2,457
2026	331	116	0	448	232	426	2,405	3,063
2027	442	146	0	588	310	536	3,007	3,853
2028	549	174	0	723	385	641	3,584	4,610
2029	651	201	0	852	457	742	4,136	5,335
2030	748	226	0	974	525	839	4,667	6,031
2035	1,131	323	0	1,454	792	1,223	6,867	8,883
2040	1,346	377	0	1,724	940	1,464	8,374	10,778
2050	1,476	428	0	1,904	1,059	1,729	10,198	12,986

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-30 MY Lifetime Fuel Consumption Reductions due to the Final Program Vs. The Flat Baseline and using Method B (Million Gallons) [a]

	GASOLINE REDUCTIONS				DIESEL REDUCTIONS			
MODEL YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	0	0	0	0	0	0	302	302
2019	0	0	0	0	0	0	293	293
2020	0	0	0	0	0	0	286	286
2021	136	186	0	322	91	701	3,852	4,643
2022	365	185	0	550	243	697	3,867	4,807
2023	588	184	0	772	391	693	3,862	4,947
2024	813	263	0	1,075	542	1,097	6,104	7,742
2025	1,036	265	0	1,301	691	1,108	6,154	7,954
2026	1,258	267	0	1,525	838	1,114	6,159	8,111
2027	1,467	368	0	1,836	980	1,481	8,184	10,646
2028	1,469	371	0	1,840	984	1,492	8,222	10,698
2029	1,468	374	0	1,841	987	1,504	8,309	10,800
Sum	8,598	2,464	0	11,062	5,748	9,887	55,593	71,229

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.2.2.2 Changes in Fuel Expenditures

Using the fuel consumption reductions presented above, the agencies have calculated the fuel expenditure changes associated with the standards, subcategory by subcategory. To do this, reduced fuel consumption is multiplied in each year by the corresponding estimated average fuel price in that year, using the reference case fuel prices from AEO 2015. As the AEO fuel price projections go through 2040 and not beyond, fuel prices beyond 2040 were set equal to the 2040 values. These estimates do not account for the significant uncertainty in future fuel prices; the monetized fuel savings would be understated if actual fuel prices are higher (or overstated if fuel prices are lower) than estimated. The Annual Energy Outlook (AEO) is a standard reference used by NHTSA and EPA and many other government agencies to estimate the projected price of fuel. This has been done using both the pre-tax and post-tax fuel prices. Since the post-tax fuel prices are the prices paid at fuel pumps, the fuel expenditure changes calculated using these prices represent the changes fuel purchasers would see. The pre-tax fuel savings are those that society would see. Assuming no change in fuel tax rates, the difference between these two columns represents the reduction in fuel tax revenues that would be received by state and federal governments, or about $200 million in 2021 and $5.8 billion by 2050 as shown in Table 7-31. Table 7-32 presents the model year lifetime fuel savings—versus the flat baseline and using Method B—discounted at 3 percent. Table 7-33 presents the model year lifetime costs fuel savings—versus the flat baseline and using Method B—discounted at 7 percent. Note that in

Chapters 8 and 11 of this RIA, the overall benefits and costs of the rulemaking are presented and only the pre-tax fuel expenditure impacts are presented there.

Table 7-31 Annual Reductions in Fuel Expenditures and Net Present Values due to the Final Program Vs. The Flat Baseline and using Method B (Millions of 2013$) [a]

	REDUCED FUEL EXPENDITURES – RETAIL				REDUCED FUEL EXPENDITURES – UNTAXED			
CALENDAR YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$114	$114	$0	$0	$97	$97
2019	$0	$0	$237	$237	$0	$0	$202	$202
2020	$0	$0	$371	$371	$0	$0	$319	$319
2021	$56	$232	$1,174	$1,462	$48	$199	$1,010	$1,258
2022	$210	$470	$2,219	$2,899	$181	$406	$1,917	$2,504
2023	$461	$713	$3,302	$4,476	$399	$619	$2,871	$3,889
2024	$812	$1,097	$5,043	$6,952	$707	$956	$4,396	$6,059
2025	$1,265	$1,482	$6,803	$9,550	$1,104	$1,295	$5,945	$8,343
2026	$1,819	$1,866	$8,561	$12,246	$1,593	$1,639	$7,527	$10,759
2027	$2,468	$2,388	$10,915	$15,772	$2,167	$2,102	$9,622	$13,892
2028	$3,121	$2,910	$13,259	$19,290	$2,747	$2,568	$11,718	$17,033
2029	$3,768	$3,429	$15,591	$22,789	$3,329	$3,041	$13,854	$20,224
2030	$4,410	$3,944	$17,921	$26,276	$3,905	$3,506	$15,961	$23,373
2035	$7,367	$6,350	$29,254	$42,971	$6,632	$5,741	$26,507	$38,880
2040	$9,717	$8,423	$39,777	$57,916	$8,865	$7,716	$36,511	$53,093
2050	$10,787	$9,881	$48,442	$69,109	$9,843	$9,052	$44,464	$63,359
NPV, 3%	$94,080	$84,437	$398,245	$576,763	$85,014	$76,542	$361,745	$523,301
NPV, 7%	$38,342	$34,811	$163,449	$236,602	$34,530	$31,433	$147,870	$213,833

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-32 Discounted MY Lifetime Reductions in Fuel Expenditures of the Final Program Vs. The Flat Baseline and using Method B (3% Discount Rate, Millions of 2013$) [a]

	REDUCED FUEL EXPENDITURES – RETAIL				REDUCED FUEL EXPENDITURES – UNTAXED			
MODEL YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$781	$781	$0	$0	$680	$680
2019	$0	$0	$747	$747	$0	$0	$653	$653
2020	$0	$0	$719	$719	$0	$0	$631	$631
2021	$507	$2,127	$9,538	$12,171	$446	$1,875	$8,425	$10,746
2022	$1,346	$2,090	$9,477	$12,912	$1,187	$1,849	$8,399	$11,435
2023	$2,142	$2,055	$9,360	$13,557	$1,895	$1,824	$8,322	$12,041
2024	$2,927	$3,155	$14,627	$20,709	$2,597	$2,809	$13,045	$18,451
2025	$3,686	$3,152	$14,582	$21,420	$3,280	$2,814	$13,044	$19,137
2026	$4,418	$3,131	$14,427	$21,976	$3,941	$2,803	$12,943	$19,688
2027	$5,096	$4,141	$18,943	$28,180	$4,557	$3,717	$17,041	$25,315
2028	$5,043	$4,118	$18,791	$27,953	$4,521	$3,707	$16,949	$25,176
2029	$4,981	$4,098	$18,749	$27,828	$4,477	$3,697	$16,954	$25,128
Sum	$30,147	$28,066	$130,741	$188,954	$26,900	$25,094	$117,087	$169,081

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-33 Discounted MY Lifetime Reductions in Fuel Expenditures of the Final Program Vs. The Flat Baseline and using Method B (7% Discount Rate, Millions of 2013$) [a]

	REDUCED FUEL EXPENDITURES – RETAIL				REDUCED FUEL EXPENDITURES – UNTAXED			
MODEL YEAR	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM	HD PICKUPS & VANS	VOC	TRACTOR/ TRAILERS	SUM
2018	$0	$0	$558	$558	$0	$0	$483	$483
2019	$0	$0	$510	$510	$0	$0	$444	$444
2020	$0	$0	$466	$466	$0	$0	$408	$408
2021	$312	$1,308	$5,831	$7,451	$274	$1,149	$5,132	$6,554
2022	$798	$1,238	$5,584	$7,620	$701	$1,091	$4,932	$6,725
2023	$1,222	$1,173	$5,315	$7,710	$1,078	$1,037	$4,711	$6,826
2024	$1,608	$1,735	$8,004	$11,347	$1,423	$1,539	$7,116	$10,078
2025	$1,951	$1,669	$7,689	$11,309	$1,731	$1,486	$6,858	$10,074
2026	$2,253	$1,598	$7,332	$11,182	$2,005	$1,427	$6,560	$9,991
2027	$2,504	$2,038	$9,276	$13,818	$2,234	$1,824	$8,323	$12,381
2028	$2,388	$1,952	$8,866	$13,206	$2,136	$1,753	$7,978	$11,866
2029	$2,274	$1,872	$8,526	$12,672	$2,039	$1,686	$7,693	$11,419
Sum	$15,311	$14,582	$67,957	$97,849	$13,621	$12,992	$60,636	$87,249

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

7.2.3 Maintenance Costs

The agencies have estimated increased maintenance costs associated with installation of new technologies. The technologies for which we have estimated increased costs are shown in Table 7-34 along with the estimated maintenance intervals and costs per event. We expect that, when replaced, the lower rolling resistance tires would be replaced by equivalent performing tires throughout the vehicle lifetime. As such, the incremental increases in costs for lower rolling resistance tires would be incurred throughout the vehicle lifetime at intervals consistent with current tire replacement intervals. Those intervals are difficult to quantify given the variety of vehicles and operating modes within the HD industry. For HD pickups and vans, we have chosen a tire replacement interval of 40,000 miles. We have done the same for all vocational vehicles which is probably overly conservative as more frequent intervals results in higher maintenance costs. For tractors and trailers, we have used a maintenance interval of 200,000 miles. The presence of tire inflation management systems, and the increased use of those systems expected due to this final rule, should serve to improve tire maintenance intervals and perhaps reduce vehicle downtime due to tire issues; they may also carry with them some increased maintenance costs to ensure that the tire inflation systems themselves remain in proper operation. For the analysis, we have considered these two competing factors to cancel each other out. Similarly, the agencies considered the maintenance impact of 6x2 axles. As noted in the NACFE Confidence Report on 6x2 axles, the industry expects an overall reduction in maintenance costs and labor for vehicles with a 6x2 configuration as compared to a 6x4 configuration.[5] The reduction in number of parts, such as the interaxle drive shaft, will reduce the number of lubrication procedures needed and reduce the overall quantity of differential fluid needed at change intervals. The agencies have taken a conservative approach to the maintenance costs for the 6x2 technology and considered the incremental maintenance cost to be zero. The other technologies shown carry with them the indicated costs per maintenance event conducted at the indicated interval. These costs will be incurred according to the technology penetration rates estimated and presented in Chapter 2 of this RIA. In other words, not all vehicles will incur these costs, only those vehicles with the technologies will incur these costs.

Table 7-34 Maintenance Costs and Miles per Event (2013$)

SEGMENT	TECHNOLOGY/SYSTEM	COST/EVENT	MILES/EVENT
Engines	Waste Heat Recovery	$300	100,000
2b/3 Pickups & Vans	Lower rolling resistance tires level 2	Dependent on package costs of the technology	40,000
Vocational vehicles	Lower rolling resistance tires	Dependent on package costs of the LRR technology	40,000
	Stop-start & automatic engine shutdown system	$10 savings on oil changes	10,000
	Axle lubrication, tied to high efficiency axles	$100	100,000
	Transmission fluids, tied to automated transmissions	$100	100,000
	Hybrid systems	$3500	250,000
Tractors	Lower rolling resistance tires	Dependent on package costs of the LRR technology	200,000
	Auxiliary Power Unit	$300	100,000
	Auxiliary Power Unit with DPF	$400	100,000
	Auxiliary Power Unit, battery powered	$310	100,000
	Axle lubrication, tied to high efficiency axles	$100	500,000
	Transmission fluids, tied to powershift automatic transmissions	$100	100,000
	Fuel Operated Heaters	$110	100,000
Trailers	Lower rolling resistance tires	Dependent on package costs of the LRR technology	200,000

In evaluating maintenance costs associated with the rule relative to the flat baseline, EPA has used the maintenance intervals noted above, MOVES VMT, and the MOVES population of specific MY vehicles in future calendar years to estimate the increased maintenance costs associated with the final rule, again for each subcategory. Note that, in the context of the benefit-cost analysis, EPA has estimated policy case maintenance costs using the policy case VMT which, by definition, includes rebound VMT (see Section IX of the Preamble and Chapter 8 of this RIA for a discussion of rebound VMT).

Table 7-35 presents the annual in-use maintenance costs associated with the final program along with net present values at 3 percent and 7 percent. This table presents costs relative to the flat baseline and using the MOVES analysis for all vehicle categories (Method B). Table 7-36 presents the model year lifetime in-use maintenance costs—versus the flat baseline and using Method B— discounted at 3 percent. Table 7-37 presents the model year lifetime in-use maintenance costs—versus the flat baseline and using Method B—discounted at 7 percent.

Table 7-35 Annual Increased Maintenance Costs and Net Present Values Associated with the Final Program Vs. The Flat Baseline and using Method B ($Millions of 2013$) [a]

CALENDAR YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$0.5	$0.5
2019	$0.0	$0.0	$1.1	$1.1
2020	$0.0	$0.0	$1.6	$1.6
2021	$0.9	$0.2	$17	$18
2022	$2.6	$0.3	$32	$35
2023	$5.2	$0.8	$47	$53
2024	$8.6	$7.6	$60	$76
2025	$13	$14	$72	$99
2026	$17	$20	$83	$119
2027	$21	$24	$106	$151
2028	$25	$28	$129	$182
2029	$28	$32	$151	$211
2030	$28	$32	$151	$211
2035	$28	$32	$151	$211
2040	$28	$32	$151	$211
2050	$28	$32	$151	$211
NPV, 3%	$367	$408	$2,014	$2,788
NPV, 7%	$167	$184	$933	$1,284

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-36 Discounted MY Lifetime Maintenance Costs of the Final Program Vs. The Flat Baseline and using Method B (3% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$6.6	$6.6
2019	$0.0	$0.0	$6.4	$6.4
2020	$0.0	$0.0	$6.4	$6.4
2021	$7.1	$1.8	$129	$138
2022	$14	$1.2	$124	$139
2023	$20	$4.2	$120	$144
2024	$26	$50	$96	$172
2025	$32	$48	$94	$174
2026	$31	$39	$92	$162
2027	$31	$31	$184	$245
2028	$30	$28	$179	$237
2029	$29	$27	$174	$230
Sum	$220	$229	$1,211	$1,660

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-37 Discounted MY Lifetime Maintenance Costs of the Final Program Vs. The Flat Baseline and using Method B (7% Discount Rate, $Millions of 2013$) [a]

MODEL YEAR	HD PICKUPS & VANS	VOCATIONAL	TRACTOR/ TRAILERS	SUM
2018	$0.0	$0.0	$4.5	$4.5
2019	$0.0	$0.0	$4.3	$4.3
2020	$0.0	$0.0	$4.1	$4.1
2021	$4.5	$1.1	$80	$86
2022	$8.3	$0.7	$75	$84
2023	$12	$2.4	$69	$83
2024	$15	$28	$54	$96
2025	$17	$26	$50	$94
2026	$16	$20	$48	$84
2027	$15	$15	$92	$122
2028	$14	$14	$86	$114
2029	$13	$13	$80	$106
Sum	$115	$120	$647	$882

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

7.2.4 Analysis of Payback Periods

An important metric to vehicle purchasers is the payback period that can be expected on any new purchase. In other words, there is greater willingness to pay for new technology if that new technology "pays back" within an acceptable period of time. We make no effort to define the acceptable period of time here, but seek to estimate the payback period for others to make the decision themselves. We define the payback period as the point at which reduced fuel expenditures outpace increased vehicle costs. For example, a new MY2027 tractor with trailer is estimated to cost roughly $13,550 more (on average, including an "average" trailer, in 2013$, and relative to the reference case vehicle) due to the addition of new GHG reducing/fuel consumption improving technology. This new technology would result in lower fuel consumption and, therefore, reduced fuel expenditures. But how many months or years would pass before the reduced fuel expenditures would surpass the increased costs?

To estimate the costs, we have considered not only the cost of the new technology, but also the taxes paid on the incrementally higher purchase expense, the slightly higher insurance expenses on the slightly higher value vehicle, and the increased maintenance costs associated with the new technology. Taxes paid were estimated as 6 percent sales tax in all regulated sectors and a 12 percent excise tax applicable in the tractor/trailer and vocational sectors. As such, the vehicle costs presented here are slightly higher than those presented elsewhere in this RIA. For insurance costs, we have estimated the collision insurance to be 2 percent of the purchase price of a vehicle consistent with the approach taken in our 2017-2025 light-duty GHG/CAFE rule.[6] Therefore, increased insurance costs would equal 2 percent of the increased technology costs, and would be incurred every year going forward. But, since collision insurance is tied to vehicle value, we have also included a depreciation rate consisting of straight-line depreciation of 3 percent each year through the 25th year of ownership at which time we have flat-lined the depreciation and held vehicle value constant (see Table 7-58 in Chapter 7.2.6, below). For maintenance costs, we have used the same method described above. Also, here we use retail fuel prices since those are the prices paid by owners of these vehicles.

We have conducted this payback analysis for HD pickups and vans, vocational vehicles and for tractor/trailers (including the engines used in each of these subcategories). All calculations are for the average vehicle, or average tractor/trailer combination, that drives the average number of miles each year. The calculations do not represent specific vehicle classes or specific use cases so should not be seen as being applicable to any particular individual's situation. However, the payback periods do provide a general sense, on average, of what sort of payback periods are likely at a national, societal perspective.

Table 7-38 presents the discounted annual increased vehicle costs and fuel expenditure impacts associated with owning a new MY2027 HD pickup or van using both 3 percent and 7 percent discount rates. The results in this table use Method B. As shown in the table, the payback for HD pickups and vans occurs in the 3rd year of ownership (the year in which cumulative expenditures become positive) using a 3 percent and 7 percent discount rate.

Table 7-38 Discounted Owner Expenditures & Payback Period for MY2027 HD Pickups & Vans under the Final Program Vs. The Flat Baseline and using Method B 3% and 7% Discount Rates (2013$) [a]

Age	3% Discount Rate				7% Discount Rate			
	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures
1	-$1,451	-$4	$550	-$905	-$1,424	-$4	$540	-$888
2	-$25	-$4	$539	-$395	-$24	-$3	$509	-$406
3	-$24	-$3	$527	$105	-$21	-$3	$479	$49
4	-$22	-$3	$515	$595	-$19	-$3	$451	$477
5	-$21	-$3	$492	$1,064	-$17	-$3	$415	$872
6	-$19	-$3	$469	$1,511	-$16	-$2	$381	$1,235
7	-$18	-$3	$446	$1,936	-$14	-$2	$348	$1,567
8	-$17	-$2	$423	$2,340	-$13	-$2	$318	$1,870

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2015 reference fuel price case.

Table 7-39 and Table 7-40 show the same information for a MY2027 vocational vehicle and a tractor/trailer, respectively. As shown, payback for vocational vehicles occurs in the 4th year of ownership while payback for tractor/trailers occurs early in the 2nd year of ownership.

Table 7-39 Discounted Owner Expenditures & Payback Period for MY2027 Vocational Vehicles under the Final Program Vs. The Flat Baseline and using Method B 3% and 7% Discount Rates (2013$) [a]

Age	3% Discount Rate				7% Discount Rate			
	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures
1	-$3,147	-$25	$1,022	-$2,151	-$3,088	-$25	$1,003	-$2,110
2	-$49	-$24	$1,004	-$1,220	-$46	-$23	$948	-$1,231
3	-$46	-$24	$987	-$303	-$42	-$21	$898	-$397
4	-$43	-$23	$970	$602	-$38	-$20	$849	$394
5	-$40	-$21	$909	$1,450	-$34	-$18	$766	$1,109
6	-$38	-$19	$850	$2,243	-$31	-$15	$689	$1,752
7	-$35	-$17	$796	$2,987	-$27	-$14	$622	$2,333
8	-$33	-$16	$743	$3,681	-$25	-$12	$558	$2,854

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax and 12% excise tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2015 reference fuel price case.

Table 7-40 Discounted Owner Expenditures & Payback Period for MY2027Tractor/Trailers under the Final Program Vs. The Flat Baseline and using Method B 3% and 7% Discount Rates (2013$) [a]

Age	3% Discount Rate				7% Discount Rate			
	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures
1	-$16,022	-$169	$15,310	-$880	-$15,719	-$166	$15,021	-$864
2	-$251	-$163	$15,095	$13,801	-$237	-$154	$14,256	$13,002
3	-$235	-$158	$14,872	$28,280	-$214	-$144	$13,521	$26,166
4	-$220	-$153	$14,637	$42,545	-$192	-$134	$12,809	$38,649
5	-$206	-$140	$13,683	$55,882	-$173	-$118	$11,527	$49,885
6	-$192	-$127	$12,730	$68,292	-$156	-$103	$10,323	$59,950
7	-$179	-$116	$11,880	$79,878	-$140	-$90	$9,274	$68,993
8	-$166	-$105	$11,025	$90,630	-$125	-$79	$8,285	$77,074

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax and 12% excise tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2015 reference fuel price case.

The fuel expenditure column uses retail fuel prices specific to gasoline and diesel fuel as projected in AEO2015. This payback analysis does not include other private impacts, such as reduced refueling events, or other societal impacts, such as noise, congestion and crashes. It also does not include societal impacts such as co-pollutant environmental benefits or benefits associated with reduced GHG emissions. We use retail fuel prices and exclude these other private and social impacts because the focus is meant to be on those factors that buyers think about most while considering a new vehicle purchase and those factors that result in more or fewer dollars in their pockets.

In an effort to provide further information on payback, we have also looked at the payback periods for more specific vehicle subcategories. For example, while the tractor/trailer payback shown in Table 7-40 occurs early in the 2nd year, the payback for a Class 8 sleeper cab would occur within the first year of ownership as shown in Table 7-41.

Table 7-41 Discounted Owner Expenditures & Payback Period for MY2027 Sleeper Cab with Trailer under the Final Program Vs. The Flat Baseline and using Method B 3% and 7% Discount Rates (2013$) [a]

Age	3% Discount Rate				7% Discount Rate			
	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures
1	-$17,523	-$538	$19,926	$1,866	-$17,192	-$528	$19,550	$1,830
2	-$274	-$521	$19,646	$20,717	-$259	-$492	$18,555	$19,635
3	-$257	-$503	$19,356	$39,314	-$234	-$458	$17,598	$36,542
4	-$241	-$486	$19,050	$57,637	-$211	-$426	$16,672	$52,577
5	-$225	-$447	$17,867	$74,832	-$189	-$376	$15,052	$67,064
6	-$210	-$409	$16,688	$90,901	-$170	-$332	$13,533	$80,094
7	-$196	-$375	$15,642	$105,972	-$153	-$293	$12,211	$91,860
8	-$182	-$343	$14,583	$120,030	-$137	-$258	$10,958	$102,423

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax and 12% excise tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2015 reference fuel price case.

Given the variety in the vocational market, the subcategory analysis becomes more interesting. For example, Table 7-42 shows the payback for an intercity bus. Table 7-43 shows the same information for a transit bus, while Table 7-44 shows this information for a school bus. These tables highlight how much the payback period can vary depending on the level of technology cost and fuel consumption improvement versus the number of miles driven. The high VMT intercity bus (~80,000 miles/year) and transit bus (~60,000 miles/year) payback in the 1st and 2nd year, respectively, despite first year costs exceeding $6, 000 and $5, 000, respectively. By contrast, the lower VMT school bus (~13,000 miles/year) pays back in the 7th year (or 8th year with 7 percent discounting) despite first year costs under $4, 000.

Table 7-42 Discounted Owner Expenditures & Payback Period for MY2027 Intercity Bus under the Final Program Vs. The Flat Baseline and using Method B 3% and 7% Discount Rates (2012$) [a]

Age	3% Discount Rate				7% Discount Rate			
	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures
1	-$5,848	-$427	$6,739	$465	-$5,738	-$419	$6,612	$456
2	-$91	-$412	$6,628	$6,589	-$86	-$389	$6,260	$6,240
3	-$86	-$398	$6,522	$12,627	-$78	-$362	$5,929	$11,730
4	-$80	-$384	$6,415	$18,578	-$70	-$336	$5,614	$16,937
5	-$75	-$370	$6,313	$24,445	-$63	-$312	$5,318	$21,880
6	-$70	-$356	$6,199	$30,218	-$57	-$289	$5,027	$26,562
7	-$65	-$344	$6,127	$35,936	-$51	-$269	$4,783	$31,025
8	-$61	-$333	$6,044	$41,586	-$46	-$250	$4,542	$35,271

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax and 12% excise tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2015 reference fuel price case.

Table 7-43 Discounted Owner Expenditures & Payback Period for MY2027 Diesel Fueled Transit Bus under the Final Program Vs. The Flat Baseline and using Method B 3% and 7% Discount Rates (2013$) [a]

Age	3% Discount Rate				7% Discount Rate			
	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures
1	-$4,908	-$79	$3,437	-$1,550	-$4,815	-$78	$3,372	-$1,521
2	-$77	-$74	$3,273	$1,571	-$73	-$70	$3,091	$1,427
3	-$72	-$69	$3,118	$4,549	-$65	-$63	$2,835	$4,134
4	-$67	-$65	$2,967	$7,384	-$59	-$57	$2,597	$6,615
5	-$63	-$60	$2,826	$10,087	-$53	-$51	$2,381	$8,892
6	-$59	-$56	$2,687	$12,659	-$48	-$46	$2,179	$10,978
7	-$55	-$53	$2,573	$15,125	-$43	-$41	$2,009	$12,903
8	-$51	-$49	$2,456	$17,481	-$38	-$37	$1,846	$14,674

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax and 12% excise tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2015 reference fuel price case.

Table 7-44 Discounted Owner Expenditures & Payback Period for MY2027 Diesel Fueled School Bus under the Final Program Vs. The Less Dynamic Baseline and using Method B 3% and 7% Discount Rates (2012$) [a]

Age	3% Discount Rate				7% Discount Rate			
	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures	Technology cost, taxes, insurance [b]	Maintenance expenditures	Fuel expenditures [c]	Cumulative expenditures
1	-$3,309	-$16	$573	-$2,752	-$3,247	-$15	$562	-$2,700
2	-$52	-$15	$563	-$2,255	-$49	-$14	$532	-$2,231
3	-$49	-$15	$554	-$1,764	-$44	-$13	$504	-$1,784
4	-$45	-$14	$545	-$1,278	-$40	-$12	$477	-$1,359
5	-$42	-$14	$537	-$798	-$36	-$11	$452	-$954
6	-$40	-$13	$527	-$323	-$32	-$11	$427	-$570
7	-$37	-$13	$521	$148	-$29	-$10	$407	-$202
8	-$34	-$12	$514	$615	-$26	-$9	$386	$149

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] 6% sales tax and 12% excise tax; insurance estimates are described in text.

[c] Fuel expenditures calculated using retail fuel prices according to AEO2014 early release, reference case estimates.

We could present tables for each MOVES subcategory, but since all are calculated using the same methodology, the detailed tables seem unnecessary. Instead, we provide Table 7-45 which summarizes the payback period for each MOVES subcategory at both 3 percent and 7 percent discount rates and for each fuel type.

Table 7-45 Payback Periods Associated with the Final Program Vs. The Flat Baseline and using Method B for MY2027 Vehicle Subcategories at 3% and 7% Discount Rates Payback occurs in Year Shown [a]

Subcategory	3% Discount Rate			7% Discount Rate		
	Gasoline	Diesel		Gasoline	Diesel	
HD Pickups & Vans (MY2027)	4	3		4	3	
Vocational (MY2027 for each)						
Intercity bus	N/A	1		N/A	1	
Transit bus	2	2		2	2	
School bus	8	7		9	8	
Refuse truck	N/A	2		N/A	2	
Single unit short haul	3	4		4	4	
Single unit long haul	N/A	3		N/A	3	
Motor home	27	29		>30	>30	
Tractor/Trailer (MY2027 for each)						
Combination short haul	N/A	2		N/A	2	
Combination long haul	N/A	1		N/A	1	

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1
N/A denotes no such vehicles in this segment.

7.2.5 Cost per Ton of CO_2 Equivalent Reduced vs. the Flat Baseline and using Method B

The agencies have calculated the cost per ton of GHG (CO_2-equivalent, or CO_2eq) reductions associated with this rulemaking using the costs presented in Chapter 7.2.1 and 7.2.2, and the GHG emissions reductions described in Chapter 5 of this RIA but expressed here as CO_2-equivalents (CO_2e). These costs per ton-reduction values are presented in Table 7-46 through Table 7-49 for HD pickups & vans, vocational vehicles, tractor/trailers and all segments, respectively. The cost per metric ton of CO_2e emissions reductions in 2050 represents the long-term cost per ton of the emissions reduced. The agencies have also calculated the cost per metric ton of CO_2e emission reductions including the savings associated with reduced fuel consumption.

The calculations presented here include all engine- and vehicle-related costs but do not include benefits associated with the final program such as those associated with criteria pollutant reductions or energy security benefits (discussed in Chapter 8 of this RIA). By including the fuel savings, the cost per ton-reduction is less than $0 since the estimated value of fuel savings outweighs the program costs.

Table 7-46 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the Final Program Vs. The Flat Baseline and using Method B HD Pickups and Vans only (dollar values are 2013$) [a]

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2021	$0.6	$0.0	0.2	$2,800	$2,500
2024	$1.1	$0.7	3.1	$370	$140
2027	$1.7	$2.2	8.9	$190	-$57
2030	$1.6	$3.9	15	$110	-$150
2035	$1.7	$6.6	23	$73	-$220
2040	$1.7	$8.9	27	$63	-$270
2050	$1.8	$9.8	30	$59	-$270

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1 GHG reductions include CO_2 and CO_2 equivalents of CH_4, and N_2O.

Table 7-47 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the Final Program Vs. The Flat Baseline and using Method B Vocational Vehicles only (dollar values are 2013$) [a]

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2021	$0.7	$0.2	1.0	$710	$510
2024	$1.2	$1.0	4.4	$270	$53
2027	$1.5	$2.1	9.0	$160	-$69
2030	$1.5	$3.5	14	$110	-$140
2035	$1.7	$5.7	20	$81	-$200
2040	$1.8	$7.7	24	$76	-$240
2050	$2.2	$9.1	29	$77	-$240

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1 GHG reductions include CO_2 and CO_2 equivalents of CH_4, N_2O and HFCs.

Table 7-48 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the Final Program Vs. The Flat Baseline and using Method B Tractor/Trailers only (dollar values are 2013$) [a]

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2021	$1.2	$1.0	5.0	$250	$46
2024	$1.9	$4.4	20	$94	-$120
2027	$2.3	$9.6	41	$54	-$180
2030	$2.3	$16	64	$36	-$210
2035	$2.6	$27	95	$27	-$250
2040	$3.0	$37	115	$26	-$290
2050	$3.5	$44	141	$25	-$290

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1 GHG reductions include CO_2 and CO_2 equivalents of CH_4, and N_2O.

Table 7-49 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the Final Program Vs. The Flat Baseline and using Method B All Vehicle Segments (dollar values are 2013$) [a]

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2021	$2.6	$1.3	6.2	$410	$210
2024	$4.2	$6.1	28	$150	-$65
2027	$5.4	$14	59	$91	-$140
2030	$5.5	$23	94	$59	-$190
2035	$5.9	$39	138	$43	-$240
2040	$6.5	$53	167	$39	-$280
2050	$7.5	$63	199	$38	-$280

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1 GHG reductions include CO_2 and CO_2 equivalents of CH_4, N_2O and HFCs.

For comparison, Table 7-50 through Table 7-53 show the same information as it was presented in Chapter 7 of the final RIA for the Phase 1 HD rule.[7]

Table 7-50 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the HD Phase 1 Final Rule HD Pickups and Vans only (dollar values are 2009$)

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2020	$0,8	$0.9	3	$240	-$30
2030	$0.9	$3.0	10	$90	-$200
2040	$1.0	$4.3	14	$70	-$240
2050	$1.2	$5.5	16	$80	-$270

Table 7-51 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the HD Phase 1 Final Rule Vocational Vehicles only (dollar values are 2009$)

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2020	$0.2	$1.1	4	$50	-$210
2030	$0.2	$2.4	9	$20	-$250
2040	$0.3	$3.5	12	$30	-$270
2050	$0.4	$4.7	14	$30	-$310

Table 7-52 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the HD Phase 1 Final Rule Tractor/Trailers only (dollar values are 2009$)

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2020	$1.0	$7.7	32	$30	-$210
2030	$1.1	$15.3	57	$20	-$250
2040	$1.4	$20.2	68	$20	-$280
2050	$1.8	$26.4	78	$20	-$320

Table 7-53 Annual Cost per Metric Ton of CO_2eq Emissions Reduced in the HD Phase 1 Final Rule All Vehicle Segments (dollar values are 2009$)

Calendar Year	Vehicle & Maintenance Costs ($Billions)	Fuel Savings ($Billions)	GHG Reduced (MMT)	$/metric ton w/o fuel	$/metric ton w/ fuel
2020	$2.0	$9.6	39	$50	-$190
2030	$2.2	$20.6	76	$30	-$240
2040	$2.7	$28.0	94	$30	-$270
2050	$3.3	$36.5	108	$30	-$310

7.2.6 Costs and Benefits for each Regulatory Subcategory using the Flat Baseline and Method B

The full presentation of program costs and benefits is in Chapter 8 of this RIA. Please see that chapter for details behind the social cost of carbon, non-GHG pollution benefits, energy security, and all of the other metrics that go into developing the full cost and benefit analysis. Here we present simply the high level cost, fuel savings, benefits and net benefits for each of the 3 regulatory subcategories: HD pickups and vans, vocational vehicles and tractor/trailers.

Table 7-54 Costs, Fuel Savings, Benefits & Net Benefits for each Regulatory Subcategory in the MY Lifetime Analysis (Billions of 2013$) [a,b,c]

		3% Discount Rate	7% Discount Rate
Costs (Technology & Maintenance)	HD Pickups & Vans	-$8.5	-$5.6
	Vocational Vehicles	-$7.4	-$4.8
	Tractor/Trailers	-$12.5	-$8.2
	Total	-$28.4	-$18.6
Fuel Savings	HD Pickups & Vans	$26.9	$13.6
	Vocational Vehicles	$25.1	$13.0
	Tractor/Trailers	$117.1	$60.6
	Total	$169.1	$87.2
Benefits	HD Pickups & Vans	$14.1	$9.8
	Vocational Vehicles	$12.3	$8.8
	Tractor/Trailers	$61.8	$43.6
	Total	$88.2	$62.3
Net Benefits	HD Pickups & Vans	$32.4	$17.8
	Vocational Vehicles	$30.0	$17.0
	Tractor/Trailers	$166.4	$96.1
	Total	$228.8	$130.9

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The monetized GHG benefits presented in this analysis exclude the value of changes in HFC emissions expected under this program (see RIA Chapter 8.5). Although EPA has not monetized changes in HFCs in the main benefits analysis, the value of any increases or reductions should not be interpreted as zero.

[c] GHG benefit estimates include reductions in CO_2, CH_4, and N_2O but do not include the HFC reductions. Note that net present value of reduced CO_2 GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CO_2 , SC-CH_4, and SC-N_2O, each discounted at rates of at 5, 3, 2.5 percent) is used to calculate net present value of SC-CO_2, SC-CH_4, and SC-N_2O, respectively, SC-CO_2 for internal consistency. Refer to the SC-CO_2 TSD for more detail.

7.3 Key Parameters Used in the Estimation of Costs and Fuel Savings

This section presents some of the parameters used in generating expenditure impacts associated with the program. Table 7-55 presents estimated sales of complying vehicles by calendar year. Table 7-56 presents $/gallon in the AEO 2015 reference fuel price case. Note that AEO projects fuel prices out to 2040. Table 7-57 presents AEO 2014 final reference case fuel prices which are used by both agencies in the CAFE Model for HD pickups and vans in the proposal, and used by EPA in this final rule. For that analysis, the retail (post-tax) prices are increased for each year after 2040 by 0.2 percent for gasoline and 0.7 percent for diesel. For years beyond 2040, EPA has kept fuel prices at the 2040 level rather than growing those fuel prices at a rate consistent with years prior to 2040. Table 7-58 shows the depreciation rates used in the payback period analysis presented in Chapter 7.2. Table 7-59 through Table 7-61 show the policy and reference case VMT values used in MOVES modeling.

Table 7-55 Estimated Calendar Year Sales by Vehicle Type using Method B [a, b]

Calendar Year	HD Pickup & Vans	Vocational Vehicles	Tractors	Semi-trailers
2018	1,206,112	471,994	134,141	158,286
2019	1,192,088	476,252	138,240	163,123
2020	1,195,369	485,983	144,154	170,102
2021	1,184,184	484,752	144,737	170,790
2022	1,176,320	486,068	145,814	172,061
2023	1,174,470	487,849	146,257	172,583
2024	1,182,761	498,683	150,729	177,860
2025	1,191,602	508,256	152,898	180,420
2026	1,200,976	515,592	154,105	181,844
2027	1,201,868	523,805	155,682	183,705
2028	1,201,965	531,284	157,395	185,726
2029	1,200,297	539,624	160,217	189,056
2030	1,196,706	549,322	164,275	193,845
2031	1,191,071	557,981	168,017	198,260
2032	1,189,075	567,362	171,578	202,462
2033	1,191,398	580,104	176,600	208,388
2034	1,199,387	595,739	182,637	215,512
2035	1,207,377	610,539	188,035	221,881
2036	1,216,582	626,546	194,248	229,213
2037	1,224,403	641,706	200,144	236,170
2038	1,231,432	656,449	205,795	242,838
2039	1,235,794	669,757	210,833	248,783
2040	1,241,415	683,894	216,332	255,272
2041	1,247,054	696,936	220,387	260,057
2042	1,252,832	710,223	224,518	264,931
2043	1,258,753	723,769	228,725	269,896
2044	1,264,820	737,569	233,014	274,957
2045	1,271,039	751,639	237,381	280,110
2046	1,277,407	765,973	241,831	285,361
2047	1,283,920	780,577	246,364	290,710
2048	1,290,589	795,451	250,981	296,158
2049	1,297,425	810,611	255,686	301,709
2050	1,304,420	826,068	260,480	307,366

Notes:

[a] Sales are estimated using population data contained in MOVES. See Chapter 5 of this RIA for a description of the MOVES modeling done in support of this rule.

[b] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-56 AEO 2015 Reference Fuel Price Case (2013$/gallon)

	Pre-Tax		Retail	
Calendar Year	Gasoline	Diesel	Gasoline	Diesel
2018	$2.30	$2.62	$2.70	$3.08
2019	$2.30	$2.66	$2.70	$3.12
2020	$2.35	$2.72	$2.74	$3.17
2021	$2.39	$2.78	$2.78	$3.23
2022	$2.43	$2.86	$2.82	$3.31
2023	$2.47	$2.93	$2.86	$3.37
2024	$2.52	$2.99	$2.90	$3.43
2025	$2.57	$3.05	$2.95	$3.49
2026	$2.62	$3.13	$3.00	$3.56
2027	$2.66	$3.20	$3.04	$3.63
2028	$2.71	$3.27	$3.09	$3.70
2029	$2.76	$3.35	$3.14	$3.77
2030	$2.82	$3.42	$3.20	$3.84
2031	$2.88	$3.50	$3.26	$3.92
2032	$2.95	$3.59	$3.33	$4.00
2033	$3.02	$3.68	$3.39	$4.09
2034	$3.09	$3.76	$3.46	$4.17
2035	$3.16	$3.86	$3.53	$4.26
2036	$3.23	$3.95	$3.60	$4.35
2037	$3.30	$4.05	$3.66	$4.45
2038	$3.38	$4.16	$3.74	$4.55
2039	$3.47	$4.26	$3.83	$4.65
2040	$3.54	$4.36	$3.90	$4.75
2041	$3.54	$4.36	$3.90	$4.75
2042	$3.54	$4.36	$3.90	$4.75
2043	$3.54	$4.36	$3.90	$4.75
2044	$3.54	$4.36	$3.90	$4.75
2045	$3.54	$4.36	$3.90	$4.75
2046	$3.54	$4.36	$3.90	$4.75
2047	$3.54	$4.36	$3.90	$4.75
2048	$3.54	$4.36	$3.90	$4.75
2049	$3.54	$4.36	$3.90	$4.75
2050	$3.54	$4.36	$3.90	$4.75

Table 7-57 AEO 2014 Final Reference Fuel Price Case Used in the CAFE Model for HD Pickups and Vans; Used by both Agencies in the Proposal & by EPA in this Final Rule (2012$/gallon)

	Pre-Tax		Post-Tax	
Calendar Year	Gasoline	Diesel	Gasoline	Diesel
2018	$2.63	$3.10	$3.02	$3.53
2019	$2.64	$3.19	$3.03	$3.61
2020	$2.69	$3.25	$3.08	$3.67
2021	$2.74	$3.32	$3.12	$3.74
2022	$2.79	$3.41	$3.17	$3.82
2023	$2.84	$3.46	$3.22	$3.87
2024	$2.88	$3.51	$3.26	$3.92
2025	$2.92	$3.58	$3.29	$3.98
2026	$2.95	$3.62	$3.32	$4.02
2027	$2.99	$3.68	$3.36	$4.08
2028	$3.00	$3.73	$3.37	$4.12
2029	$3.03	$3.77	$3.40	$4.16
2030	$3.07	$3.81	$3.43	$4.20
2031	$3.10	$3.87	$3.46	$4.25
2032	$3.14	$3.92	$3.50	$4.30
2033	$3.18	$3.98	$3.54	$4.36
2034	$3.27	$4.06	$3.62	$4.43
2035	$3.30	$4.10	$3.65	$4.47
2036	$3.34	$4.14	$3.69	$4.51
2037	$3.38	$4.18	$3.73	$4.54
2038	$3.43	$4.22	$3.77	$4.58
2039	$3.49	$4.29	$3.83	$4.65
2040	$3.56	$4.38	$3.90	$4.73
2041	$3.57	$4.41	$3.91	$4.76
2042	$3.58	$4.44	$3.92	$4.80
2043	$3.59	$4.48	$3.93	$4.83
2044	$3.59	$4.51	$3.93	$4.86
2045	$3.60	$4.54	$3.94	$4.90
2046	$3.61	$4.58	$3.95	$4.93
2047	$3.62	$4.61	$3.96	$4.97
2048	$3.63	$4.65	$3.97	$5.00
2049	$3.63	$4.68	$3.97	$5.04
2050	$3.64	$4.72	$3.98	$5.07

Table 7-58 Depreciation Schedule used in Payback Analysis for Method B [a]

Age	Depreciation
0	0%
1	3%
2	7%
3	10%
4	13%
5	17%
6	20%
7	23%
8	27%
9	30%
10	33%
11	37%
12	40%
13	43%
14	47%
15	50%
16	53%
17	57%
18	60%
19	63%
20	67%
21	70%
22	73%
23	77%
24	80%
25	83%
26	83%
27	83%
28	83%
29	83%
30	83%

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-59 Reference Case and Policy Case Vehicle Miles Traveled (VMT) For the Final Program relative to the Flat Baseline using Method B HD Pickups and Vans [a]

Model Year	Reference case	Policy Case	Rebound VMT
2018	243,446,459,798	243,446,459,798	0
2019	240,544,622,588	240,544,622,588	0
2020	241,190,926,860	241,190,926,860	0
2021	238,846,698,033	241,426,272,670	2,579,574,637
2022	237,380,423,724	239,944,040,068	2,563,616,344
2023	237,153,891,479	239,715,144,759	2,561,253,281
2024	239,066,747,610	241,648,660,086	2,581,912,475
2025	241,062,399,725	243,665,842,812	2,603,443,087
2026	243,119,992,516	245,745,591,658	2,625,599,142
2027	243,534,755,232	246,164,989,408	2,630,234,175
2028	243,820,406,557	246,453,561,767	2,633,155,210
2029	243,718,985,090	246,351,151,547	2,632,166,457

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-60 Reference Case and Policy Case Vehicle Miles Traveled (VMT) For the Final Program relative to the Flat Baseline using Method B Vocational Vehicles [a]

Model Year	Reference case	Policy Case	Rebound VMT
2018	109,299,356,451	109,299,356,451	0
2019	109,171,917,190	109,171,917,190	0
2020	110,312,045,137	110,312,045,137	0
2021	108,908,544,746	109,235,261,181	326,716,435
2022	108,219,636,901	108,544,256,343	324,619,441
2023	107,648,982,428	107,971,989,117	323,006,689
2024	109,094,964,009	109,422,205,744	327,241,735
2025	110,256,962,536	110,587,744,520	330,781,984
2026	110,830,009,427	111,162,555,501	332,546,074
2027	111,618,481,660	111,953,312,055	334,830,395
2028	112,430,556,692	112,767,875,523	337,318,830
2029	113,281,216,713	113,621,013,246	339,796,533

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 7-61 Reference Case and Policy Case Vehicle Miles Traveled (VMT) For the Final Program relative to the Flat Baseline using Method B Tractor/Trailer [a]

Model Year	Reference case	Policy Case	Rebound VMT
2018	196,687,058,720	197,818,200,910	1,131,142,190
2019	202,939,391,970	204,223,800,600	1,284,408,630
2020	211,438,197,150	212,899,481,640	1,461,284,490
2021	211,708,016,651	213,296,020,576	1,588,003,925
2022	212,548,914,706	214,143,012,332	1,594,097,627
2023	212,247,027,109	213,838,908,002	1,591,880,893
2024	217,583,929,523	219,215,829,412	1,631,899,889
2025	219,380,061,614	221,025,659,538	1,645,597,923
2026	219,528,087,171	221,174,595,841	1,646,508,670
2027	220,148,138,758	221,799,166,682	1,651,027,924
2028	221,151,741,304	222,810,299,501	1,658,558,197
2029	223,496,517,913	225,173,028,204	1,676,510,291

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

References

[1] Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rulemaking 75 Fed. Reg. 25323 (May 7, 2010).
[2] Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Regulatory Impact Analysis, EPA-420-R-11-901, August 2011.
[3] All of EPA's calculations of costs and benefits (monetized) along with paybacks can be found in the docket on a DVD titled, "GHGHD2_BCA."
[4] Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Regulatory Impact Analysis, EPA-420-R-11-901, August 2011.
[5] North American Council for Freight Efficiency. Confidence Findings on the Potential of 6x2 Axles. 2013. Pages 30-31.
[6] Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards, Regulatory Impact Analysis, EPA-420-R-12-016, August 2012.
[7] Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles, Regulatory Impact Analysis, EPA-420-R-11-901, August 2011.

Chapter 8. Economic and Other Impacts

8.1 Framework for Benefits and Costs

This chapter presents the costs, benefits and other economic impacts of the Phase 2 standards. It is important to note that NHTSA's fuel consumption standards and EPA's GHG standards will both be in effect, and each will lead to average fuel efficiency increases and GHG emission reductions.

The net benefits of the Phase 2 standards consist of the effects of the program on:

- vehicle program costs (costs of complying with the vehicle CO_2 and fuel consumption standards)
- changes in fuel expenditures associated with reduced fuel use resulting from more efficient vehicles and increased fuel use associated with the "rebound" effect, both of which result from the program
- economic value of reductions in GHGs
- economic value of reductions in other non-GHG pollutants
- costs associated with increases in noise, congestion, and crashes resulting from increased vehicle use
- savings in drivers' time from less frequent refueling
- benefits of increased vehicle use associated with the "rebound" effect
- economic value of improvements in U.S. energy security

The benefits and costs of these rules are analyzed using 3 percent and 7 percent discount rates, consistent with current OMB guidance.[A] These rates are intended to represent consumers' preference for current over future consumption (3 percent), and the real rate of return on private investment (7 percent) which indicates the opportunity cost of capital. However, neither of these rates necessarily represents the discount rate that individual decision-makers use.

The program may also have other economic effects that are not included here. In particular, as discussed in Chapter 2 of the RIA, the technology cost estimates developed here take into account the costs to hold other vehicle attributes, such as size and performance, constant. With these assumptions, and because welfare losses represent monetary estimates of how much buyers would have to be compensated to be made as well off as they would have been in the absence of this regulation,[B] price increases for new vehicles measure the welfare losses to

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[A] The range of Social Cost of Carbon (SCC) values uses several discount rates because the literature shows that the SCC is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context (where costs and benefits are incurred by different generations). Refer to Section 8.4 for more information.

[B] This approach describes the economic concept of compensating variation, a payment of money after a change that would make a consumer as well off after the change as before it. A related concept, equivalent variation, estimates the income change that would be an alternative to the change taking place. The difference between them is whether the vehicle buyers.[C] If the full technology cost gets passed along to the buyer as an increase in price, the technology cost thus measures the primary welfare loss of the standards, including impacts on buyers. Increasing fuel efficiency would have to lead to other changes in the vehicles that buyers find undesirable for there to be additional welfare losses that are not included in the technology costs.

As the 2012-2016 and 2017-2025 light-duty GHG/CAFE rules discussed, if other vehicle attributes are not held constant, then the technology cost estimates do not capture the losses to vehicle buyers associated with these changes.[1] The light-duty rules also discussed other potential issues that could affect the calculation of the welfare impacts of these types of changes, such as aspects of buyers' behavior that might affect the demand for technology investments, uncertainty in buyers' investment horizons, and the rate at which truck owners' trade off higher vehicle purchase price against future fuel savings.

Where possible, we identify the uncertain aspects of these economic impacts and attempt to quantify them (e.g., sensitivity ranges associated with quantified and monetized GHG impacts; range of dollar-per-ton values to monetize non-GHG health benefits; uncertainty with respect to learning and markups). The agencies have examined the sensitivity of our estimates of savings in fuel expenditures to alternative assumptions about future fuel prices; results of this sensitivity analysis can be found in Chapter 8.12 of this RIA. NHTSA's EIS also characterizes the uncertainty in economic impacts associated with the HD national program. For other impacts, however, there is inadequate information to inform a thorough, quantitative assessment of uncertainty. EPA and NHTSA continue to work toward developing a comprehensive strategy for characterizing the aggregate impact of uncertainty in key elements of its analyses and we will continue to work to refine these uncertainty analyses in the future as time and resources permit.

This and other chapters of the RIA address section 317 of the Clean Air Act on economic assessment of standards implementing section 202 of the Act. Chapter 8.11 addresses section 321 of the Clean Air Act on evaluation of potential loss of shifts of employment. The total monetized benefits and costs of the program are summarized in Chapter 8.10 for the final program and in Chapter 11 for all alternatives.

8.2 Conceptual Framework for Evaluating Impacts

The HD Phase 2 standards will implement both the 2007 Energy Independence and Security Act requirement that NHTSA establish fuel efficiency standards for medium- and heavy-duty vehicles and the Clean Air Act requirement that EPA adopt technology-based standards to control pollutant emissions from new motor vehicles and engines contributing to air

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the consumer's point of reference is her welfare before the change (compensating variation) or after the change (equivalent variation). In practice, these two measures are typically very close together.

[C] Indeed, it is likely to be an overestimate of the loss to the consumer, because the buyer has choices other than buying the same vehicle with a higher price; she could choose a different vehicle, or decide not to buy a new vehicle. The buyer would choose one of those options only if the alternative involves less loss than paying the higher price. Thus, the increase in price that the buyer faces would be the upper bound of loss of consumer welfare, unless there are other changes to the vehicle due to the fuel efficiency improvements that make the vehicle less desirable to consumers.

pollution that endangers public health and welfare. NHTSA's statutory mandate is intended to further the agency's long-standing goals of reducing U.S. consumption and imports of petroleum energy to improve the nation's energy security.

From an economics perspective, government actions to improve our nation's energy security and to protect our nation from the potential threats of climate change address "externalities," or economic consequences of decisions by individuals and businesses that extend beyond those who make these decisions. For example, users of transportation fuels increase the entire U.S. economy's risk of having to make costly adjustments due to rapid increases in oil prices, but these users generally do not consider such costs when they decide to consume more fuel.

Similarly, consuming transportation fuel also increases emissions of greenhouse gases and other more localized air pollutants that occur when fuel is refined, distributed, and consumed. Some of these emissions increase the likelihood and severity of potential climate-related economic damages, and others cause economic damages by adversely affecting human health. The need to address these external costs and other adverse effects provides a well-established economic rationale that supports the statutory direction given to government agencies to establish regulatory programs that reduce the magnitude of these adverse effects at reasonable costs.

The Phase 2 standards will require manufacturers of new heavy-duty vehicles, including trailers (HDVs), to improve the fuel efficiency of the products that they produce. As HDV users purchase and operate these new vehicles, they would consume significantly less fuel, in turn reducing U.S. petroleum consumption and imports as well as emissions of GHGs and other air pollutants. Thus as a consequence of the agencies' efforts to meet NHTSA statutory obligations to improve U.S. energy security and EPA's obligation to issue standards "to regulate emissions of the deleterious pollutant… from motor vehicles" that endangers public health and welfare,[2] the fuel efficiency and GHG emission standards would also reduce HDV operators' outlays for fuel purchases. These fuel savings are one measure of the final rule's effectiveness in promoting NHTSA's statutory goal of conserving energy, as well as EPA's obligation under section 202 (a)(1) and (2) of the Clean Air Act to assess the cost of standards. Although these savings are not the agencies' primary motivation for adopting higher fuel efficiency standards, these substantial fuel savings represent significant additional economic benefits of these rules.

Potential savings in fuel costs appear to offer HDV buyers' strong incentives to pay higher prices for vehicles that feature technology or equipment that reduces fuel consumption. These potential savings also appear to offer HDV manufacturers similarly strong incentives to produce more fuel-efficient vehicles. Economic theory suggests that interactions between vehicle buyers and sellers in a normally-functioning competitive market would lead HDV manufacturers to incorporate all technologies that contribute to lower net costs into the vehicles they offer, and buyers to purchase them willingly. Nevertheless, many readily available technologies that appear to offer cost-effective increases in HDV fuel efficiency (when evaluated over their expected lifetimes using conventional discount rates) have not been widely adopted, despite their potential to repay buyers' initial investments rapidly.

This economic situation is commonly known as the "energy efficiency gap" or "energy paradox." This situation is perhaps more challenging to understand with respect to the heavy-duty sector versus the light-duty vehicle sector. Unlike light-duty vehicles – which are purchased and used mainly by individuals and households – the vast majority of HDVs are purchased and operated by profit-seeking businesses for which fuel costs represent a substantial operating expense. Nevertheless, on the basis of evidence reviewed below, the agencies believe that a significant number of fuel efficiency improving technologies will remain far less widely adopted in the absence of these standards. The economic analysis of these standards is based in the engineering analysis of the costs and effectiveness of the technologies. The agencies have detailed their findings on costs and effectiveness in Preamble Sections III, IV, V, and VI, and RIA Chapter 2. If these cost and effectiveness estimates are correct, and if the agencies have not omitted key costs or benefits, then the efficiency gap exists, even if it seems implausible. Explaining why the gap exists is a separate and difficult challenge from observing the existence of the gap, because of the difficulties involved in developing tests of the different possible explanations. As discussed below, there is very little empirical evidence on behaviors that might lead to the gap, even while there continues to be substantial evidence, via the cost and effectiveness analysis, of the gap's existence.

Economic research offers several possible explanations for why the prospect of these apparent savings might not lead HDV manufacturers and buyers to adopt technologies that would be expected to reduce HDV operating costs. Some of these explanations involve failures of the HDV market for reasons other than the externalities caused by producing and consuming fuel. Examples include situations where information about the performance of fuel economy technologies is incomplete, costly to obtain, or available only to one party to a transaction (or "asymmetrical"), as well as behavioral rigidities in either the HDV manufacturing or HDV-operating industries, such as standardized or inflexibly administered operating procedures, or requirements of other regulations on HDVs. Examples that do not involve market failures include possible effects on the performance, reliability, carrying capacity, maintenance requirements of new technology under the demands of everyday use, or transactions or adjustment costs. We note again that these and other hypotheses are presented as potential explanations of the finding of an efficiency gap based on an engineering analysis. They are not themselves the basis for regulation.

In the HD Phase 1 rulemaking (which, in contrast to these standards, did not apply to trailers), and in the Phase 2 NPRM, the agencies raised various hypotheses that might explain this energy efficiency gap or paradox:

- Imperfect information in the new vehicle market: information available to prospective buyers about the effectiveness of some fuel-saving technologies for new vehicles may be inadequate or unreliable. If reliable information on their effectiveness in reducing fuel consumption is unavailable or difficult to obtain, HDV buyers will understandably be reluctant to pay higher prices to purchase vehicles equipped with unproven technologies.

As discussed in the NPRM, one common theme from recent research[3] is the inability of HDV buyers to obtain reliable information about the fuel savings, reliability, and maintenance costs of technologies that improve fuel efficiency. See 80 FR 40436. In the trucking industry, the performance of fuel-saving technology is likely to depend on many firm-specific attributes, including the intensity of HDV use, the typical distance and routing of HDV trips, driver characteristics, road conditions, regional geography and traffic patterns. As a result, businesses that operate HDVs have strong preferences for testing fuel-saving technologies "in-house" because they are concerned that their patterns of vehicle use may lead to different results from those reported in published information. Businesses with less capability to do in-house testing often seek information from peers, yet often remain skeptical of its applicability due to differences in the nature of their operations.

- Imperfect information in the resale market: buyers in the used vehicle market may not be willing to pay adequate premiums for more fuel efficient vehicles when they are offered for resale to ensure that buyers of new vehicles can recover the remaining value of their original investment in higher fuel efficiency. The prospect of an inadequate return on their original owners' investments in higher fuel efficiency may contribute to the short payback periods that buyers of new vehicles appear to demand.[4]

The recent research cited above (Klemick et al. 2015, Roeth et al. 2013, Aarnink et al. 2012) found mixed evidence for imperfect information in the market for used HDVs. On the one hand, some studies noted that fuel-saving technology is often not appreciated in the used vehicle market, because of imperfect information about its benefits, or greater mistrust of its performance among buyers in the used vehicle market than among buyers of new vehicles. When buyers of new vehicles considered features that would affect value in the secondary market, those features were rarely related to fuel economy. In addition, some used-vehicle buyers might have a larger "knowledge gap" than new-vehicle buyers. In other cases, the lack of interest might be due to the intended use of the used HDVs, which may not reward the presence of certain fuel-saving technologies. In other cases, however, fuel-saving technology can lead to a premium in the used market, as for instance to meet the more stringent requirements for HDVs operating in California.

- Principal-agent problems causing split incentives: an HDV buyer may not be directly responsible for its future fuel costs, or the individual who will be responsible for fuel costs may not participate in the HDV purchase decision. In these cases, the signal to invest in higher fuel efficiency normally provided by savings in fuel costs may not be transmitted effectively to HDV buyers, and the incentives of HDV buyers and fuel buyers will diverge, or be "split." The trailers towed by heavy-duty tractors, which are typically not supplied by the tractor manufacturer or seller, present an obvious potential situation of split incentives that was not addressed in the HD Phase 1 rulemaking, but it may apply in this rulemaking. If there is inadequate pass-through of price signals from trailer users to their buyers, then low adoption of fuel-saving technologies may result.

All of the recent research identifies split incentives, or principal-agent problems, as a potential barrier to technology adoption. Vernon and Meier (2012) estimate that 23 percent of trailers may be exposed to split incentives due to businesses that own and lease trailers to HDV operators not having an incentive to invest in trailer-specific fuel-saving technology.[5] They also estimate that 5 percent of HDV fuel use is subject to split incentives that arise when the firm paying fuel costs does not make the tractor investment decision (e.g., because a carrier subcontracts to an owner-operator but still pays for fuel). They do not quantify the financial significance of these problems.

Klemick et al. (2015), Aarnink et al. (2012), and Roeth et al. (2013) provide mixed evidence on the severity of the split-incentive problem. Focus groups often identify diverging incentives between drivers and the decision-makers responsible for purchasing vehicles. Aarnink et al. (2012) and Roeth et al. (2013) cite examples of split incentives involving trailers and fuel surcharges, although the latter also cites other examples where these same issues do not lead to split incentives. In an effort to minimize problems that can arise form split incentives, many businesses that operate HDVs also train drivers in the use of specific technologies or to modify their driving behavior in order to improve fuel efficiency, while some also offer financial incentives to their drivers to conserve fuel. All of these options can help to reduce the split incentive problem, although they may not be effective where it arises from different ownership of combination tractors and trailers.

- Uncertainty about future fuel cost savings: HDV buyers may be uncertain about future fuel prices, or about maintenance costs and reliability of some fuel efficiency technologies. In contrast, the costs of fuel-saving technologies are immediate. If buyers are loss-averse, they may react to this uncertainty by underinvesting in technologies to improve fuel economy. In contrast, the costs of fuel-saving or maintenance-reducing technologies are immediate and thus not subject to discounting. In this situation, potential variability about buyers' expected returns on capital investments to achieve higher fuel efficiency may shorten the payback period – the time required to repay those investments – they demand in order to make them.

Questions related to uncertainty about future costs for fuel and maintenance, as well as about the reliability of new technology that could result in costly downtime, illustrate the problem of uncertain or unreliable information about the actual performance of fuel efficiency technology discussed above. Roeth et al. (2013) and Klemick et al. (2015) both document the short payback periods that HDV buyers require on their investments -- usually about 2 years -- which may be partly attributable to these uncertainties.

- Adjustment and transactions costs: potential resistance to new technologies – stemming, for example, from drivers' reluctance or slowness to adjust to changes in the way vehicles operate – may slow or inhibit new technology adoption. If a conservative approach to new technologies leads HDV buyers to adopt them slowly, then successful new technologies will be adopted over time without market intervention, but only with potentially significant delays in achieving the fuel saving, environmental, and energy security benefits they offer. There also may be costs associated with training drivers to realize potential fuel savings enabled by new technologies, or with accelerating fleet operators' scheduled fleet turnover and replacement to hasten their acquisition of vehicles equipped with these technologies. These factors might present real resource costs to firms that are not reflected in a typical engineering analysis.

Klemick et al. (2015), Roeth et al. (2013), and Aarnink et al. (2012) provide some support for the view that adjustment and transactions costs may impede HDV buyers from investing in higher fuel efficiency. These studies note that HDV buyers are less likely to select new technology when it is not available from their preferred manufacturers. Some technologies are only available as after-market additions, which can add other costs to adopting them.

- Driver acceptance of new equipment or technologies as a barrier to their adoption. HDV driver turnover is high in the U.S., and businesses that operate HDVs are concerned about retaining their best drivers. Therefore, they may avoid technologies that require significant new training or adjustments in driver behavior.

For some technologies that can be used to meet these standards, such as automatic tire inflation systems, training costs are likely to be minimal. Other technologies, such as stop-start systems, may require drivers to adjust their expectations about vehicle operation, and it is difficult for the agencies to anticipate how drivers will respond to such changes.[D]

- Constraints on access to capital for investment. If buyers of new vehicles have limited funds available, then they must choose between investing in fuel-saving technology and other vehicle technologies or attributes.

There would be tradeoffs if capital markets are constrained, and fuel-saving technologies do not provide returns sufficient to achieve the hurdle rates that the buyers require. Klemick et al. (2015) did not find capital constraints to be a problem for the medium- and large-sized businesses participating in Klemick et al.'s (2013) study. On the other hand, Roeth et al. (2013) noted that access to capital can be a significant challenge to smaller or independent businesses, and that price is always a concern to buyers.

- "Network externalities," where the benefits to new users of a technology depend on how many others have already adopted it. If the value of a technology increases with increasing adoption, then it can be difficult for the adoption process to begin: each potential adopter has an incentive to wait for others to adopt before making the investment. If all adopters wait for others, then adoption may not happen.

One example where network externalities seem likely to arise is the market for natural gas-fueled HDVs: the limited availability of refueling stations may reduce potential buyers' willingness to purchase natural gas-fueled HDVs, while the small number of such HDVs in use does not provide sufficient economic incentive to construct more natural gas refueling stations. Some businesses that operate HDVs may also be concerned about the difficulty in locating repair facilities or replacement parts, such as single-wide tires, wherever their vehicles operate. When a technology has been widely adopted, then it is likely to be serviceable even in remote or rural places, but until it becomes widely available, its early adopters may face difficulties with repairs

[D] The distinction between simply requiring drivers (or mechanics) to adjust their expectations and compromises in vehicle performance or utility is subtle. While the former may not impose significant compliance costs in the long run, the latter would represent additional economic costs of complying with the standard.

or replacements. By accelerating the widespread adoption of these technologies, the standards may assist in overcoming these difficulties.

- First-mover disadvantage. Many manufacturers prefer to observe the market and follow other manufacturers rather than be the first to market with a specific technology. The "first-mover disadvantage" has been recognized in other research where the "first-mover" pays a higher proportion of the costs of developing technology, but loses the long-term advantage when other businesses follow quickly.[6,E] In this way, there may be barriers to innovation on the supply side that result in lower adoption rates of fuel-efficiency technology than would be optimal.

Roeth et al. (2013) noted that HDV buyers often prefer to have technology or equipment installed by their favored original equipment manufacturers. However, some technologies may not be available through these preferred sources, or may be available only as after-market installations from third parties (Aarnink et al. 2012, Roeth et al. 2013). Manufacturers may be hesitant to offer technologies for which there is not strong demand, especially if the technologies require significant research and development expenses and other costs of bringing the technology to a market of uncertain demand. Roeth et al. (2013) noted that it can take years, and sometimes as much as a decade, for a specific technology to become available from all manufacturers.

In summary, the agencies recognize that businesses that operate HDVs are under competitive pressure to reduce operating costs, which should compel HDV buyers to identify and rapidly adopt cost-effective fuel-saving technologies. Outlays for labor and fuel generally constitute the two largest shares of HDV operating costs, depending on the price of fuel, distance traveled, type of HDV, and commodity transported (if any), so businesses that operate HDVs face strong incentives to reduce these costs.[7,8]

However, the relatively short payback periods that buyers of new HDVs appear to require suggest that some combination of the factors cited above impedes this process. Markets for both new and used HDVs may face these problems, although it is difficult to assess empirically the degree to which they actually do. Even if the benefits from widespread adoption of fuel-saving technologies exceed their costs, their use may remain limited or spread slowly because their early adopters bear a disproportionate share of those costs. In this case, the standards may help to overcome such barriers by ensuring that these measures will be widely adopted.

Providing information about fuel-saving technologies, offering incentives for their adoption, and sharing HDV operators' real-world experiences with their performance through voluntary programs such as EPA's SmartWay Transport Partnership should assist in the adoption of new cost-saving technologies. Nevertheless, other barriers that impede the diffusion of new technologies are likely to remain. Buyers who are willing to experiment with new technologies expect to find cost savings, but those savings may be difficult to verify or replicate. As noted previously, because benefits from employing these technologies are likely to vary with the characteristics of individual routes and traffic patterns, buyers of new HDVs may find it difficult

[E] This first-mover disadvantage must be large enough to overcome the potential incentive for first movers to earn unusually high but temporary profit levels.

to identify or verify the effects of fuel-saving technologies in their operations. Risk-averse buyers may also avoid new technologies out of concerns over the possibility of inadequate returns on their investments, or with other possible adverse impacts.

Competitive pressures in the HDV freight transport industry can provide a strong incentive to reduce fuel consumption and improve environmental performance. Nevertheless, HDV manufacturers may delay in investing in the development and production of new technologies, instead waiting for other manufacturers to bear the initial risks of those investments. In addition, not every HDV operator has the requisite ability or interest to access and utilize the technical information, or the resources necessary to evaluate this information within the context of his or her own operations.

As discussed previously, whether the technologies available to improve HDVs' fuel efficiency would be adopted widely in the absence of the program is challenging to assess. To the extent that these technologies would be adopted in its absence, neither their costs nor their benefits should be attributed to the program.

The agencies will continue to explore reasons for the slow adoption of readily available and apparently cost-effective technologies for improving fuel efficiency.

8.3 Analysis of the Rebound Effect

The "rebound effect" has been defined in a variety of different ways in the energy policy and economics literature. One common definition states that the rebound effect is the increase in demand for an energy service when the cost of the energy service is reduced due to efficiency improvements.[9,10,11] In the context of heavy-duty vehicles (HDVs), this can be interpreted as an increase in HDV fuel consumption resulting from more intensive vehicle use in response to increased vehicle fuel efficiency.[F] Although much of this vehicle use increase is likely to take the form of increases in the number of miles vehicles are driven, it can also take the form of increases in the loaded weight at which vehicles operate or changes in traffic and road conditions vehicles encounter as operators alter their routes and schedules in response to improved fuel efficiency. Because this more intensive use consumes fuel and generates emissions, it reduces the fuel savings and avoided emissions that would otherwise be expected to result from the increases in fuel efficiency in this rulemaking.

Unlike the light-duty vehicle (LDV) rebound effect, the HDV rebound effect has not been extensively studied. According to a 2010 HDV report published by the National Research Council of the National Academies (NRC)[12], it is "not possible to provide a confident measure of the rebound effect," yet NRC concluded that a HDV rebound effect probably exists and that, "estimates of fuel savings from regulatory standards will be somewhat misestimated if the rebound effect is not considered." Although we believe the HDV rebound effect needs to be

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[F] We discuss other potential rebound effects in Section 8.3.3.2, such as the indirect and economy-wide rebound effects. Note also that there is more than one way to measure HDV energy services and vehicle use. The agencies' analyses use VMT as a measure (as discussed below); other potential measures include ton-miles, cube-miles, and fuel consumption.

studied in more detail, we have nevertheless attempted to capture its potential effect in our analysis of these final rules, rather than to await further study. We have elected to do so because the magnitude of the rebound effect is an important determinant of the actual fuel savings and emission reductions that are likely to result from adopting stricter fuel efficiency and GHG emission standards.

In our analysis and discussion below, we focus on one widely-used metric to estimate the rebound effect associated with all types of more intensive vehicle use, the increase in vehicle miles traveled (VMT) that results from improved fuel efficiency. VMT can often provide a reasonable approximation for all types of more intensive vehicle use. For simplicity, we refer to this as “the VMT rebound effect” or “the direct VMT rebound” throughout this section, although we acknowledge that it is an approximation to the rebound effect associated with all types of more intensive vehicle use. The agencies use our VMT rebound estimates to generate VMT inputs that are then entered into the EPA MOVES national emissions inventory model and the Volpe Center’s HD CAFE model. Both of these models use these inputs along with many others to generate projected emissions and fuel consumption changes resulting from each of the regulatory alternatives analyzed.

Using VMT rebound to approximate the fuel consumption impact from all types of more intensive vehicle use may not be completely accurate. Many factors other than distance traveled – for example, a vehicle’s loaded weight – play a role in determining its fuel consumption, so it is also important to consider how changes in these factors are correlated with variation in vehicle miles traveled. Empirical estimates of the effect of weight on HDV fuel consumption vary, but universally show that loaded weight has some effect on fuel consumption that is independent of distance traveled. Therefore, the product of vehicle payload and miles traveled, which typically is expressed in units of “ton-miles” or “ton-kilometers,” has also been considered as a metric to approximate the rebound effect. Because this metric’s value depends on both payload and distance, it is important to note that changes in these two variables can have different impacts on HDV fuel consumption. This is because the fuel consumed by HDV freight transport is determined by several vehicle attributes including engine and accessory efficiencies, aerodynamic characteristics, tire rolling resistance and total vehicle mass—including payload carried, if any. Other factors such as vehicle route and traffic patterns can also affect how each of these vehicle attributes contributes to the overall fuel consumption of a vehicle. While it seems intuitive that if all of these other conditions remain constant, a vehicle driving the same route and distance twice will consume twice as much fuel as driving that same route once. However, because of the other vehicle attributes, it is less intuitive how a change in vehicle payload would affect vehicle fuel consumption.

Because the factors influencing HDV VMT rebound are generally different from those affecting LDV VMT rebound, much of the research on the LDV sector is likely to not apply to the HDV sector. For example, the owners and operators of LDVs may respond to the costs and benefits associated with changes in their personal vehicle’s fuel efficiency very differently than a HDV fleet owner or operator would view the costs and benefits (e.g., profits, offering more competitive prices for services) associated with changes in their HDVs’ fuel efficiency. To the extent the response differs, such differences may be smaller for HD pickups and vans, which share some similarities with LDVs. As discussed in the 2010 NRC HD report, one difference from the LDV case is that when calculating the change in HDV costs that causes the rebound effect, it is more important to consider all components of HDV operating costs. The costs of labor and fuel generally constitute the two largest shares of HDV operating costs, depending on the price of petroleum, distance traveled, type of vehicle, and commodity transported (if any).[13,14] Equipment depreciation costs associated with the purchase or lease of an HDV are another significant component of total operating costs (Figure 8-1).[15] Even when HDV purchases involve upfront, one-time payments, HDV operators must recover the depreciation in the value of their vehicles resulting from their use, so this is likely to be considered as an operating cost they will attempt to pass on to final consumers of HDV operator services.

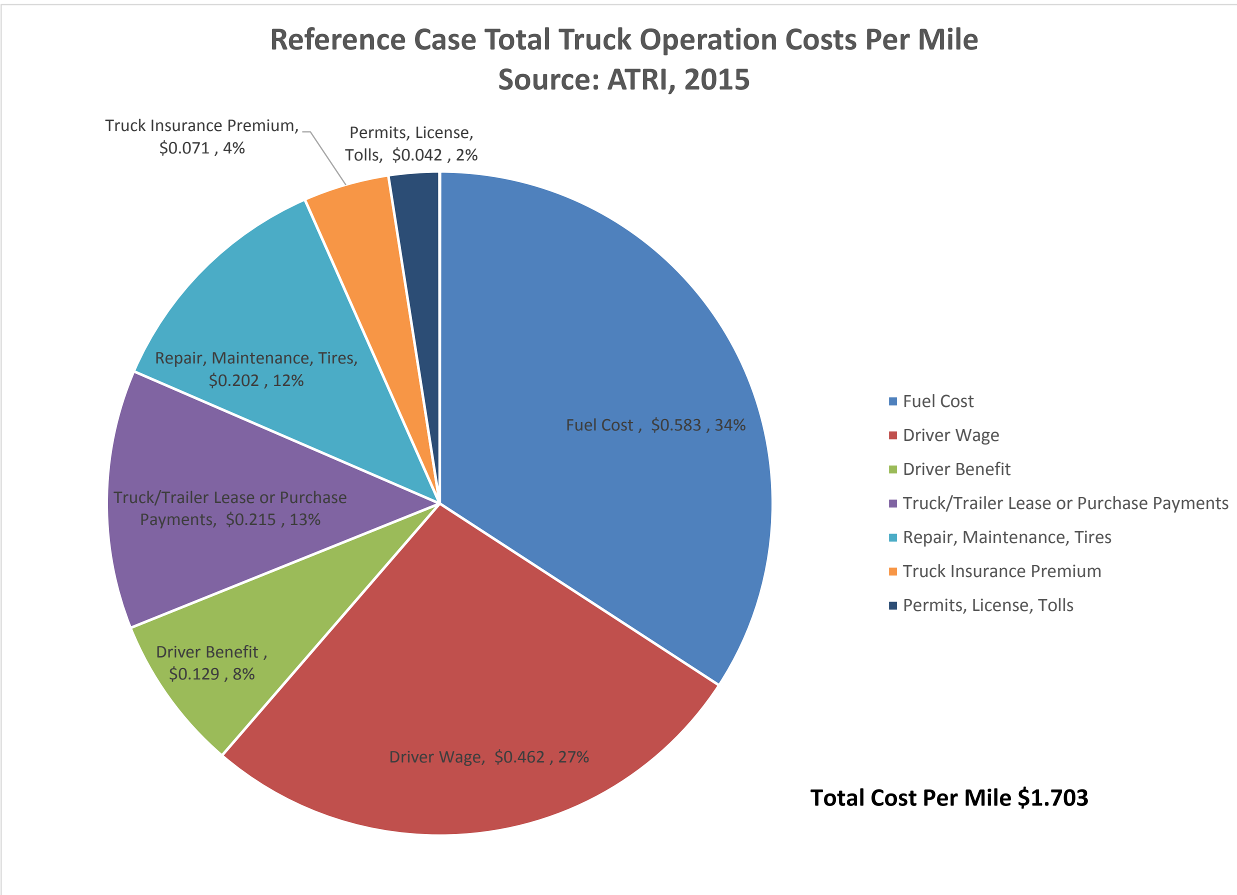

Figure 8-1 Average Truck Operation Costs

Estimates of the impact of fuel efficiency standards on HDV VMT, and hence fuel consumption, should account for changes in all of these components of HDV operating costs. The higher the net savings in total operating costs is, the higher the expected rebound effect would be. Conversely, if higher HDV purchase costs and any other ancillary costs of adopting more fuel-efficiency vehicles outweigh future cost savings, and total operating costs increase, HDV costs could rise, which would likely result in a decrease in HDV VMT. In theory, other cost changes resulting from any requirement to achieve higher fuel efficiency, such as changes in maintenance costs or insurance rates, should also be taken into account, although information on these elements of HDV operating costs is extremely limited. In this analysis, the agencies adapt estimates of the VMT rebound effect to project the response of HDV use to the estimated changes in total operating costs that result from the Phase 2 standards.

Since businesses are profit-driven, one would expect their decisions to be based on the costs and benefits of different operating decisions, both in the near-term and long-term. Specifically, one would expect commercial HDV operators to take into account changes in overall operating costs per mile when making decisions about HDV use and setting rates they charge for their services. If demand for those services is sensitive to the rates HDV operators charge, HDV VMT could change in response to the effect of higher fuel efficiency on the rates HDV operators charge. If demand for HDV services is insensitive to price (e.g., due to lack of good substitutes), however, or if changes in HDV operating costs due to the standards are not passed on to final consumers of HDV operator services, the standards may have a limited impact on HDV VMT.

The following sections describe the factors affecting the magnitude of HDV VMT rebound; review the econometric and other evidence related to HDV VMT rebound; and summarize how we estimated the HDV rebound effect for this rulemaking.

8.3.1 Factors Affecting the Magnitude of HDV VMT Rebound

The magnitude and timing of HDV VMT rebound result from the interaction of many different factors.[16] Fuel savings resulting from fuel efficiency standards may cause HDV operators and their customers to change their patterns of HDV use and fuel consumption in a variety of ways. As discussed later in this section and in the proposal to this rule, HDV VMT rebound estimates determined via other proxy elasticities vary, but in no case has there been an estimate that fully offsets the fuel saved due to efficiency improvements (i.e., no direct rebound effect greater than or equal to 100 percent). [G]

If fuel cost savings are passed on to the HDV operators' customers (e.g., logistics businesses, manufacturers, retailers, municipalities, utilities consumers), those customers might reorganize their logistics and distribution networks over time to take advantage of lower operating costs. For example, customers might order more frequent shipments or choose products that entail longer shipping distances, while freight carriers might divert some shipments to trucks from other shipping modes such as rail, barge or air. In addition, customers might choose to reduce their number of warehouses, reduce shipment rates or make smaller but more frequent shipments, all of which could lead to an increase in HDV VMT. Ultimately, fuel cost savings could ripple through the entire economy, thus increasing demand for goods and services shipped by trucks, and therefore increase HDV VMT due to increased gross domestic product (GDP).

[G] Elasticity is the measurement of how responsive an economic variable is to a change in another. For example: *price elasticity of demand* is a measure used in economics to show the responsiveness, or elasticity, of the quantity demanded of a good or service to a change in its price. More precisely, it gives the percentage change in quantity demanded in response to a one percent change in price.

Conversely, if fuel efficiency standards lead to net increases in the total costs of HDV operation because fuel cost savings do not fully offset the increase in HDV purchase prices and associated depreciation costs, then the price of HDV services could rise. This is likely to spur a decrease in HDV VMT, and perhaps a shift to alternative shipping modes. These effects could also ripple through the economy and affect GDP. Note, however, that we project fuel cost savings will offset technology costs in our analysis supporting the final standards.

It is also important to note that any increase in VMT on HDVs impacted by the final standards may be offset, to some extent, by a decrease in VMT on older HDVs. This may occur if lower fuel costs resulting from our standards cause multi-vehicle fleet operators to shift VMT to newer, more efficient HDVs in their fleet or cause operators with newer, more efficient HDVs to be more successful at winning contracts than operators with older HDVs.

Also, as discussed in Chapter 8.2 of this RIA, the magnitude of the rebound effect is likely to be influenced by the extent of any market failures that affect the demand for more fuel efficient HDVs, as well as by HDV operators' responses to their perception of the tradeoff between higher upfront HDV purchase costs versus lower but uncertain future expenditures on fuel.

8.3.2 Recent Econometric and Other Evidence Related to HDV VMT Rebound

As discussed above, HDV VMT rebound is defined as the change in HDV VMT that occurs in response to an increase in HDV fuel efficiency. We are not aware of any studies that directly estimate this elasticity for the U.S. In the RIA that accompanied the proposal, we discussed a number of econometric analyses of other related elasticities that could potentially be used as a proxy for measuring HDV VMT rebound, as well as several other analyses that may provide insight into the magnitude of HDV VMT rebound.[17] These studies produced a wide range of estimates for HDV VMT rebound however, and we were unable to draw any strong conclusions about the magnitude of rebound based on this available literature.

We also discussed several challenges that researchers face in attempting to quantify the VMT rebound effect for HDVs,[18] including limited data on the HD sector and the difficulty of specifying mathematical models that reflect the complex set of factors that influence HD VMT. Given these limitations, the agencies requested comment on a number of aspects of the proposed VMT rebound analysis, including procedures for measuring the rebound effect and the studies discussed in the proposal. The agencies also committed to reviewing and considering revisions to VMT rebound estimates for the final rule based on submissions from public commenters and new research on the rebound effect. This section reviews new econometric analyses that have been produced since the release of the proposal. All of these analyses study the change in HDV use (measured in VMT, ton-mile, or fuel consumption) in response to changes in fuel price ($/gallon) or fuel cost ($/mile or $/ton-mile). The studies presented below attempt to estimate these elasticities in the HDV sector using varying approaches and data sources.

During the same period that agencies were developing the proposal for this rulemaking, EPA contracted with Energy and Environmental Research Associates (EERA) to analyze the HDV rebound effect for regulatory assessment purposes. Excerpts of EERA's initial report to EPA are included in the NPRM docket and contain detailed qualitative discussions of the rebound effect as well as data sources that could be used in quantitative analysis.[19] EERA also conducted follow-on quantitative analyses focused on estimating the impact of fuel prices on VMT and fuel consumption. We included a Working Paper in the NPRM docket that described much of this work.[20] Note that EERA's Working Paper was not available at the time the agencies conducted the analysis of the rebound effect for the proposal, but the agencies agreed to consider this work, and any other work, in the final rule.

At the time of the filing of the NPRM, Winebrake et al. (2015) published two papers in Transportation Research Part D: Transport and Environment based on EERA work mentioned above.[21] These two papers have been filed in the NPRM docket and received public review and comment. In the first paper, the fuel price elasticities of VMT and fuel consumption for combination trucks are estimated with regression models. The combination trucks paper uses annual data for the period 1970-2012. VMT and fuel consumption are used as the dependent variables. The control variables include: a macroeconomic variable (e.g., gross domestic product (GDP)), imports/exports, and fuel price, among other variables. In the second paper, the fuel price elasticity of VMT for single unit vehicles is estimated by using annual data for the period 1980-2012. The single unit vehicle paper uses similar control variables but includes additional variables related to lane miles and housing construction. VMT is the only dependent variable modeled in the single unit vehicle paper (i.e., fuel consumption is not modeled).

The results in Winebrake et al. are that the null hypothesis – which states that the fuel price elasticity of VMT and the fuel price elasticity of fuel consumption are zero – cannot be rejected with statistical confidence. The papers hypothesize that low elasticities may be due to a range of possibilities including: (1) the common use of fuel surcharges; (2) adjustments in other operational costs, such as labor; (3) possible principal-agent problems affecting driver behavior; and (4) the nature of freight transportation as an input to a larger supply chain system that is driven by other factors. These two papers suggest that previous regulatory analysis that uses a five percent rebound effect for combination trucks and a 15 percent rebound effect for single unit trucks may be overestimating the direct VMT rebound effect.

To the best of our knowledge, the Winebrake et al. paper represents the first peer-reviewed work in the last two decades, after Gately (1990)[H] that attempts to estimate quantitatively the impact of a change in fuel costs on HDV VMT in the U.S. context. A subsequent paper by Wadud, discussed in more detail below, states that there is "only one creditable study" on "the responses of different [heavy duty] vehicle sectors to fuel price or income changes," specifically the Winebrake et al. combination truck work.

However, there is other recent work that has not been peer reviewed, or that studies HDV VMT rebound in other countries, that bears mentioning as well. Resources for the Future (RFF) filed a comment on the proposal with a Working Paper by Leard et al. (2015) to address HDV rebound effects during the comment period of NPRM.[22] Leard et al.'s Working Paper uses detailed truck-level micro-data from Vehicle Use and Inventory Survey (VIUS) for six survey years (specifically, 1977, 1982, 1987, 1992, 1997, and 2002). The "rebound effect" in this paper

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[H] Gately, D., 1990. The U.S. demand for highway travel and motor fuel. Energy Journal. 11, p. 59–74.

is defined to be a combination of a “VMT elasticity with respect to fuel costs per mile” ($/mile); and a “truck count elasticity with respect to fuel costs per mile.” Fuel costs per mile are defined as fuel price ($/gal) divided by efficiency (mpg). Because the agencies do not estimate the directional impact of this rulemaking on vehicle sales, the portion of Leard et al.’s estimates associated with VMT rebound with respect to fuel costs per mile are the most useful point of comparison to our estimates in the proposal.

Leard et al. report a VMT rebound effect result of 18.5 percent with respect to fuel costs per mile for combination trucks.[I] This finding suggests that previous estimates of combination truck rebound effects used in this proposal, a five percent rebound effect, may be underestimating the true rebound effect. Leard et al. also report a VMT rebound effect with respect to fuel costs per mile of 12.2 percent for single unit trucks.[J] This finding suggests that the previous use of a 15 percent rebound effect for single unit vehicles in the proposed rule may be overestimating the true rebound effect. As noted, VIUS was discontinued in 2002, so the most recent data in this study is 2002 which is fourteen years old. In addition, as noted, Leard et al. Working Paper has not been peer reviewed or published.

Recently, Wadud (2016) has estimated price elasticities of diesel demand in the U.K.[K] The paper aims to model diesel demand elasticity for different freight duty vehicle types in the U.K. Wadud uses a similar model specification as Winebrake et al. in the regression analysis. Wadud finds that diesel consumption in freight vehicles overall is quite inelastic. Diesel demand from articulated trucks and light goods vehicles (similar to combination trucks in the U.S.) does not respond to changes in diesel prices at all. Demand in rigid trucks (similar to single unit trucks in the U.S.) responds to fuel price changes with a 15 percent elasticity. Wadud’s work presents empirical results in the U.K., which might not be appropriate to apply to the U.S.

8.3.3 How the Agencies Estimated the HDV Rebound Effect for this Final Rulemaking

8.3.3.1 Values Used in the Phase 2 NPRM Analysis

At the time the agencies conducted their analysis of the Proposed Phase 2 fuel efficiency and GHG emissions standards, the agencies determined that the evidence did not lend itself to any changes in the values used to estimate the VMT rebound effect in the HD Phase 1 rulemaking. The agencies used the rebound effect estimates of 15 percent for vocational vehicles, five percent for combination tractors, and 10 percent for HD pickup trucks and vans from the HD Phase 1 rulemaking.

[I] Leard et al. report a total VMT rebound effect result of 29.7 percent for combination trucks, which is a sum of separate estimates associated with both VMT elasticity and truck count elasticity with respect to fuel costs per mile.
[J] For vocational trucks, Leard et al. report an overall 9.3 percent rebound value, which is a sum of separate estimates associated with both VMT elasticity and truck count elasticity with respect to fuel costs per mile.
[K] Wadud, Zia, Diesel Demand in the Road Freight Sector in the UK: Estimates for Different Vehicle Types, Applied Energy 165 (2016), p. 849-857.

8.3.3.2 How the Agencies Analyzed VMT Rebound in this Final Rulemaking

The emergence of new information as well as the public comments are cause for updating the quantitative values used to estimate the VMT rebound effect from those estimated by the analysis conducted for the HDV Phase 1 rulemaking. For vocational trucks, the Winebrake et al. study found no responsiveness of truck travel to diesel fuel prices, suggesting a VMT rebound effect of essentially zero. Leard et al. suggested a VMT rebound effect for vocational trucks of roughly 12 percent. For combination trucks, the Winebrake et al. study found a rebound effect of essentially zero percent. The Leard et al. study found a VMT elasticity rebound effect of roughly 18 percent for combination trucks. In addition to the RFF comments to which Leard et al. was included, EPA and NHTSA received ten other comments on HDV rebound during the comment period for the proposal, six of which were substantive. One of these commenters suggested that the agencies' rebound numbers "appear reasonable." The five others commented that the rebound estimates for both combination and vocational vehicles used in the proposal were overestimated, and suggested using the Winebrake et al. estimates.

In revising the HD VMT rebound estimates, we give somewhat greater consideration to the findings of Winebrake et al. because it is peer-reviewed and published, whereas Leard et al. is a Working Paper. Based on this consideration and on the comments that we received in response to the proposal, the agencies have chosen to revise the VMT rebound estimate for vocational trucks down to five percent, and have elected to maintain the use of the five percent rebound effect for combination tractor-trailers. We note that while the Winebrake et al. work supports rebound estimates of zero percent for vocational vehicles and combination tractor-trailers, using a five percent value is conservative and leaves some consideration of uncertainty, as well as some consideration of the (un-peer reviewed and unpublished) findings of the Leard et al. study. The five percent value is in range of the two U.S. studies and generally addresses the issues raised by the commenters.

We did not receive new data or comments on our estimated VMT rebound effect for heavy-duty pick-up trucks and vans. Therefore, we have elected to use the 10 percent value used at proposal. It should be noted that the rebound estimates we have selected for our analysis represent the VMT impact from our final standards with respect to changes in the fuel cost per mile driven.

As described previously, the HDV rebound effect should ideally be a measure of the change in fuel consumed with respect to the change in *overall* operating costs due to a change in HDV fuel efficiency. Such a measure would incorporate all impacts from our rules, including those from incremental increases in vehicle prices that reflect costs for improving their fuel efficiency. Therefore, VMT rebound estimates with respect to fuel costs per mile must be "scaled" to apply to total operating costs, by dividing them by the fraction of total operating costs accounted for by fuel use.

The agencies scaled the VMT rebound calculations to total operating costs using the most recent information from the American Transportation Research Institute (ATRI), which has been updated for this final rulemaking.[23] ATRI estimates that the average motor carrier cost per mile is $1.703 for 2014. Other elements of the total costs are listed below in Table 8-1.

Table 8-1 Elements of the Operating Costs per Mile

OPERATING COST PER MILE	ATRI
Fuel Cost	$0.583
New Vehicle Cost	$0.215
Maintenance & Repair Cost	$0.158
All Other (labor, insurance, etc.)	$0.747
Total Motor Carrier Costs	$1.703

For the final rulemaking, the agencies determined VMT rebound separately for each HDV category and for each alternative. However, the agencies made simplifying assumptions in the VMT rebound analysis for this rulemaking, similar to the approach taken in the HD GHG Phase 1 final rule. Chapter 7 of the RIA presents VMT rebound values for each HDV sector that we estimated for the final program. These VMT impacts are reflected in the estimates of total fuel savings and reductions in emissions of GHG and other air pollutants presented in Section VI and VII of the Preamble for all categories.

For the purposes of this final rulemaking, we made simplifying assumptions when applying the overall rebound effect to each class of truck. For example, we assumed that per mile vehicle costs were based on the new vehicle cost (*e.g.*, $175,000 for the reference case Class 8 combination tractor with three box trailers, $40,000 for the reference case HD pickups, and $100,000 for the vocational vehicles) [24] divided by the total lifetime number of expected vehicle miles (*e.g.*, 1.12 million miles for a Class 8 combination tractor-trailer, 169,249 miles for 2b/3 trucks, and 203,548 miles for vocational vehicles). [25] We recognize that this calculation implicitly assumes that truck depreciation is strictly a function of usage, and that it does not take into account the opportunity cost of alternative uses of capital. As a result, the new vehicle cost per mile assumptions used in these calculations represent a smaller percentage of total operating costs compared to the ATRI and CSI examples.

The agencies assumed in this final rulemaking an “average” incremental technology cost for the alternatives, as shown in Table 8-2. Due to timing constraints, the agencies were not able to determine the technology costs for the final alternatives prior to conducting the emission inventory modeling. Therefore, the technology costs for Alternatives 1b, 2, 3, and 4 were assumed to be the values developed in the HD Phase 2 NPRM.[26] The agencies did not develop a technology package cost for Alternative 5 because we believe that there would be such substantial additional costs related to pulling ahead the development of so many additional technologies that we cannot accurately predict these costs (even assuming that it is technically feasible to do so, which is at the least doubtful).[27] For the rebound calculation, the technology package cost of Alternative 5 was assumed to be twice the cost of Alternative 4.

Table 8-2 Technology Costs Used to Determine the Rebound Effect of Each Alternative

	ALTERNATIVE				
Vehicle Category	**1b**	**2**	**Final Program**	**4**	**5**
Combination Tractors	$362	$8,358	$12,849	$12,849	$25,698
HD Pickup & Vans	$15	$714	$1,342	$1,841	$3,682
Vocational Vehicles	$0	$380	$3,381	$3,382	$6,762

The fuel costs per mile in the analysis were calculated using EIA's Annual Energy Outlook 2015's projections for diesel fuel price.[28] The average fuel economy for each category was determined using MOVES2014a. The combination tractor-trailer fuel economy used was 6.2 mpg, the vocational vehicle category was 9.8 mpg, and the HD pickup category was 14.5 mpg. The technology effectiveness of the alternatives in the final rules was assumed to be equal to the technology effectiveness developed for each alternative in the Phase 2 NPRM, as show in Table 8-3.[29]

Table 8-3 Technology Effectiveness Used to Determine the Rebound Effect of Each Alternative

	ALTERNATIVE				
Vehicle Category	**1b**	**2**	**Final Program**	**4**	**5**
Combination Tractors	2.1%	12.1%	20.4%	20.5%	25.5%
HD Pickup & Vans	2.9%	9.6%	16.2%	16.3%	18.5%
Vocational Vehicles	0%	3.2%	11.8%	11.9%	17.4%

The operating costs calculated based on all of these inputs are shown below in Table 8-4.

Table 8-4 Operating Costs for the Reference and Final Program

OPERATING COST PER MILE	REFERENCE CASE	FINAL PROGRAM
Tractor-Trailers		
Fuel Cost	$0.586	$0.49
New Vehicle Cost	$0.156	$0.17
Maintenance & Repair Cost	$0.158	$0.158
All Other (labor, insurance, etc.)	$0.747	$0.747
Total Motor Carrier Costs	$1.647	$1.559
Pickups and Vans		
Fuel Cost	$0.250	$0.220
New Vehicle Cost	$0.236	$0.240
Maintenance & Repair Cost	$0.158	$0.158
All Other (labor, insurance, etc.)	$0.747	$0.747
Total Motor Carrier Costs	$1.392	$1.365
Vocational Vehicles		
Fuel Cost	$0.37	$0.33
New Vehicle Cost	$0.491	$0.508
Maintenance & Repair Cost	$0.158	$0.158
All Other (labor, insurance, etc.)	$0.747	$0.747
Total Motor Carrier Costs	$1.767	$1.744

Other simplifying assumptions include the use of an average cost rather than a marginal cost. Some trucking firms may use a marginal cost to determine whether to increase their fuel usage, however we do not have any data on when firms might use a marginal cost calculation rather than an average cost calculation. Although using a marginal cost might be more appropriate for calculating the rebound effect, we do not have a methodology for calculating the marginal cost.[30]

In the costs and benefits summarized in Preamble Section IX.K, we have not explicitly taken into account any potential fuel savings or GHG emission reductions from the rail, air or water-borne shipping sectors due to mode shifting because estimates of this effect seem too speculative at this time. Likewise we have not taken into account any fuel savings or GHG emissions reductions from the potential shift in VMT from older HDVs to newer, more efficient HDVs. As discussed in the Preamble at Section IX.E, we have found limited evidence of the impact of HDV fuel efficiency standards on mode shifting and no evidence on shifting activity away from older HDVs to newer HDVs. The agencies requested comment on these assumptions in the NPRM, but did not receive any.

In addition, we have not attempted to capture the extent of how current market failures might impact the rebound effect. The direction and magnitude of the rebound effect in the HD truck market are expected to vary depending on the existence and types of market failures affecting the fuel efficiency of the trucking fleet. If firms are already accurately accounting for the costs and benefits of these technologies and fuel savings, then these regulations would increase their net costs, because trucks would already include all cost-effective fuel saving technologies. As a result, the rebound effect would actually be negative and truck VMT would decrease as a result of these regulations.

However, if firms are not optimizing their behavior today due to factors such as lack of reliable information (see Preamble Section IX.A or RIA Chapter 8.2 for further discussion), it is more likely that truck VMT would increase. If firms recognize their lower net costs as a result of these regulations and pass those costs along to their customers, then the rebound effect would increase truck VMT. This response assumes that trucking rates include both truck purchase costs and fuel costs, and that the truck purchase costs included in the rates spread those costs over the full expected lifetime of the trucks. If those costs are spread over a shorter period, as the expected short payback period implies, then those purchase costs will inhibit reduction of freight rates, and to the extent that they do so the rebound effect will be proportionally smaller.

As discussed in more detail in Preamble Section IX.A and RIA Chapter 8.2, if there are market failures such as split incentives, estimating the rebound effect may depend on the nature of the failures. For example, if the original purchaser cannot fully recoup the higher upfront costs through fuel savings before selling the vehicle nor pass those costs onto the resale buyer, the firm would be expected to raise shipping rates. A firm purchasing the truck second-hand might lower shipping rates if the firm recognizes the cost savings after operating the vehicle, leading to an increase in VMT. Similarly, if there are split incentives and the vehicle buyer is not the same entity that purchases the fuel, than there would theoretically be a positive rebound effect. In this scenario, fuel savings would lower the net costs to the fuel purchaser, which would result in a larger increase in truck VMT.

Note that while we focus on the VMT rebound effect in our analysis of this final rule, there are at least two other types of rebound effects discussed in the energy policy and economics literature. In addition to VMT rebound effects, there are “indirect” rebound effects, which refers to the purchase of other goods or services (that consume energy) with the costs savings from energy efficiency improvements; and “economy-wide” rebound effects, which refers to the increased demand for energy throughout the economy in response to the reduced market price of energy that happens as a result of energy efficiency improvements. One commenter pointed out that consumers may use their savings from lower fuel costs as a result of the direct rebound effect to buy more goods and services, which indirectly increases the use of energy (i.e., the indirect rebound effect).[L] The commenter states that the indirect rebound effect represents a positive economic result for consumers, since consumer welfare increases, although it could result in increased energy use and GHG emissions. We agree with this commenter's observation that, to the extent that indirect rebound does occur, it could have both positive and negative impacts.

Another commenter suggested that the indirect or economy-wide rebound effect could be large enough so as to fully offset the fuel savings and GHG emissions benefits of the rule.[M] The commenter provides multiple estimates of the potential size of the indirect rebound effect. However, the unpublished methodology used to perform these estimates has not undergone peer review and, as explained in the response to comment document, the agencies find it to be dubious. Further, as discussed in detail in the proposed rule and our response to comment

[L] EPA-HQ-OAR-2014-0827-1336.
[M] EPA-HQ-OAR-2014-0827-1467.

document, there are a number of other important questions not addressed by the commenter that must be examined before we can have enough confidence in these kinds of estimates to include them in our economic analysis.

As discussed in this proposed rule, all of the fuel costs savings will not necessarily be passed through to the consumer in terms of cheaper goods and services. First, there may be market barriers that impede trucking companies from passing along the fuel cost savings from the rule in the form of lower rates. Second, there are upfront vehicle costs (and potentially transaction or transition costs associated with the adoption of new technologies) that would partially offset some of the fuel cost savings from our rule, thereby limiting the magnitude of the impact on prices of final goods and services. Also, it is not clear how the fuel savings from the rule would be utilized by trucking firms. For example, trucking firms may reinvest fuel savings in their own company; retain fuel savings as profits; pass fuel savings onto customers or others; or increase driver pay. Finally, it is not clear how the different pathways that fuel savings would be utilized would affect greenhouse gas emissions.

Research on indirect and economy-wide rebound effects is scant, and we have not identified any peer-reviewed research that attempts to quantify indirect or economy-wide rebound effects for HDVs. In particular, the agencies are not aware of any peer-reviewed approach which indicates that the magnitude of indirect or economy-wide rebound effects, if any, would be significant for this final rule.[N] Therefore, we rely on the analysis of vehicle miles traveled to estimate the rebound effect in this rule, as we did for the HD Phase 1 rule, where we attempted to quantify only rebound effects from our rule that impact HDV VMT.

In order to test the effect of alternative assumptions about the rebound effect, NHTSA examined the sensitivity of its estimates of benefits and costs of the proposed Phase 2 program for HD pickups and vans to alternative assumptions about the rebound effect. While the main analysis for pickups and vans assumes a 10 percent rebound effect, the sensitivity analysis estimates the benefits and costs of the standards under the assumptions of 5, 15, and 20 percent rebound effects. This sensitivity analysis can be found in Section IX.E.3 of the NPRM Preamble[O] and shows that (a) using a 5 percent value for the rebound effect reduced benefits and costs of the proposed standards by identical amounts, leaving net benefits unaffected; and (b) values of the rebound effect above 10 percent increased costs and reduced benefits from their values in the main analysis, thus reducing net benefits of the proposed standards. Nevertheless, the proposed and now the final program have significant net benefits and these alternative values of the rebound effect would not have affected the agencies' selection of the final program stringency, as that selection is based on NHTSA's assessment of the maximum feasible fuel

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[N] The same entity responsible for these comments also sought reconsideration of the Phase 1 rule on the grounds that indirect rebound effects had not been considered by the agencies and could negate all of the benefits of the standards. This assertion rested on an unsupported affidavit lacking any peer review or other indicia of objectivity. This affidavit cited only one published study. The study cited did not deal with vehicle efficiency, has methodological limitations (many of them acknowledged), and otherwise was not pertinent. EPA and NHTSA thus declined to reconsider the Phase 1 rule based on these speculative assertions. See generally 77 FR 51703-04 (Aug. 27, 2012) and 77 FR 51502-03 (Aug. 24, 2012). The analysis in this entity's comments on this rulemaking rests largely on that same unsupported affidavit.

[O] 80 FR 40137.

efficiency standards and EPA's selection of appropriate GHG standards to address energy security and the environment.

8.4 Impact on Class Shifting, Fleet Turnover, and Sales

The agencies considered two additional potential indirect effects which may lead to unintended consequences of the program to improve the fuel efficiency and reduce GHG emissions from HD trucks. The next sections cover the agencies' qualitative discussions on potential class shifting and fleet turnover effects.

8.4.1 Class Shifting

Heavy-duty vehicles are typically configured and purchased to perform a function. For example, a concrete mixer truck is purchased to transport concrete, a combination tractor is purchased to move freight with the use of a trailer, and a Class 3 pickup truck could be purchased by a landscape company to pull a trailer carrying lawnmowers. The purchaser makes decisions based on many attributes of the vehicle, including the gross vehicle weight rating of the vehicle, which in part determines the amount of freight or equipment that can be carried. If the Phase 2 standards impact either the performance of the vehicle or the marginal cost of the vehicle relative to the other vehicle classes, then consumers may choose to purchase a different vehicle, resulting in the unintended consequence of increased fuel consumption and GHG emissions in-use.

The agencies, along with the NAS panel, found that there is little or no literature which evaluates class shifting between trucks.[31] In addition, the agencies did not receive comments specifically raising concerns about class shifting. NHTSA and EPA qualitatively evaluated the final rules in light of potential class shifting. The agencies looked at four potential cases of shifting: - from light-duty pickup trucks to heavy-duty pickup trucks; from sleeper cabs to day cabs; from combination tractors to vocational vehicles; and within vocational vehicles.

Light-duty pickup trucks, those with a GVWR of less than 8,500 pounds, are currently regulated under the existing GHG/CAFE standards for light duty vehicles. The increased stringency of the light-duty 2017-2025 MY vehicle rule has led some to speculate that vehicle consumers may choose to purchase heavy-duty pickup trucks that are currently regulated under the HD Phase 1 program if the cost of the light-duty regulation is high relative to the cost to buy the larger heavy-duty pickup trucks. Since fuel consumption and GHG emissions rise significantly with vehicle mass, a shift from light-duty trucks to heavy-duty trucks would likely lead to higher fuel consumption and GHG emissions, an untended consequence of the regulations. Given the significant price premium of a heavy-duty truck (often five to ten thousand dollars more than a light-duty pickup), we believe that such a class shift would be unlikely whether or not this program existed. These final rules would continue to diminish any incentive for such a class shift because they would narrow the GHG and fuel efficiency performance gap between light-duty and heavy-duty pickup trucks. The regulations for the HD pickup trucks, and similarly for vans, are based on similar technologies and therefore reflect a similar expected increase in cost when compared to the light-duty GHG regulation. Hence, the combination of the two regulations provides little incentive for a shift from light-duty trucks to HD trucks. To the extent that this regulation of heavy-duty pickups and vans could conceivably encourage a class shift towards lighter pickups, this unintended consequence would in fact be expected to lead to lower fuel consumption and GHG emissions as the smaller light-duty pickups have significantly better fuel economy ratings than heavy-duty pickup trucks.

The projected cost increases for this action differ between Class 8 day cabs and Class 8 sleeper cabs, reflecting our conservative assumption for purposes of this analysis on shifting that compliance with the standards would lead truck consumers to specify sleeper cabs equipped with APUs or alternatives to APU while day cab consumers would not. Since Class 8 day cab and sleeper cab trucks perform essentially the same function when hauling a trailer, this raises the possibility that the additional cost for an APU or alternatives to APU equipped sleeper cab could lead to a shift from sleeper cab to day cab trucks. We do not believe that such an intended consequence would occur for the following reasons. The addition of a sleeper berth to a tractor cab is not a consumer-selectable attribute in quite the same way as other vehicle features. The sleeper cab provides a utility that long-distance trucking fleets need to conduct their operations -- an on-board sleeping berth that lets a driver comply with federally-mandated rest periods, as required by the Department of Transportation Federal Motor Carrier Safety Administration's hours-of-service regulations. The cost of sleeper trucks is already higher than the cost of day cabs, yet the fleets that need this utility purchase them.[32] A day cab simply cannot provide this utility with a single driver. The need for this utility would not be changed even if the additional costs to reduce greenhouse gas emissions from sleeper cabs exceed those reducing greenhouse gas emissions from day cabs.[P]

A trucking fleet could instead decide to put its drivers in hotels in lieu of using sleeper berths, and switch to day cabs. However, this is unlikely to occur in any great number, since the added cost for the hotel stays would far overwhelm differences in the marginal cost between day and sleeper cabs. Even if some fleets do opt to buy hotel rooms and switch to day cabs, they would be highly unlikely to purchase a day cab that was aerodynamically worse than the sleeper cab they replaced, since the need for features optimized for long-distance hauling would not have changed. So in practice, there would likely be little difference to the environment for any switching that might occur. Further, while our projected costs in the NPRM assumed the purchase of an APU for compliance for nearly all sleeper cabs, the updated analysis reflects additional flexibility in the final rules that would allow manufacturers to use several other alternatives to APUs that would be much less expensive. Thus, even though we are now projecting that APU costs will be somewhat higher than what we projected for the NPRM, manufacturers and consumers will not be required to use them. In fact our regulatory structure would allow compliance using a near zero cost software utility that eliminates tractor idling after five minutes. Using this compliance approach, the cost difference between a Class 8 sleeper cab and day cab due to our regulations is small. We are proposing this alternative compliance approach reflecting that some sleeper cabs are used in team driving situations where one driver sleeps while the other drives. In that situation, an APU is unnecessary since the tractor is continually being driven when occupied. When it is parked, it would automatically eliminate

[P] The average marginal cost difference between sleeper cabs and day cabs in the final rule is roughly $2,500.

any additional idling through the shutdown software. If trucking businesses choose this option, then costs based on purchase of APUs may overestimate the costs of this program to this sector.

Class shifting from combination tractors to vocational vehicles may occur if a customer deems the additional marginal cost of tractors due to the regulation to be greater than the utility provided by the tractor. The agencies initially considered this issue when deciding whether to include Class 7 tractors with the Class 8 tractors or regulate them as vocational vehicles. The agencies' evaluation of the combined vehicle weight rating of the Class 7 shows that if these vehicles were treated significantly differently from the Class 8 tractors, then they could be easily substituted for Class 8 tractors. Therefore, the agencies would continue to include both classes in the tractor category. The agencies believe that a shift from tractors to vocational vehicles would be limited because of the ability of tractors to pick up and drop off trailers at locations which cannot be done by vocational vehicles.

The agencies do not envision that the regulatory program would cause class shifting within the vocational vehicle class. As vocational vehicles include a wide variety of vehicle types, and serve a wide range of functions, the diversity in the vocational vehicle segment can be primarily attributed to the variety of customer needs for specialized vehicle bodies and added equipment, rather than to the chassis. The new standards are projected to lead to a small increase in the incremental cost per vehicle. However, these cost increases are consistent across the board for both vocational vehicles and the engines used in the vehicle (Table V-30 at Preamble Section V.C.3). The agencies believe that the utility gained from the additional technology package would outweigh the additional cost for vocational vehicles.[Q]

In conclusion, NHTSA and EPA believe that the regulatory structure for HD vehicles and engines would not significantly change the current competitive and market factors that determine purchaser preferences. Furthermore, even if a small amount of shifting would occur, any resulting GHG impacts would likely to be negligible because any vehicle class that sees an uptick in sales is also being regulated for GHG emission control and fuel efficiency. Therefore, the agencies did not include an impact of class shifting on the vehicle populations used to assess the benefits of the program.

8.4.2 Fleet Turnover and Sales Effects

A regulation that affects the cost to purchase and/or operate trucks could affect whether a consumer decides to purchase a new truck and the timing of that purchase. The term pre-buy refers to the idea that truck purchases may occur earlier than otherwise planned to avoid the additional costs associated with a new regulatory requirement. Slower fleet turnover, or low-

[Q] The final rule projects the average per-vehicle costs associated with the 2027 MY standards are projected to be generally less than six percent of the overall price of a new vehicle. The cost-effectiveness of these vocational vehicle standards in dollars per ton is similar to the cost effectiveness estimated for light-duty trucks in the 2017-2025 light duty greenhouse gas standards (Preamble Section V.C.3) (which the agencies found to be highly cost-effective, even without considering payback due to fuel savings).

buys, may occur when owners opt to keep their existing truck rather than purchase a new truck due to the incremental cost of the regulation.

The 2010 NAS HD Report discussed the topics associated with medium- and heavy-duty vehicle fleet turnover. NAS noted that there is some empirical evidence of pre-buy behavior in response to the 2004 and 2007 heavy-duty engine emission standards, with larger impacts occurring in response to higher costs.[33] However, those regulations increased upfront costs to firms without any offsetting future cost savings from reduced fuel purchases. In summary, NAS stated that:

> …during periods of stable or growing demand in the freight sector, pre-buy behavior may have significant impact on purchase patterns, especially for larger fleets with better access to capital and financing. Under these same conditions, smaller operators may simply elect to keep their current equipment on the road longer, all the more likely given continued improvements in diesel engine durability over time. On the other hand, to the extent that fuel economy improvements can offset incremental purchase costs, these impacts will be lessened. Nevertheless, when it comes to efficiency investments, most heavy-duty fleet operators require relatively quick payback periods, on the order of two to three years.[34]

The regulations are projected to return fuel savings to the vehicle owners that offset the cost of the regulation within a few years. The effects of the regulation on purchasing behavior and sales will depend on the nature of the market failures and the extent to which firms consider the projected future fuel savings in their purchasing decisions.

If trucking firms or other buyers account for the rapid payback, they are unlikely to strategically accelerate or delay their purchase plans at additional cost in capital to avoid a regulation that will lower their overall operating costs. As discussed in Chapter 8.2, this scenario may occur if this program reduces uncertainty about fuel-saving technologies. More reliable information about ways to reduce fuel consumption allows truck purchasers to evaluate better the benefits and costs of additional fuel savings, primarily in the original vehicle market, but possibly in the resale market as well. In addition, the standards are expected to lead manufacturers to install more fuel-saving technologies and promote their purchase; the increased availability and promotion may encourage sales.

Other market failures may leave open the possibility of some pre-buy or delayed purchasing behavior. Firms may not consider the full value of the future fuel savings for several reasons. For instance, truck purchasers may not want to invest in fuel efficiency because of uncertainty about fuel prices. Another explanation is that the resale market may not fully recognize the value of fuel savings, due to lack of trust of new technologies or changes in the uses of the vehicles. Lack of coordination (also called split incentives—see Chapter 8.2) between truck purchasers (who may emphasize the up-front costs of the trucks) and truck operators, who like the fuel savings, can also lead to pre-buy or delayed purchasing behavior. If these market failures prevent firms from fully internalizing fuel savings when deciding on vehicle purchases, then pre-buy and delayed purchase could occur and could result in a slight decrease in the GHG benefits of the regulation.

Thus, whether pre-buy or delayed purchase is likely to play a significant role in the truck market depends on the specific behaviors of purchasers in that market. Without additional information about which scenario is more likely to be prevalent, the agencies are not projecting a change in fleet turnover characteristics due to this regulation.

Whether vehicle sales appear to be affected by the HD Phase 1 standards could provide some insight into the impacts of the standards. The Environmental Defense Fund observes that MY 2014 heavy-duty trucks had the highest sales since 2005. Any trends in sales are likely to be affected by macroeconomic conditions, which have been recovering since 2009-2010. The standards may have affected sales, but the size of that effect is likely to be swamped by the effects of the economic recovery. It is unlikely to be possible to separate the effects of the existing standards from other confounding factors.

8.5 Monetized GHG Impacts

8.5.1 Monetized CO_2 Impacts - Social Cost of Carbon

We estimate the global social benefits of CO_2 emission reductions expected from the HD Phase 2 program using the social cost of carbon (SC-CO_2) estimates presented in the *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 (May 2013, Revised July 2015)* ("current SC-CO_2 TSD"). We refer to these estimates, which were developed by the U.S. government, as "SC-CO_2 estimates." The SC-CO_2 is a metric that estimates the monetary value of impacts associated with marginal changes in CO_2 emissions in a given year. It includes a wide range of anticipated climate impacts, such as net changes in agricultural productivity and human health, property damage from increased flood risk, and changes in energy system costs, such as reduced costs for heating and increased costs for air conditioning. It is typically used to assess the avoided damages as a result of regulatory actions (i.e., benefits of rulemakings that lead to an incremental reduction in cumulative global CO_2 emissions).

The SC-CO_2 estimates used in this analysis were developed over many years, using the best science available, and with input from the public. Specifically, an interagency working group (IWG) that included the EPA and other executive branch agencies and offices used three integrated assessment models (IAMs) to develop the SC-CO_2 estimates and recommended four global values for use in regulatory analyses. The SC-CO_2 estimates were first released in February 2010 and updated in 2013 using new versions of each IAM. The 2013 update did not revisit the 2010 modeling decisions with regards to the discount rate, reference case socioeconomic and emission scenarios, and equilibrium climate sensitivity distribution. Rather, improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves and published in the peer-reviewed literature. The 2010 SC-CO_2 Technical Support Document (2010 SC-CO_2 TSD) provides a complete discussion of the methods used to develop these estimates and the current

$SC\text{-}CO_2$ TSD presents and discusses the 2013 update (including recent minor technical corrections to the estimates).[R]

One key methodological aspect discussed in the $SC\text{-}CO_2$ TSDs is the global scope of the estimates. The $SC\text{-}CO_2$ estimates represent global measures because of the distinctive nature of the climate change, which is highly unusual in at least three respects. First, emissions of most GHGs contribute to damages around the world independent of the country in which they are emitted. Second, the U.S. operates in a global, highly interconnected economy, such that impacts on the other side of the world can affect our economy. This means that the true costs of climate change to U.S. are much larger than the direct impacts that simply occur in the U.S. Third, climate change represents a classic public goods problem because each country's reductions benefit everyone else and no country can be excluded from enjoying the benefits of other countries' reductions, even if it provides no reductions itself. In this situation, the only way to achieve an economically efficient level of emissions reductions is for countries to cooperate in providing mutually beneficial reductions beyond the level that would be justified only by their own domestic benefits. In reference to the public good nature of mitigation and its role in foreign relations, thirteen prominent academics noted that these "are compelling reasons to focus on a global SCC" (Pizer et al., 2014). In addition, the IWG recently noted that there is no bright line between domestic and global damages. Adverse impacts on other countries can have spillover effects on the United States, particularly in the areas of national security, international trade, public health and humanitarian concerns.[S]

The 2010 $SC\text{-}CO_2$ TSD also noted a number of limitations to the $SC\text{-}CO_2$ analysis, including the incomplete way in which the IAMs capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. Currently IAMs do not assign value to all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature due to a lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research.[T] The limited amount of research linking climate impacts to economic damages makes the modeling exercise even more difficult. These individual limitations do not all work in the same direction in terms of their influence on the $SC\text{-}CO_2$ estimates, though taken together they suggest that the $SC\text{-}CO_2$ estimates are likely conservative. In particular, the IPCC Fourth Assessment Report (2007) concluded that "It is very likely that [$SC\text{-}CO_2$ estimates] underestimate the damage costs because they cannot include many non-quantifiable impacts." Since then, the peer-reviewed literature has continued to

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[R] Both the 2010 $SC\text{-}CO_2$ TSD and the current $SC\text{-}CO_2$ TSD are available at: https://www.whitehouse.gov/omb/oira/social-cost-of-carbon.

[S] See Response to Comments: Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866, July 2015, page 31, at https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-response-to-comments-final-july-2015.pdf.

[T] Climate change impacts and social cost of greenhouse gases modeling is an area of active research. For example, see: (1) Howard, Peter, "Omitted Damages: What's Missing from the Social Cost of Carbon." March 13, 2014, http://costofcarbon.org/files/Omitted_Damages_Whats_Missing_From_the_Social_Cost_of_Carbon.pdf; and (2) Electric Power Research Institute, "Understanding the Social Cost of carbon: A Technical Assessment," October 2014, www.epri.com.

support this conclusion. For example, the IPCC Fifth Assessment report (2014) observed that SC-CO_2 estimates continue to omit various impacts, such as “the effects of the loss of biodiversity among pollinators and wild crops on agriculture.” Nonetheless, these estimates and the discussion of their limitations represent the best available information about the social benefits of CO_2 reductions to inform benefit-cost analysis. The new versions of the models used to estimate the values presented below offer some improvements in these areas, although further work is warranted.

Accordingly, EPA and other agencies continue to engage in research on modeling and valuation of climate impacts with the goal to improve these estimates. The EPA and other federal agencies also continue to consider feedback on the SC-CO_2 estimates from stakeholders through a range of channels, including public comments on Agency rulemakings that use the SC-CO_2 in supporting analyses and through regular interactions with stakeholders and research analysts implementing the SC-CO_2 methodology used by the IWG. The SC-CO_2 comments received on this rulemaking covered the technical details of the modeling conducted to develop the SC-CO_2 estimates and some also provided constructive recommendations for potential opportunities to improve the SC-CO_2 estimates in future updates. Section 11.8 of the RTC document provides a summary and response to the SC-CO_2 comments submitted to this rulemaking. In addition, OMB sought public comment on the approach used to develop the SC-CO_2 estimates through a separate comment period and published a response to those comments in 2015.[U]

After careful evaluation of the full range of comments submitted to OMB, the IWG continues to recommend the use of the SC-CO_2 estimates in regulatory impact analysis. With the July 2015 release of the response to comments, the IWG announced plans to obtain expert independent advice from the National Academies of Sciences, Engineering and Medicine to ensure that the SC-CO_2 estimates continue to reflect the best available scientific and economic information on climate change.[V] The Academies then convened a committee, “Assessing Approaches to Updating the Social Cost of Carbon,” (Committee) which is reviewing the state of the science on estimating the SC-CO_2, and will provide expert, independent advice on the merits of different technical approaches for modeling and highlight research priorities going forward. EPA will evaluate its approach based upon any feedback received from the Academies’ panel.

To date, the Committee has released an interim report, which recommended against doing a near term update of the SC-CO_2 estimates. For future revisions, the Committee recommended the IWG move efforts towards a broader update of the climate system module consistent with the most recent, best available science, and also offered recommendations for how to enhance the discussion and presentation of uncertainty in the SC-CO_2 estimates. Specifically, the Committee recommended that “the IWG provide guidance in their technical support documents about how [SC-CO_2] uncertainty should be represented and discussed in individual regulatory impact

[U] See https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-response-to-comments-final-july-2015.pdf.
[V] The Academies’ review will be informed by public comments and focus on the technical merits and challenges of potential approaches to improving the SC-CO_2 estimates in future updates. See https://www.whitehouse.gov/blog/2015/07/02/estimating-benefits-carbon-dioxide-emissions-reductions.

analyses that use the [SC-CO_2]" and that the technical support document for each update of the estimates present a section discussing the uncertainty in the overall approach, in the models used, and uncertainty that may not be included in the estimates.[W] At the time of this writing, the IWG is reviewing the interim report and considering the recommendations. EPA looks forward to working with the IWG to respond to the recommendations and will continue to follow IWG guidance on SC-CO_2.

The four SC-CO_2 estimates are as follows: $13, $46, $68, and $140 per metric ton of CO_2 emissions in the year 2020 (2013$).[X] Table 8-5 presents the SC-CO_2 estimates in selected years, rounded to two significant digits. The first three values are based on the average SC-CO_2 from the three IAMs, at discount rates of 5, 3, and 2.5 percent, respectively. SC-CO_2 estimates for several discount rates are included because the literature shows that the SC-CO_2 is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context (where costs and benefits are incurred by different generations). The fourth value is the 95th percentile of the SC-CO_2 from all three models at a 3 percent discount rate. It is included to represent lower probability but higher impact outcomes from climate change, which are captured further out in the tail of the SC-CO_2 distribution, and while less likely than those reflected by the average SC-CO_2 estimates, would be much more harmful to society and therefore, are relevant to policy makers. The SC-CO_2 increases over time because future emissions are expected to produce larger incremental damages as economies grow and physical and economic systems become more stressed in response to greater climate change.

Table 8-5 Social Cost of CO_2, 2012 – 2050[a] (in 2013$ per Metric Ton)

CALENDAR YEAR	DISCOUNT RATE AND STATISTIC			
	5% Average	3% Average	2.5% Average	3% 95th percentile
2012	$12	$36	$58	$100
2015	$12	$40	$62	$120
2020	$13	$46	$68	$140
2025	$15	$51	$75	$150
2030	$18	$55	$80	$170
2035	$20	$60	$86	$180
2040	$23	$66	$92	$200
2045	$25	$70	$98	$220
2050	$29	$76	$100	$230

Note:
[a] The SC-CO_2 values are dollar-year and emissions-year specific and have been rounded to two significant digits. Unrounded numbers from the current SC-CO_2 TSD were adjusted to 2013$ and used to calculate the CO_2 benefits.

[W] National Academies of Sciences, Engineering, and Medicine. (2016). *Assessment of Approaches to Updating the Social Cost of Carbon: Phase 1 Report on a Near-Term Update*. Committee on Assessing Approaches to Updating the Social Cost of Carbon, Board on Environmental Change and Society. Washington, DC: The National Academies Press. doe 10.17226/21898. See Executive Summary, page 1, for quoted text.
[X] The SC-CO_2 values have been rounded to two significant digits. Unrounded numbers from the current SC-CO_2 TSD were adjusted to 2013$ and used to calculate the CO_2 benefits.

Applying the global SC-CO_2 estimates, shown in Table 8-5, to the estimated reductions in domestic CO_2 emissions for the program, we estimate the dollar value of the climate related benefits for each analysis year. In order to calculate the dollar value for emission reductions, the SC-CO_2 estimate for each emissions year will be applied to changes in CO_2 emissions for that year, and then discounted back to the analysis year using the same discount rate used to estimate the SC-CO_2. For internal consistency, the annual benefits are discounted back to net present value terms using the same discount rate as each SC-CO_2 estimate (i.e. 5 percent, 3 percent, and 2.5 percent) rather than the discount rates of 3 percent and 7 percent used to derive the net present value of other streams of costs and benefits of the final rule.[Y] The SC-CO_2 estimates and the associated CO_2 benefit estimates for each calendar year are shown in Table 8-6.

Table 8-6 Annual Upstream and Downstream CO_2 Benefits and Net Present Values for the Given SC-CO_2 Value for the Final Program Relative to the Flat Baseline and using Method B,[a,b] (Millions of 2012$)

CALENDAR YEAR	5% (AVERAGE SC-CO_2 = $12 IN 2012)	3% (AVERAGE SC-CO_2 = $36 IN 2012)	2.5% (AVERAGE SC-CO_2 = $58 IN 2012)	3% (95^{TH} PERCENTILE = $100 IN 2012)
2018	$6.5	$22	$33	$63
2019	$13	$46	$68	$130
2020	$21	$73	$110	$210
2021	$80	$280	$420	$840
2022	$170	$550	$820	$1,700
2023	$250	$850	$1,300	$2,600
2024	$390	$1,300	$2,000	$4,000
2025	$560	$1,800	$2,700	$5,500
2026	$700	$2,400	$3,500	$7,100
2027	$950	$3,000	$4,400	$9,100
2028	$1,100	$3,700	$5,400	$11,000
2029	$1,300	$4,300	$6,400	$13,000
2030	$1,600	$5,000	$7,300	$15,000
2035	$2,700	$8,100	$11,000	$25,000
2040	$3,700	$11,000	$15,000	$33,000
2050	$5,500	$15,000	$20,000	$45,000
NPV[b]	$24,000	$110,000	$180,000	$340,000

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The SC-CO_2 values are dollar-year and emissions-year specific. Note that discounted values of reduced GHG emissions are calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CO_2 at 5, 3, and 2.5 percent) is used to calculate discounted values of SC-CO_2 for internal consistency. Refer to SC-CO_2 TSD for more detail.

[Y] See more discussion on the appropriate discounting of climate benefits using SC-CO_2 in the 2010 SC-CO_2 TSD. Other benefits and costs of regulations unrelated to CO_2 emissions are discounted at the 3% and 7% rates specified in OMB guidance for regulatory analysis.

We also conducted a separate analysis of the CO_2 benefits over the model year lifetimes of vehicles sold in the regulatory timeframe. In contrast to the calendar year analysis, the model year lifetime analysis shows the impacts of the program on each of these MY fleets over the course of their lifetimes. Full details of the inputs to this analysis can be found in RIA Chapter 5. The CO_2 benefits in the context of this MY lifetime analysis are shown in Table 8-7 for each of the four different social cost of carbon values. The CO_2 benefits shown for each model year represent the net present value of the benefits in each year in the model year life discounted back to the first year of the model year. The same discount rate used to discount the value of damages from future emissions (SC-CO_2 at 5, 3, and 2.5 percent) is used to calculate the net present value of SC-CO_2 for internal consistency.

Table 8-7 Discounted Model Year Lifetime Upstream & Downstream CO_2 Benefits for the Given SC-CO_2 Value for the Final Program Relative to the Less Dynamic Baseline and using Method B (Millions of 2012$)[a,b]

MODEL YEAR	5% (AVERAGE SC-CO_2 = $12 IN 2012)	3% (AVERAGE SC-CO_2 = $36 IN 2012)	2.5% (AVERAGE SC-CO_2 = $58 IN 2012)	3% (95^{TH} PERCENTILE = $100 IN 2012)
2018	$38	$150	$230	$450
2019	$36	$140	$220	$430
2020	$34	$140	$220	$420
2021	$560	$2,300	$3,600	$7,000
2022	$590	$2,500	$3,900	$7,500
2023	$610	$2,600	$4,000	$7,800
2024	$920	$4,000	$6,200	$12,000
2025	$940	$4,100	$6,400	$12,000
2026	$950	$4,200	$6,600	$13,000
2027	$1,200	$5,400	$8,500	$16,000
2028	$1,200	$5,300	$8,400	$16,000
2029	$1,200	$5,300	$8,400	$16,000
Sum	$8,200	$36,000	$57,000	$110,000

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The SC-CO_2 values are dollar-year and emissions-year specific. Note that discounted values of reduced GHG emissions are calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CO_2 at 5, 3, and 2.5 percent) is used to calculate discounted values of SC-CO_2 for internal consistency. Refer to SC-CO_2 TSD for more detail.

8.5.2 Non-CO_2 GHG Impacts

EPA calculated the global social benefits of CH_4 and N_2O emissions reductions expected from the final rulemaking using estimates of the social cost of methane (SC-CH_4) and the social cost of nitrous oxide (SC-N_2O). Similar to the SC- CO_2, the SC- CH_4 and SC- N_2O estimate the monetary value of impacts associated with marginal changes in CH_4 and N_2O emissions, respectively, in a given year. Each metric includes a wide range of anticipated climate impacts, such as net changes in agricultural productivity and human health, property damage from increased flood risk, and changes in energy system costs, such as reduced costs for heating and increased costs for air conditioning. The SC-CH_4 and SC-N_2O estimates applied in this analysis were developed by Marten *et al.* (2014) and are discussed in greater detail below. EPA is unaware of analogous estimates of HFC-134a and has therefore presented a sensitivity analysis, separate from the main benefit cost analysis, that approximates the benefits of HFC-134a reductions based on global warming potential (GWP) gas comparison metrics ("GWP approach"). Other unquantified non-CO_2 benefits are discussed in this section as well.

8.5.2.1 Monetized CH_4 and N_2O Impacts

As discussed in the proposed rulemaking, a challenge particularly relevant to the monetization of non- CO_2 GHG impacts is that the IWG did not estimate the social costs of non-CO_2 GHG emissions at the time the SC-CO_2 estimates were developed. While there are other estimates of the social cost of non- CO_2 GHGs in the peer review literature, none of those estimates are consistent with the SC- CO_2 estimates developed by the IWG and most are likely underestimates due to changes in the underlying science subsequent to their publication.[Z]

However, in the time leading up to the proposal for this rulemaking, a paper by Marten *et al.* (2014) provided the first set of published SC-CH_4 and SC-N_2O estimates in the peer-reviewed literature that are consistent with the modeling assumptions the IWG used to develop the SC-CO_2 estimates. Specifically, the estimation approach Marten *et al.* used incorporated the same set of three IAMs, five socioeconomic and emissions scenarios, equilibrium climate sensitivity distribution, three constant discount rates, and the aggregation approach used by the IWG to develop the SC-CO_2 estimates. The aggregation method involved distilling the 45 distributions of each metric produced for each emissions year into four estimates: the mean across all models and scenarios using a 2.5 percent, 3 percent, and 5 percent discount rate, and the 95th percentile of the pooled estimates from all models and scenarios using a 3 percent discount rate. Marten et al. also used the same rationale as the IWG to develop global estimates of the SC-CH_4 and the SC-N_2O, given that CH_4 and N_2O are global pollutants.

In addition, the atmospheric lifetime and radiative efficacy of methane used by Marten *et al.* is based on the estimates reported by the IPCC in their Fourth Assessment Report (AR4, 2007), including an adjustment in the radiative efficacy of methane to account for its role as a precursor for tropospheric ozone and stratospheric water. These values represent the same ones used by the IPCC in AR4 for calculating GWPs. At the time Marten *et al.* developed their estimates of the SC-CH_4, AR4 was the latest assessment report by the IPCC. The IPCC updates GWP estimates with each new assessment, and in the most recent assessment, AR5, the latest estimate of the methane GWP ranged from 28-36, compared to a GWP of 25 in AR4. The updated values reflect a number of changes: changes in the lifetime and radiative efficiency estimates for CO_2, changes in the lifetime estimate for methane, and changes in the correction factor applied to methane's GWP to reflect the effect of methane emissions on other climatically

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[Z] As discussed in previous RIAs (e.g., EPA 2012), there is considerable variation among these published estimates in the models and input assumptions they employ. These studies differ in the emission perturbation year, employ a wide range of constant and variable discount rate specifications, and consider a range of baseline socioeconomic and emissions scenarios that have been developed over the last 20 years. The researchers cited in EPA 2012 include: Fankhauser (1994); Kandlikar (1995); Hammitt et al. (1996); Tol et al. (2003); Tol (2004); and Hope and Newberry (2006).

important substances such as tropospheric ozone and stratospheric water vapor. In addition, the range presented in the latest IPCC report reflects different choices regarding whether to account for climate feedbacks on the carbon cycle for both methane and CO_2 (rather than just for CO_2 as was done in AR4).[AA,BB]

The resulting SC-CH_4 and SC-N_2O estimates are presented in Table 8-8. Marten *et al.* (2014) discuss these estimates and compare them with other recent estimates in the literature. The authors noted that a direct comparison of their estimates with all of the other published estimates is difficult, given the differences in the models and socioeconomic and emissions scenarios, but results from three relatively recent studies offer a better basis for comparison (see Hope (2006), Marten and Newbold (2012), Waldhoff et al. (2014)). Marten *et al.* found that, in general, the SC-CH_4 estimates from their 2014 paper are higher than previous estimates and the SC- N_2O estimates from their 2014 paper fall within the range from Waldhoff et al. The higher SC- CH_4 estimates are partially driven by the higher effective radiative forcing due to the inclusion of indirect effects from methane emissions in their modeling. Marten *et al*., similar to other recent studies, also find that their directly modeled SC- CH_4 and SC-N_2O estimates are higher than the GWP-weighted estimates. More detailed results and a comparison to other published estimates can be found in Marten *et al*. (2014).

Table 8-8 Social Cost of CH_4 and N_2O, 2012 – 2050[a] [2013$ per metric ton]
(Source: Marten et al. (2014)[b])

YEAR	SC-CH_4				SC-N_2O			
	5% Average	3% Average	2.5% Average	3% 95th percentile	5% Average	3% Average	2.5% Average	3% 95th percentile
2012	$440	$1,000	$1,400	$2,800	$4,000	$14,000	$21,000	$36,000
2015	490	1,100	1,500	3,100	4,400	14,000	22,000	38,000
2020	590	1,300	1,800	3,500	5,200	16,000	24,000	43,000
2025	710	1,500	2,000	4,100	6,000	19,000	26,000	48,000
2030	830	1,800	2,200	4,600	6,900	21,000	30,000	54,000
2035	990	2,000	2,500	5,400	8,100	23,000	32,000	60,000
2040	1,100	2,200	2,900	6,000	9,200	25,000	35,000	66,000
2045	1,300	2,500	3,100	6,700	10,000	27,000	37,000	73,000
2050	1,400	2,700	3,400	7,400	12,000	30,000	41,000	79,000

Notes:
[a] The values are emissions-year specific and have been rounded to two significant digits, as shown in Marten et al. (2014). These rounded numbers were used to calculate the GHG benefits.

[AA] *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
[BB] Note that this analysis uses a GWP value for methane of 25 for CO_2 equivalency calculations, consistent with the GHG emissions inventories and the IPCC Fourth Assessment Report (AR4).

[b] The estimates in this table have been adjusted to reflect the minor technical corrections to the $SC\text{-}CO_2$ estimates described above. See the Corrigendum to Marten et al. (2014), http://www.tandfonline.com/doi/abs/10.1080/14693062.2015.1070550

In addition to requesting comment on these estimates in the proposed rulemaking, EPA noted that it had initiated a peer review of the application of the Marten *et al* (2014) non- CO_2 social cost estimates in regulatory analysis.[CC] EPA also stated that, pending a favorable peer review, it planned to use the Marten *et al* (2014) estimates to monetize benefits of CH_4 and N_2O emission reduction in the main benefit-cost analysis of the final rule.

Since then, EPA received responses that supported this application. Three reviewers considered seven charge questions that covered issues such as the EPA's interpretation of the Marten *et al.* estimates, the consistency of the estimates with the $SC\text{-}CO_2$ estimates, the EPA's characterization of the limits of the GWP-approach to value non-CO_2 GHG impacts, and the appropriateness of using the Marten *et al.* estimates in regulatory impact analyses. The reviewers agreed with the EPA's interpretation of Marten *et al.*'s estimates, generally found the estimates to be consistent with the $SC\text{-}CO_2$ estimates, and concurred with the limitations of the GWP approach, finding directly modeled estimates to be more appropriate. While outside of the scope of the review, the reviewers briefly considered the limitations in the $SC\text{-}CO_2$ methodology (e.g., those discussed earlier in this section) and noted that because the $SC\text{-}CO_2$ and $SC\text{-}CH_4$ and $SC\text{-}N_2O$ methodologies are similar, the limitations also apply to the resulting $SC\text{-}CH_4$ and $SC\text{-}N_2O$ estimates. Two of the reviewers concluded that use of the $SC\text{-}CH_4$ and $SC\text{-}N_2O$ estimates developed by Marten *et al.* and published in the peer-reviewed literature is appropriate in RIAs, provided that the Agency discuss the limitations, similar to the discussion provided for $SC\text{-}CO_2$ and other economic analyses. All three reviewers encouraged continued improvements in the $SC\text{-}CO_2$ estimates and suggested that as those improvements are realized they should also be reflected in the $SC\text{-}CH_4$ and $SC\text{-}N_2O$ estimates, with one reviewer suggesting the $SC\text{-}CH_4$ and $SC\text{-}N_2O$ estimates lag this process. The EPA supports continued improvement in the $SC\text{-}CO_2$ estimates developed by the U.S. government and agrees that improvements in the $SC\text{-}CO_2$ estimates should also be reflected in the $SC\text{-}CH_4$ and $SC\text{-}N_2O$ estimates. The fact that the reviewers agree that the $SC\text{-}CH_4$ and $SC\text{-}N_2O$ estimates are generally consistent with the $SC\text{-}CO_2$ estimates that are recommended by OMB's guidance on valuing CO_2 emissions reductions, leads the EPA to conclude that use of the $SC\text{-}CH_4$ and $SC\text{-}N_2O$ estimates is an analytical improvement over excluding CH_4 and N_2O emissions from the monetized portion of the benefit cost analysis.

The EPA also carefully considered the full range of public comments and associated technical issues on the Marten et al. estimates received through this rulemaking and determined that it would continue to use the estimates in the final rulemaking analysis. Based on the evaluation of the public comments on this rulemaking, the favorable peer review of the

[CC] For a copy of the peer review and the responses, see https://cfpub.epa.gov/si/si_public_pra_view.cfm?dirEntryID=291976 (see "SCCH4 EPA PEER REVIEW FILES.PDF").

application of Marten *et al.* estimates, and past comments urging EPA to value non-CO_2 GHG impacts in its rulemakings,[DD] EPA concluded that the estimates represent the best scientific information on the impacts of climate change available in a form appropriate for incorporating the damages from incremental CH_4 and N_2O emissions changes into regulatory analysis and has therefore included those benefits in the main benefits analysis. Please see the Response to Comments document, Section X, for detailed responses to the comments on non-CO_2 GHG valuation.

The application of directly modeled estimates from Marten *et al.* (2014) to benefit-cost analysis of a regulatory action is analogous to the use of the SC-CO_2 estimates. Specifically, the SC-CH_4 and SC-N_2O estimates in Table 8-8 are used to monetize the benefits of reductions in CH_4 and N_2O emissions, respectively, expected as a result of the rulemaking. Forecasted changes in CH_4 (N_2O) emissions in a given year, expected as a result of the regulatory action, are multiplied by the SC-CH_4 (SC-N_2O) estimate for that year. To obtain a present value estimate, the monetized stream of future non-CO_2 benefits are discounted back to the analysis year using the same discount rate used to estimate the social cost of the non-CO_2 GHG emission changes. The limitations for the SC-CO_2 estimates discussed above likewise apply to the SC-CH_4 and SC-N_2O estimates, given the consistency in the methodology.

The CH_4 and N_2O benefits based on Marten *et al.* (2014) are presented for each calendar year in Table 8-9 and Table 8-10, respectively.

[DD] EPA sought public comments on the valuation of non-CO_2 GHG impacts in previous rulemakings (e.g., U.S. EPA 2012b, 2012d). In general, the commenters that support valuation of CO_2 impacts strongly encouraged EPA to incorporate the monetized value of non-CO_2 GHG impacts into the benefit cost analysis, however they noted the challenges associated with the GWP-approach, as discussed later in this section, and encouraged the use of directly-modeled estimates of the social cost of non- CO_2 GHGs to overcome those challenges.

Table 8-9 Annual Upstream and Downstream CH_4 GHG Benefits and Net Present Values for the Given SC-CH_4 Value for the Final Program Relative to the Flat Baseline and using Method B, using the Directly Modeled Approach, Calendar Year Analysis (Millions of 2013$)[a,b]

CALENDAR YEAR	5% (AVERAGE SC-CH_4 = $440 IN 2012)	3% (AVERAGE SC-CH_4 = $1000 IN 2012)	2.5% (AVERAGE SC-CH_4 = $1400 IN 2012)	3% (95^{TH} PERCENTILE = $2800 IN 2012)
2018	$0.3	$0.6	$0.8	$1.6
2019	$0.6	$1.3	$1.7	$3.4
2020	$0.9	$2.0	$2.7	$5.4
2021	$3.7	$8.2	$11	$22
2022	$7.4	$16	$21	$43
2023	$12	$26	$33	$68
2024	$19	$40	$52	$110
2025	$26	$56	$72	$150
2026	$34	$72	$92	$190
2027	$44	$94	$120	$250
2028	$54	$120	$150	$300
2029	$65	$140	$170	$360
2030	$76	$160	$200	$420
2035	$130	$260	$340	$720
2040	$180	$360	$460	$980
2050	$280	$530	$660	$1,400
NPV[b]	$1,200	$3,800	$5,400	$10,000

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The SC-CH_4 values are dollar-year and emissions-year specific. Note that discounted values of reduced GHG emissions are calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CH_4 at 5, 3, and 2.5 percent) is used to calculate discounted values of SC-CH_4 for internal consistency.

Table 8-10 Annual Upstream and Downstream N_2O GHG Benefits and Net Present Values for the Given SC-N_2O Value for the Final Program Relative to the Less Dynamic Baseline and using Method B, using the Directly Modeled Approach, Calendar Year Analysis (Millions of 2013$)[a,b]

CALENDAR YEAR	5% (AVERAGE SC-N_2O = $4000 IN 2012)	3% (AVERAGE SC-N_2O = $14000 IN 2012)	2.5% (AVERAGE SC-N_2O = $21000 IN 2012)	3% (95^{TH} PERCENTILE = $36000 IN 2012)
2018	$0.0	$0.0	$0.0	$0.1
2019	$0.0	$0.1	$0.1	$0.2
2020	$0.0	$0.1	$0.2	$0.3
2021	$0.1	$0.4	$0.5	$1.0
2022	$0.2	$0.7	$1.1	$1.9
2023	$0.4	$1.2	$1.7	$3.0
2024	$0.6	$1.8	$2.6	$4.7
2025	$0.8	$2.5	$3.6	$6.6
2026	$1.1	$3.3	$4.6	$8.5
2027	$1.4	$4.2	$6.0	$11
2028	$1.7	$5.2	$7.4	$13
2029	$2.0	$6.2	$8.8	$16
2030	$2.4	$7.2	$10	$19
2035	$4.1	$12	$16	$31
2040	$5.7	$16	$22	$41
2050	$8.9	$22	$30	$58
NPV[b]	$37	$160	$250	$430

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The SC-N_2O values are dollar-year and emissions-year specific. Note that discounted values of reduced GHG emissions are calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (N_2O at 5, 3, and 2.5 percent) is used to calculate discounted values of N_2O for internal consistency.

8.5.2.2 Sensitivity Analysis – HFC-134a Benefits Based on the GWP Approximation Approach

While the rulemaking will result in reductions of HFC-134a, EPA is unaware of estimates of the social cost of HFC-134a that are analogous to the SC- CO_2, SC- CH_4, and SC- N_2O estimates discussed in the previous section. Therefore, EPA has used an alternative approach to approximate the value of HFC-134a impacts and presents the results in this sensitivity analysis, separate from the main benefit cost analysis. Specifically, EPA has used the GWP for HFC-134a to convert the emissions of this gas to CO_2 equivalents, which are then valued using the SC-CO_2 estimates.

The GWP measures the cumulative radiative forcing from a perturbation of a non-CO_2 GHG relative to a perturbation of CO_2 over a fixed time horizon, often 100 years. The GWP mainly reflects differences in the radiative efficiency of gases and differences in their atmospheric lifetimes. While the GWP is a simple, transparent, and well-established metric for assessing the relative impacts of non-CO_2 emissions compared to CO_2 on a purely physical basis, there are several well-documented limitations in using it to value non-CO_2 GHG benefits, as discussed in the 2010 SC-CO_2 TSD and previous rulemakings (e.g., U.S. EPA 2012b, 2012d).[EE] In particular, several recent studies found that GWP-weighted benefit estimates for CH_4 and N_2O are likely to be lower than the estimates derived using directly modeled social cost estimates for these gases (Marten and Newbold, 2012; Marten et al. 2014; and Waldhoff et al. 2014). Gas comparison metrics, such as the GWP, are designed to measure the impact of non-CO_2 GHG emissions relative to CO_2 at a specific point along the pathway from emissions to monetized damages (Depicted in Figure 8-2), and this point may differ across measures.

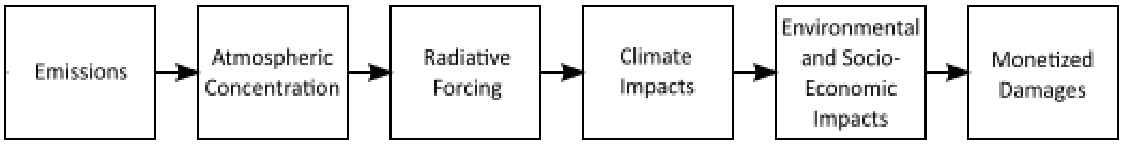

Figure 8-2 Path from GHG Emissions to Monetized Damages (Source: Marten et al., 2014)

The GWP is not ideally suited for use in benefit-cost analyses to approximate the social cost of non-CO_2 GHGs because they ignore important nonlinear relationships beyond radiative forcing in the chain between emissions and damages. These can become relevant because gases have different lifetimes and the SC-CO_2 takes into account the fact that marginal damages from an increase in temperature are a function of existing temperature levels. Another limitation of gas comparison metrics for this purpose is that some environmental and socioeconomic impacts are not linked to all of the gases under consideration, or radiative forcing for that matter, and will therefore be incorrectly allocated. For example, the economic impacts associated with increased agricultural productivity due to higher atmospheric CO_2 concentrations included in the SC-CO_2 will be incorrectly allocated to HFC-134a emissions with the GWP-based valuation approach.

Furthermore, the assumptions made in estimating the GWP are not consistent with the assumptions underlying SC-CO_2 estimates in general, and the SC-CO_2 estimates developed by the IWG more specifically. For example the 100-year time horizon usually used in estimating the GWP is less than the 300-year horizon the IWG used in developing the SC-CO_2 estimates. The GWP approach also treats all impacts within the time horizon equally, independent of the time at which they occur. This is inconsistent with the role of discounting in economic analysis, which accounts for a basic preference for earlier over later gains in utility and expectations regarding future levels of economic growth. While EPA is unaware of studies that have examined HFC-134a specifically, which has a relatively short lifetime compared to CO_2, the findings from Marten and Newbold 2012 suggest that the temporal independence of the GWP could lead the GWP approach to underestimate the SC-HFC-134a with a larger downward bias under higher discount rates. Additionally, because HFC-134a does not contribute to CO_2 fertilization, that would also lead the GWP approach to underestimate the SC-HFC-134a (Marten and Newbold 2012).[FF]

[EE] See also Reilly and Richards, 1993; Schmalensee, 1993; Fankhauser, 1994; Marten and Newbold, 2012.
[FF] The average atmospheric lifetime of HFC-134a is about 13 years. Marten and Newbold (2012) examined CH_4, which also has a relatively short atmospheric lifetime compared to CO_2, and found that the GWP approach could underestimate the SC-CH_4. We note that the truncation of the time period in the GWP calculation could lead to an

Although directly modeled estimates of the social cost of HFC-134a may offer an improvement over the GWP approach, EPA is unaware of published estimates that are consistent with the SC-CO_2 estimates developed by the IWG. Therefore, EPA has continued to apply the GWP approach to approximate the HFC-134a benefits. Given the limitations discussed above, EPA also continues to present the results in a sensitivity analysis rather than the main benefit-cost analysis.[GG]

Under the GWP approach, EPA converted HFC-134a to CO_2 equivalents for each calendar year using the AR4 100-year GWP for HFC-134a (1,430).[35] These CO_2-equivalent emission reductions are multiplied by the SC-CO_2 estimate corresponding to each year of emission reductions. As with the calculation of annual benefits of CO_2 emission reductions, the annual benefits of HFC-134a emission reductions based on the GWP approach are discounted back to net present value terms using the same discount rate as each SC-CO_2 estimate. The estimated HFC-134a benefits using the GWP approach are presented in Table 8-11.

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overestimate of the SC-non- CO_2 for near term perturbation years in cases where the SC-CO_2 is based on a sufficiently low or steeply declining discount rate.

[GG] For example, the 2012 New Source Performance Standards and Amendments to the National Emissions Standards for Hazardous Air Pollutants for the Oil and Natural Gas Industry are expected to reduce methane emissions by 900,000 metric tons annually, see http://www.gpo.gov/fdsys/pkg/FR-2012-08-16/pdf/2012-16806.pdf. Additionally, the 2017-2025 Light-duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards, promulgated jointly with the National Highway Traffic Safety Administration, is expected to reduce methane emissions by over 100,000 metric tons in 2025 increasing to nearly 500,000 metric tons in 2050, see http://www.gpo.gov/fdsys/pkg/FR-2012-10-15/pdf/2012-21972.pdf.

Table 8-11 Annual Upstream and Downstream HFC-134a GHG Benefits and Net Present Values for the Given SC-CO_2 Value for Final Program Relative to the Flat Baseline and using Method B, using the GWP Approach (Millions of 2013$)[a,b]

CALENDAR YEAR	5% (AVERAGE SC-CO_2 = $12 IN 2012)	3% (AVERAGE SC-CO_2 = $36 IN 2012)	2.5% (AVERAGE SC-CO_2 = $58 IN 2012)	3% (95TH PERCENTILE = $100 IN 2012)
2018	$0.0	$0.0	$0.0	$0.0
2019	$0.0	$0.0	$0.0	$0.0
2020	$0.0	$0.0	$0.0	$0.0
2021	$0.2	$0.8	$1.3	$2.5
2022	$0.5	$1.7	$2.6	$5.1
2023	$0.8	$2.6	$3.9	$7.9
2024	$1.1	$3.6	$5.3	$11
2025	$1.4	$4.7	$7.0	$14
2026	$1.7	$5.9	$8.6	$18
2027	$2.2	$7.1	$10	$21
2028	$2.6	$8.3	$12	$25
2029	$2.9	$10	$14	$29
2030	$3.5	$11	$16	$33
2035	$5.0	$15	$22	$47
2040	$6.2	$18	$25	$54
2050	$8.6	$23	$31	$70
NPV[b]	$44	$200	$320	$620

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The SC-CO_2 values are dollar-year and emissions-year specific. Note that discounted values of reduced GHG emissions are calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CO_2 at 5, 3, and 2.5 percent) is used to calculate discounted values of SC-CO_2 for internal consistency. Refer to 2010 SC-CO_2 TSD for more detail.

8.5.2.3 Additional non-CO_2 GHGs Co-Benefits

In determining the relative social costs of the different gases, the Marten et al. (2014) analysis accounts for differences in lifetime and radiative efficiency between the non-CO_2 GHGs and CO_2. The analysis also accounts for radiative forcing resulting from methane's effects on tropospheric ozone and stratospheric water vapor, and for at least some of the fertilization effects of elevated carbon dioxide concentrations. However, there exist several other differences between these gases that have not yet been captured in this analysis, for example the non-radiative effects of methane-driven elevated tropospheric ozone levels on human health, agriculture, and ecosystems, and the effects of carbon dioxide on ocean acidification. Inclusion of these additional non-radiative effects would potentially change both the absolute and relative value of the various gases.

Of these effects, the human health effect of elevated tropospheric ozone levels resulting from methane emissions is the closest to being monetized in a way that would be comparable to the SCC. Premature ozone-related cardiopulmonary deaths resulting from global increases in tropospheric ozone concentrations produced by the methane oxidation process have been the focus of a number of studies over the past decade (e.g., West et al. 2006[36]). Recent studies have produced an estimate of a monetized benefit of methane emissions reductions, with results on the order of $1000 per metric ton of CH_4 emissions reduced (Anenberg et al. 2012[37]; Shindell et al. 2012[38]; Sarofim et al. 2015[39]), an estimate similar in magnitude to the climate benefits of CH_4 reductions estimated by the Marten et al. or GWP methods. However, though EPA is continuing to monitor this area of research as it evolves, EPA is not applying them for benefit estimates at this time.

8.6 Quantified and Monetized Non-GHG Health and Environmental Impacts

This section discusses the economic benefits from reductions in health and environmental impacts resulting from non-GHG emission reductions that can be expected to occur as a result of the Phase 2 standards. CO_2 emissions are predominantly the byproduct of fossil fuel combustion processes that also produce criteria and hazardous air pollutant emissions. The vehicles that are subject to the Phase 2 standards are also significant sources of mobile source air pollution such as direct PM, NO_X, VOCs and air toxics. The standards will affect exhaust emissions of these pollutants from vehicles and will also affect emissions from upstream sources that occur during the refining and distribution of fuel. Changes in ambient concentrations of ozone, $PM_{2.5}$, and air toxics that will result from the Phase 2 standards are expected to affect human health by reducing premature deaths and other serious human health effects, as well as other important improvements in public health and welfare. Children especially benefit from reduced exposures to criteria and toxic pollutants, because they tend to be more sensitive to the effects of these respiratory pollutants. Ozone and particulate matter have been associated with increased incidence of asthma and other respiratory effects in children, and particulate matter has been associated with a decrease in lung maturation. Some minority groups and children living under the poverty line are even more vulnerable with higher prevalence of asthma.

It is important to quantify the health and environmental impacts associated with the standards because a failure to adequately consider ancillary impacts could lead to an incorrect assessment of their costs and benefits. Moreover, the health and other impacts of exposure to criteria air pollutants and airborne toxics tend to occur in the near term, while most effects from reduced climate change are likely to occur only over a time frame of several decades or longer.

As mentioned in Chapter 7, impacts such as emissions reductions, costs and benefits are presented in this analysis from two perspectives:

- A "model year lifetime analysis" (MY), which shows impacts of the program that occur over the lifetime of the vehicles produced during the model years subject to the Phase 2 standards (MYs 2018 through 2029); and,
- A "calendar year analysis" (CY), which shows annual costs and benefits of the Phase 2 standards for each year from 2018 through 2050. We assume the standard in the last model year subject to the standards applies to all subsequent MY fleets developed in the future.

In previous light-duty and heavy-duty GHG rulemakings, EPA has quantified and monetized non-GHG health impacts using two different methods. For the MY analysis, EPA applies PM-related "benefits per-ton" values to the stream of lifetime estimated emission reductions as a reduced-form approach to estimating the $PM_{2.5}$-related benefits of the rule.[40,HH] For the CY analysis, EPA typically conducts full-scale photochemical air quality modeling to quantify and monetize the $PM_{2.5}$- and ozone-related health impacts of a single representative future year. EPA then assumes these benefits are repeated in subsequent future years when criteria pollutant emission reductions are equal to or greater than those modeled in the representative future year.

This two-pronged approach to estimating non-GHG impacts is precipitated by the length of time needed to prepare the necessary emissions inventories and the processing time associated with full-scale photochemical air quality modeling for a *single* representative future year. The timing requirements (along with other resource limitations) preclude EPA from being able to do the more detailed photochemical modeling for every year that we include in our benefit and cost estimates, and require EPA to make air quality modeling input decisions early in the analytical process. As a result, it was necessary to use emissions from the proposed program to conduct the air quality modeling for this action.

The chief limitation when using air quality inventories based on emissions from the proposal in the CY modeling analysis is that they can diverge from the estimated emissions of the final rulemaking. How much the emissions might diverge and how that difference would impact the air quality modeling and health benefit results is difficult to anticipate. For the FRM, EPA concluded that when comparing the proposal and final rule inventories, the differences were enough to justify the move of the typical CY benefits analysis (based on air quality modeling) from the primary estimate of costs and benefits to a supplemental analysis in an appendix to the RIA (See Appendix 8A).[II] While we believe this supplemental analysis is still illustrative of the standard's potential benefits, EPA has instead chosen to characterize the CY benefits in a manner consistent with the MY lifetime analysis. That is, we apply the PM-related "benefits per-ton" values to the CY final rule emission reductions to estimate the PM-related benefits of the final rule.

This section presents the benefits-per-ton values used to monetize the benefits from reducing population exposure to PM associated with the standards. EPA bases its analyses on peer-reviewed studies of air quality and health and welfare effects and peer-reviewed studies of the monetary values of public health and welfare improvements, and is generally consistent with benefits analyses performed for the analysis of the final Tier 3 Vehicle Rule,[41] the final 2012 PM NAAQS Revision,[42] and the final 2017-2025 Light Duty Vehicle GHG Rule.[43]

EPA is also requiring that rebuilt engines installed in new incomplete vehicles (i.e., "glider kit" vehicles) meet the emission standards applicable in the year of assembly of the new vehicle, including all applicable standards for criteria pollutants (Section XIII.B of the Preamble). For the final rule, EPA has updated its analysis of the environmental impacts of these glider kit vehicles (see Section XIII.B.1 of the Preamble). These standards will decrease PM and

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[HH] See: http://www3.epa.gov/airquality/benmap/sabpt.html. The current values available on the webpage have been updated since the publication of the Fann et al., 2012 paper. For more information regarding the updated values, see https://www3.epa.gov/sites/production/files/2014-10/documents/sourceapportionmentbpttsd.pdf (accessed May 2, 2016).

[II] Chapter 5 of the RIA discusses the reasons for these differences in more detail.

NO_X emissions dramatically, leading to substantial public health-related benefits. Although we only present these benefits as a sensitivity analysis in Section XIII of the Preamble, it is clear that removing even a fraction of glider kit vehicles from the road will yield substantial health-related benefits that are not captured by the primary estimate of monetized non-GHG health impacts described in this section.

8.6.1 Economic Value of Reductions in Particulate Matter

As described in Chapter 5, the standards will reduce emissions of several criteria and toxic pollutants and their precursors. In this analysis, EPA only estimates the economic value of the human health benefits associated with the resulting reductions in $PM_{2.5}$ exposure. Due to analytical limitations with the benefit per-ton method, this analysis does not estimate benefits resulting from reductions in population exposure to other criteria pollutants such as ozone.[JJ] Furthermore, the benefits per-ton method, like all air quality impact analyses, does not monetize all of the potential health and welfare effects associated with reduced concentrations of $PM_{2.5}$.

This analysis uses estimates of the benefits from reducing the incidence of the specific $PM_{2.5}$-related health impacts described below. These estimates, which are expressed per ton of $PM_{2.5}$-related emissions eliminated by the final program, represent the total monetized value of human health benefits (including reduction in both premature mortality and premature morbidity) from reducing each ton of directly emitted $PM_{2.5}$, or its precursors (SO_2 and NO_X), from a specified source. Ideally, the human health benefits would be estimated based on changes in ambient $PM_{2.5}$ as determined by full-scale air quality modeling. However, the length of time needed to prepare the necessary emissions inventories, in addition to the processing time associated with the modeling itself, has precluded us from performing air quality modeling for this final program.

The PM-related dollar-per-ton benefit estimates used in this analysis are provided in Table 8-12. As the table indicates, these values differ among pollutants, and also depend on their original source, because emissions from different sources can result in different degrees of population exposure and resulting health impacts. In the summary of costs and benefits, Chapter 8.10, EPA presents the monetized value of PM-related improvements associated with the final program.

[JJ] The air quality modeling that underlies the PM-related benefit per ton values also produced estimates of ozone levels attributable to each sector. However, the complex non-linear chemistry governing ozone formation prevented EPA from developing a complementary array of ozone benefit per ton values. This limitation notwithstanding, we anticipate that the ozone-related benefits associated with reducing emissions of NO_X and VOC could be substantial.

Table 8-12 PM-related Benefits-per-ton Values (thousands, 2013$) [a]

YEAR[C]	ON-ROAD MOBILE SOURCES			UPSTREAM SOURCES[D]		
	Direct $PM_{2.5}$	SO_2	NO_X	Direct $PM_{2.5}$	SO_2	NO_X
Estimated Using a 3 Percent Discount Rate[b]						
2016	$380-$870	$20-$46	$7.8-$18	$330-$760	$71-$160	$6.9-$16
2020	$410-$920	$22-$50	$8.2-$18	$350-$800	$76-$170	$7.5-$17
2025	$450-$1,000	$25-$56	$9.0-$20	$400-$890	$84-$190	$8.2-$18
2030	$490-$1,100	$28-$62	$9.7-$22	$430-$960	$92-$200	$8.9-$20
Estimated Using a 7 Percent Discount Rate[b]						
2016	$340-$780	$18-$42	$7.1-$16	$300-$680	$64-$140	$6.3-$14
2020	$370-$830	$20-$45	$7.5-$17	$320-$730	$68-$150	$6.7-$15
2025	$410-$920	$22-$50	$8.1-$18	$350-$800	$76-$170	$7.4-$17
2030	$440-$990	$25-$56	$8.8-$20	$380-$870	$82-$180	$8.0-$18

Notes:
[a] The benefit-per-ton estimates presented in this table are based on a range of premature mortality estimates derived from the ACS study (Krewski et al., 2009) and the Six-Cities study (Lepeule et al., 2012).
[b] The benefit-per-ton estimates presented in this table assume either a 3 percent or 7 percent discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag.
[c] Benefit-per-ton values were estimated for the years 2016, 2020, 2025 and 2030. We hold values constant for intervening years (e.g., the 2016 values are assumed to apply to years 2017-2019; 2020 values for years 2021-2024; 2030 values for years 2031 and beyond).
[d] We assume for the purpose of this analysis that "upstream emissions" are most closely associated with refinery sector benefit per-ton values. The majority of upstream emission reductions associated with the final rule are related to domestic onsite refinery emissions and domestic crude production. While upstream emissions also include storage and transport sources, as well as upstream refinery sources, we have chosen to simply apply the refinery values.

The benefit per-ton technique has been used in previous analyses, including EPA's 2017-2025 Light-Duty Vehicle Greenhouse Gas Rule,[44] the Reciprocating Internal Combustion Engine rules,[45,46] and the Residential Wood Heaters NSPS.[47] Table 8-13 shows the quantified $PM_{2.5}$-related co-benefits captured in those benefit per-ton estimates, as well as unquantified effects the benefits per-ton estimates are unable to capture.

Table 8-13 Human Health and Welfare Effects of $PM_{2.5}$

POLLUTANT	QUANTIFIED AND MONETIZED IN PRIMARY ESTIMATES	UNQUANTIFIED EFFECTS CHANGES IN:
$PM_{2.5}$	Adult premature mortality Acute bronchitis Hospital admissions: respiratory and cardiovascular Emergency room visits for asthma Nonfatal heart attacks (myocardial infarction) Lower and upper respiratory illness Minor restricted-activity days Work loss days Asthma exacerbations (asthmatic population) Infant mortality	Chronic and subchronic bronchitis cases Strokes and cerebrovascular disease Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Non-asthma respiratory emergency room visits Visibility Household soiling

Consistent with the cost-benefit analysis that accompanied the 2012 PM NAAQS revision, the benefits estimates utilize the concentration-response functions as reported in the epidemiology literature. [KK,48] To calculate the total monetized impacts associated with quantified health impacts, EPA applies values derived from a number of sources. For premature mortality, EPA applies a value of a statistical life (VSL) derived from the mortality valuation literature. For certain health impacts, such as respiratory-related ailments, EPA applies willingness-to-pay estimates derived from the valuation literature. For the remaining health impacts, EPA applies values derived from current cost-of-illness and/or wage estimates.

Readers interested in reviewing the complete methodology for creating the benefit-per-ton estimates used in this analysis can consult EPA's "Technical Support Document: Estimating the Benefit per Ton of Reducing $PM_{2.5}$ Precursors from 17 Sectors."[LL] Readers can also refer to Fann et al. (2012)[49] for a detailed description of the benefit-per-ton methodology.

As described in the documentation for the benefit per-ton estimates cited above, national per-ton estimates were developed for selected pollutant/source category combinations. The per-ton values calculated therefore apply only to tons reduced from those specific pollutant/source combinations (e.g., NO_2 emitted from on-road mobile sources; direct PM emitted from electricity generating units). Our estimate of $PM_{2.5}$ benefits is therefore based on the total direct $PM_{2.5}$ and PM-related precursor emissions controlled by sector and multiplied by each per-ton value.

As Table 8-12 indicates, EPA projects that the per-ton values for reducing emissions of non-GHG pollutants from both vehicle use and upstream sources such as fuel refineries will increase over time.[MM] These projected increases reflect rising income levels, which increase affected individuals' willingness to pay for reduced exposure to health threats from air pollution.[NN] They also reflect future population growth and increased life expectancy, which expands the size of the population exposed to air pollution in both urban and rural areas, especially among older age groups with the highest mortality risk.[OO]

[KK] Although we summarize the main issues in this chapter, we encourage interested readers to see the benefits chapter of the RIA that accompanied the PM NAAQS for a more detailed description of recent changes to the quantification and monetization of PM benefits. Note that the cost-benefit analysis was prepared solely for purposes of fulfilling analysis requirements under Executive Order 12866 and was not considered, or otherwise played any part, in the decision to revise the PM NAAQS.

[LL] For more information regarding the updated values, see: http://www3.epa.gov/airquality/benmap/models/Source_Apportionment_BPT_TSD_1_31_13.pdf (accessed September 9, 2014).

[MM] As we discuss in the emissions chapter (Chapter 5), the rule would yield emission reductions from upstream refining and fuel distribution due to decreased petroleum consumption.

[NN] The issue is discussed in more detail in the 2012 PM NAAQS RIA, Section 5.6.8. See U.S. Environmental Protection Agency. (2012). *Regulatory Impact Analysis for the Final Revisions to the National Ambient Air Quality Standards for Particulate Matter*, Health and Environmental Impacts Division, Office of Air Quality Planning and Standards, EPA-452-R-12-005, December 2012. Available on the internet: http://www3.epa.gov/ttnecas1/regdata/RIAs/finalria.pdf.

[OO] For more information about EPA's population projections, please refer to the following: http://www3.epa.gov/air/benmap/models/BenMAPManualAppendicesAugust2010.pdf (See Appendix K).

The benefit-per-ton estimates are subject to a number of assumptions and uncertainties:

- The benefit-per-ton estimates used here reflect specific geographic patterns of emissions reductions and specific air quality and benefits modeling assumptions associated with the derivation of those estimates (see the TSD describing the calculation of the national benefit-per-ton estimates). [50,PP] Consequently, these estimates may not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors associated with the current analysis. Therefore, use of these benefit-per-ton values to estimate non-GHG benefits may lead to higher or lower benefit estimates than if these benefits were calculated based on direct air quality modeling.
- This analysis assumes that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because $PM_{2.5}$ produced via transported precursors emitted from stationary sources may differ significantly from direct $PM_{2.5}$ released from diesel engines and other industrial sources. The PM ISA, which was twice reviewed by SAB-CASAC, concluded that "many constituents of $PM_{2.5}$ can be linked with multiple health effects, and the evidence is not yet sufficient to allow differentiation of those constituents or sources that are more closely related to specific outcomes."[51] PM composition and the size distribution of those particles vary within and between areas due to source characteristics. Any specific location could have higher or lower contributions of certain PM species and other pollutants than the national average, meaning potential regional differences in health impact of given control strategies. Depending on the toxicity of each PM species reduced by the standards, assuming equal toxicity could over or underestimate benefits.
- This analysis assumes that the health impact function for fine particles is linear within the range of ambient concentrations under consideration. Thus, the estimates include health benefits from reducing fine particles in areas with varied concentrations of $PM_{2.5,}$ including regions that are in attainment with the fine particle standard. The direction of bias that assuming linear-no threshold model or alternative model introduces depends upon the "true" functional from of the relationship and the specific assumptions and data in a particular analysis. For example, if the true function identifies a threshold below which health effects do not occur, benefits may be overestimated if a substantial portion of those benefits were estimated to occur below that threshold. Alternately, if a substantial portion of the benefits occurred above that threshold, the benefits may be underestimated because an assumed linear no-threshold function may not reflect the steeper slope above that threshold to account for all health effects occurring above that threshold.

[PP] See also: http://www3.epa.gov/airquality/benmap/sabpt.html. The current values available on the webpage have been updated since the publication of the Fann et al., 2012 paper. For more information regarding the updated values, see: http://www3.epa.gov/airquality/benmap/models/Source_Apportionment_BPT_TSD_1_31_13.pdf (accessed September 9, 2014).

- There are several health benefit categories that EPA was unable to quantify due to limitations associated with using benefits-per-ton estimates, several of which could be substantial. Because the NO_X and VOC emission reductions associated with the final program are also precursors to ozone, reductions in NO_X and VOC would also reduce ozone formation and the health effects associated with ozone exposure. Unfortunately, ozone-related benefits-per-ton estimates do not exist due to issues associated with the complexity of the atmospheric air chemistry and nonlinearities associated with ozone formation. The PM-related benefits-per-ton estimates also do not include any human welfare or ecological benefits.
- There are many uncertainties associated with the health impact functions that underlie the benefits-per-ton estimates. These include: within-study variability (the precision with which a given study estimates the relationship between air quality changes and health effects); across-study variation (different published studies of the same pollutant/health effect relationship typically do not report identical findings and in some instances the differences are substantial); the application of concentration-response functions nationwide (does not account for any relationship between region and health effect, to the extent that such a relationship exists); extrapolation of impact functions across population (we assumed that certain health impact functions applied to age ranges broader than that considered in the original epidemiological study); and various uncertainties in the concentration-response function, including causality and thresholds. These uncertainties may under- or over-estimate benefits.
- EPA has investigated methods to characterize uncertainty in the relationship between $PM_{2.5}$ exposure and premature mortality. EPA's final $PM_{2.5}$ NAAQS analysis provides a more complete picture about the overall uncertainty in $PM_{2.5}$ benefits estimates. For more information, please consult the $PM_{2.5}$ NAAQS RIA.[52]
- The benefit-per-ton unit values used in this analysis incorporate projections of key variables, including atmospheric conditions, source level emissions, population, health baselines, incomes, and technology. These projections introduce some uncertainties to the benefit per ton estimates.

8.6.2 Unquantified Health and Environmental Impacts

In addition to the co-pollutant health impacts EPA quantifies in this analysis, there are a number of other health and human welfare endpoints that we will not be able to quantify because of current limitations in the methods or available data. These impacts are associated with emissions of air toxics (including benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, and ethanol), ambient ozone, and ambient $PM_{2.5}$ exposures. For example, we have not quantified a number of known or suspected health effects linked with ozone and PM for which appropriate health impact functions are not available or which do not provide easily interpretable outcomes (i.e., changes in heart rate variability). In addition, we are currently unable to quantify a number of known welfare effects, including reduced acid and particulate deposition damage to cultural monuments and other materials, and environmental benefits due to reductions of impacts of eutrophication in coastal areas.

Although there will be impacts associated with air toxic pollutant emission changes that result from this action, we do not attempt to monetize those impacts. This is primarily because currently available tools and methods to assess air toxics risk from mobile sources at the national scale are not adequate for extrapolation to incidence estimations or benefits assessment. The best suite of tools and methods currently available for assessment at the national scale are those used in the National-Scale Air Toxics Assessment (NATA). EPA's Science Advisory Board specifically commented in their review of the 1996 NATA that these tools were not yet ready for use in a national-scale benefits analysis, because they did not consider the full distribution of exposure and risk, or address sub-chronic health effects.[53] While EPA has since improved these tools, there remain critical limitations for estimating incidence and assessing benefits of reducing mobile source air toxics.

As part of the second prospective analysis of the benefits and costs of the Clean Air Act,[54] EPA conducted a case study analysis of the health effects associated with reducing exposure to benzene in Houston from implementation of the Clean Air Act. While reviewing the report, EPA's Advisory Council on Clean Air Compliance Analysis concluded that "the challenges for assessing progress in health improvement as a result of reductions in emissions of hazardous air pollutants (HAPs) are daunting...due to a lack of exposure-response functions, uncertainties in emissions inventories and background levels, the difficulty of extrapolating risk estimates to low doses and the challenges of tracking health progress for diseases, such as cancer, that have long latency periods."[55] EPA continues to work to address these limitations; however, EPA did not have the methods and tools available for national-scale application in time for the analysis of the final action.[QQ]

8.7 Additional Impacts

8.7.1 Cost of Noise, Congestion, and Crashes

Chapter 8.3 discusses the likely sign of the rebound effect. If net operating costs of the vehicle decline, then we expect a positive rebound effect. Increased vehicle use associated with a positive rebound effect also contributes to increased traffic congestion, motor vehicle crashes, and highway noise. Depending on how the additional travel is distributed throughout the day and on where it takes place, additional vehicle use can contribute to traffic congestion and delays by increasing traffic volumes on facilities that are already heavily traveled during peak periods. These added delays impose higher costs on drivers and other vehicle occupants in the form of increased travel time and operating expenses. Because drivers do not take these added costs into account in deciding when and where to travel, they must be accounted for separately as a cost of the added driving associated with the rebound effect.

[QQ] In April, 2009, EPA hosted a workshop on estimating the benefits or reducing hazardous air pollutants. This workshop built upon the work accomplished in the June 2000 Science Advisory Board/EPA Workshop on the Benefits of Reductions in Exposure to Hazardous Air Pollutants, which generated thoughtful discussion on approaches to estimating human health benefits from reductions in air toxics exposure, but no consensus was reached on methods that could be implemented in the near term for a broad selection of air toxics. Please visit http://epa.gov/air/toxicair/2009workshop.html for more information about the workshop and its associated materials.

Our approach in this final rule is identical to that used in the proposal. EPA and NHTSA rely on estimates of congestion, crash, and noise costs caused by pickup trucks and vans, single unit trucks, buses, and combination tractors developed by the Federal Highway Administration to estimate the increased external costs caused by added driving due to the rebound effect.[56] The FHWA estimates are intended to measure the increases in costs from added congestion, property damages and injuries in traffic crashes, and noise levels caused by various classes of trucks that are borne by persons other than their drivers (or "marginal" external costs). EPA and NHTSA employed estimates from this source previously in the analysis accompanying the light-duty 2012-2016 vehicle rulemaking. The agencies continue to find them appropriate for this analysis after reviewing the procedures used by FHWA to develop them and considering other available estimates of these values.

FHWA's congestion cost estimates for trucks, which are weighted averages based on the estimated fractions of peak and off-peak freeway travel for each class of trucks, already account for the fact that trucks make up a smaller fraction of peak period traffic on congested roads because they try to avoid peak periods when possible. FHWA's congestion cost estimates focus on freeways because non-freeway effects are less serious due to lower traffic volumes and opportunities to re-route around the congestion. The agencies, however, applied the congestion cost to the overall VMT increase, though the fraction of VMT on each road type used in MOVES range from 27 to 29 percent of the vehicle miles on freeways for vocational vehicles and 53 percent for combination tractors. The results of this analysis potentially overestimate the congestions costs associated with increased truck use, and thus lead to a conservative estimate of benefits.

EPA and NHTSA estimated the costs of additional vocational vehicle travel using a weighted average of 15 percent of the FHWA estimate for bus costs and 85 percent of the FHWA estimate for single unit truck costs to reflect the make-up of this segment. The low, mid, and high cost estimates from FHWA updated to 2012 dollars are included in Table 8-14.

Table 8-14 Low-Mid-High Cost Estimates (2013$/mile)

NOISE			
	High	**Middle**	**Low**
Pickup Truck, Van	$0.002	$0.001	$0.000
Vocational Vehicle	$0.024	$0.009	$0.003
Combination Tractor	$0.055	$0.021	$0.006
Crashes			
	High	**Middle**	**Low**
Pickup Truck, Van	$0.088	$0.028	$0.015
Vocational Vehicle	$0.051	$0.017	$0.009
Combination Tractor	$0.074	$0.023	$0.011
Congestion			
	High	**Middle**	**Low**
Pickup Truck, Van	$0.153	$0.052	$0.014
Vocational Vehicle	$0.350	$0.119	$0.032
Combination Tractor	$0.337	$0.115	$0.030

The agencies are using FHWA's "Middle" estimates for marginal congestion, crash, and noise costs caused by increased travel from trucks.[57] This approach is consistent with the methodology used in the HD GHG Phase 1 rule and both LD GHG rules. These costs are multiplied by the annual increases in vehicle miles travelled from the rebound effect to yield the estimated increases in congestion, crash, and noise externality costs during each future year. The results are shown in Table 8-15 through Table 8-17.

Table 8-15 Annual Costs & Net Present Values Associated with Increased Noise, Crashes and Congestion for the Final Program Relative to the Flat Baseline and using Method B (Millions of 2013$) [a]

CALENDAR YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/TRAILER	SUM
2018	$0	$0	$0	$0
2019	$0	$0	$0	$0
2020	$0	$0	$0	$0
2021	$17	$4	$77	$99
2022	$34	$8	$97	$139
2023	$51	$12	$116	$178
2024	$67	$16	$134	$216
2025	$82	$20	$150	$252
2026	$97	$23	$165	$285
2027	$111	$26	$179	$317
2028	$124	$30	$192	$345
2029	$136	$32	$203	$372
2030	$147	$35	$214	$396
2035	$188	$45	$255	$487
2040	$206	$50	$285	$541
2050	$218	$57	$329	$604
NPV, 3%	$2,462	$599	$3,694	$6,755
NPV, 7%	$1,100	$266	$1,704	$3,070

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 8-16 Discounted Model Year Lifetime Costs Associated with Increased Noise, Crashes and Congestion for the Final Program Relative to the Flat Baseline and using Method B (3% discount rate, Millions of 2013$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/TRAILER	SUM
2018	$0	$0	$124	$124
2019	$0	$0	$140	$140
2020	$0	$0	$158	$158
2021	$141	$32	$170	$343
2022	$136	$31	$166	$333
2023	$132	$30	$161	$323
2024	$129	$30	$160	$319
2025	$127	$29	$157	$313
2026	$124	$28	$153	$305
2027	$121	$28	$149	$297
2028	$117	$27	$145	$289
2029	$114	$26	$142	$283
Sum	$1,140	$261	$1,825	$3,227

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 8-17 Discounted Model Year Lifetime Costs Associated with Increased Noise, Crashes and Congestion for the Final Program Relative to the Flat Baseline and using Method B (7% discount rate, Millions of 2013$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/TRAILER	SUM
2018	$0	$0	$80	$80
2019	$0	$0	$89	$89
2020	$0	$0	$100	$100
2021	$88	$20	$106	$215
2022	$82	$19	$100	$201
2023	$76	$18	$93	$187
2024	$72	$17	$90	$178
2025	$68	$16	$84	$168
2026	$64	$15	$79	$158
2027	$60	$14	$74	$148
2028	$56	$13	$70	$139
2029	$53	$12	$66	$131
Sum	$619	$143	$1,030	$1,793

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

8.7.2 Benefits of Reduced Refueling Time

Reducing the fuel consumption of heavy-duty trucks will either increase their driving range before they require refueling, or lead truck manufacturers to offer, and truck purchasers to buy, smaller fuel tanks. Keeping the fuel tank the same size will allow truck operators to reduce the frequency with which drivers typically refuel their vehicles, by extending the upper limit on the distance they can travel before requiring refueling. Alternatively, if truck purchasers and manufacturers respond to improved fuel economy by reducing the size of fuel tanks, the smaller tank will require less time to fill during each refueling stop.

Because refueling time represents a time cost of truck operation, these time savings should be incorporated into truck purchasers' decisions about how much fuel-saving technology they purchase as part of their choices of new vehicles. The savings calculated here thus raise the same questions discussed in Preamble Section IX VIII.A and RIA Chapter 8.2: does the apparent existence of these savings reflect failures in the market for fuel economy, or does it reflect costs that are not addressed in this analysis? The response to these questions could vary across truck segment.

No direct estimates of the value of extended vehicle range or reduced fuel tank size are readily available. Instead, this analysis calculates the reduction in the annual amount of time a driver of each type of truck would spend filling its fuel tank; this reduced time could result either from fewer refueling events, if new trucks' fuel tanks stay the same size, or from less time spent filling the tank during each refueling stop, if new trucks' fuels tank are made proportionately smaller. As discussed in Chapter 8.3 in this RIA, the average number of miles each type of vehicle is driven annually would likely increase under the regulation, as truck operators respond to lower fuel expenditures (the "rebound effect"). The estimates of refueling time with the rule in effect allow for this increase in truck use. However, the estimate of the rebound effect does not account for any reduction in net operating costs from lower refueling time. Because the rebound effect should measure the change in VMT with respect to the net change in overall operating costs, refueling time costs would ideally factor into this calculation. The effect of this omission is expected to be minor because refueling time savings are generally small relative to the value of reduced fuel expenditures.

Our approach to calculating refueling savings in this final rule is identical to the approach used in the proposal. The savings in refueling time are calculated as the total amount of time the driver of a typical truck in each class would save each year as a consequence of pumping less fuel into the vehicle's tank. The calculation also includes a fixed time per refill event of 3.5 minutes which would not occur as frequently due to the fewer number of refills.

The calculation uses the reduced number of gallons consumed by truck type and divides that value by the tank volume and refill amount to get the number of refills, then multiplies that by the time per refill to determine the number of hours saved in a given year. The calculation then applies DOT-recommended values of travel time savings to convert the resulting time savings to their economic value. The input metrics used in the analysis are included in Table 8-18. The equation for the calculation is shown below:

$$Refueling\ Benefit = \left(\frac{Gal_{reference} - Gal_{policy}}{Gal\ per\ refill}\right) \times \left(\frac{Gal\ per\ refill}{Fuel\ dispense\ rate} + time\ per\ refill\right) \times \left(\frac{\$}{hr}\right)_{labor}$$

The annual impacts associated with reduced refueling time are shown in Table 8-19 and the MY lifetime impacts are shown in Table 8-20 and Table 8-21.

Table 8-18 Inputs to Calculate Refueling Time Savings

	HD PICKUP AND VAN	VOCATIONAL VEHICLE	TRACTOR
Fuel Dispensing Rate (gallon/minute)[58]	10	10	20
Refueling fixed time (minutes/refill)[59]	3.5	3.5	3.5
Tank volume (gallons)[a]	30	40	200
Refill amount (%volume/refill)[a]	60%	75%	75%
Resultant time/refill (minutes/refill)	5.3	6.5	11.0
Wage rate (2012$/hr)[60,b]	$27.22	31.01	28.56

Notes:
[a] HD pickup and van values based on a NHTSA survey, other are estimated.
[b] A wage growth rate of 1.2% has been assumed for future years.

Table 8-19 Annual Refueling Benefits and Net Present Values for the Final Program Relative to the Flat Baseline and using Method B
(Dollar Values in Millions of 2013$)[a]

CALENDAR YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/TRAILER	SUM OF BENEFITS
2018	$0	$0	$1	$1
2019	$0	$0	$3	$3
2020	$0	$0	$5	$5
2021	$3	$9	$14	$27
2022	$11	$19	$27	$56
2023	$23	$28	$40	$91
2024	$41	$43	$60	$144
2025	$63	$58	$81	$202
2026	$90	$73	$101	$264
2027	$122	$93	$128	$342
2028	$153	$112	$154	$420
2029	$184	$131	$180	$495
2030	$214	$150	$205	$570
2035	$344	$231	$321	$895
2040	$434	$293	$415	$1,141
2050	$542	$386	$569	$1,497
NPV, 3%	$4,444	$3,119	$4,422	$11,985
NPV, 7%	$1,814	$1,290	$1,821	$4,925

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 8-20 Discounted Model Year Lifetime Refueling Benefits at 3% for the Final Program Relative to the Flat Baseline and using Method B (Millions of 2013$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/ TRAILER	SUM
2018	$0	$0	$9	$9
2019	$0	$0	$9	$9
2020	$0	$0	$8	$8
2021	$25	$82	$111	$218
2022	$66	$80	$109	$255
2023	$104	$78	$107	$290
2024	$142	$119	$167	$428
2025	$178	$119	$165	$461
2026	$212	$117	$162	$491
2027	$243	$154	$212	$609
2028	$239	$153	$209	$601
2029	$235	$151	$208	$594
Sum	$1,445	$1,054	$1,478	$3,976

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 8-21 Discounted Model Year Lifetime Refueling Benefits at 7% for the Final Program Relative to the Flat Baseline and using Method B (Millions of 2013$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/ TRAILER	SUM
2018	$0	$0	$7	$7
2019	$0	$0	$6	$6
2020	$0	$0	$6	$6
2021	$15	$51	$68	$135
2022	$39	$48	$65	$152
2023	$60	$45	$61	$166
2024	$78	$66	$92	$236
2025	$94	$63	$88	$245
2026	$108	$60	$83	$251
2027	$120	$76	$104	$300
2028	$114	$73	$99	$285
2029	$108	$69	$95	$272
Sum	$737	$551	$773	$2,061

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

8.7.3 Benefits of Increased Travel Associated with Rebound Driving

The increase in travel associated with the rebound effect produces additional benefits to vehicle owners and operators, which reflect the value of the added (or more desirable) social and economic opportunities that become accessible with additional travel. The analysis estimates the economic benefits from increased rebound-effect driving as the sum of fuel expenditures incurred plus the vehicle owner/operator surplus from the additional accessibility it provides. As evidenced by the fact that vehicles make more frequent or longer trips when the cost of driving declines, the benefits from this added travel exceed added expenditures for the fuel consumed. Note that the amount by which the benefits from this increased driving *exceed* its increased fuel costs measures the net benefits from the additional travel, usually referred to as increased consumer surplus or, in this case, increased owner/operator surplus. The equation for the calculation of the *total* travel benefit is shown below:

$$Travel\ Benefit = (VMT_{rebound})\left(\frac{\$}{mi}\right)_{policy} + \left(\frac{1}{2}\right)(VMT_{rebound})\left[\left(\frac{\$}{mile}\right)_{reference} - \left(\frac{\$}{mile}\right)_{policy}\right]$$

The analysis in this final rule is identical to that used in the proposal. The agencies' analysis estimates the economic value of the increased owner/operator surplus provided by added driving using the conventional approximation, which is one half of the product of the decline in vehicle operating costs per vehicle-mile and the resulting increase in the annual number of miles driven. Because it depends on the extent of improvement in fuel economy, the value of benefits from increased vehicle use changes by model year and varies among alternative standards. Under even those alternatives that will impose the highest standards, however, the magnitude of the surplus from additional vehicle use represents a small fraction of this benefit. The benefits are shown in Table 8-22 through Table 8-24

Table 8-22 Annual Value of Increased Travel and Net Present Values at 3% and 7% Discount Rates for the Final Program Relative to the Flat Baseline and using Method B (Millions of 2013$) [a]

CALENDAR YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/TRAILER	SUM
2018	$0	$0	$0	$0
2019	$0	$0	$0	$0
2020	$0	$0	$0	$0
2021	$43	$9	$247	$298
2022	$86	$18	$314	$417
2023	$128	$27	$379	$534
2024	$171	$36	$442	$648
2025	$212	$45	$502	$759
2026	$253	$53	$559	$866
2027	$292	$62	$613	$967
2028	$330	$70	$664	$1,064
2029	$367	$78	$712	$1,157
2030	$402	$85	$759	$1,247
2035	$558	$120	$982	$1,660
2040	$678	$149	$1,215	$2,043
2050	$721	$169	$1,394	$2,284
NPV, 3%	$7,427	$1,627	$14,303	$23,357
NPV, 7%	$3,232	$701	$6,410	$10,343

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 8-23 Discounted Model Year Lifetime Value of Increased Travel for the Final Program Relative to the Flat Baseline and using Method B (3% discount rate, Millions of 2013$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/TRAILER	SUM
2018	$0	$0	$452	$452
2019	$0	$0	$511	$511
2020	$0	$0	$580	$580
2021	$383	$77	$594	$1,054
2022	$372	$76	$590	$1,038
2023	$362	$74	$583	$1,020
2024	$357	$73	$572	$1,001
2025	$351	$73	$570	$994
2026	$346	$72	$564	$982
2027	$338	$70	$542	$951
2028	$335	$70	$538	$942
2029	$331	$70	$536	$937
Sum	$3,174	$655	$6,633	$10,462

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Table 8-24 Discounted Model Year Lifetime Value of Increased Travel for the Final Program Relative to the Flat Baseline and using Method B (7% discount rate, Millions of 2013$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/TRAILER	SUM
2018	$0	$0	$285	$285
2019	$0	$0	$319	$319
2020	$0	$0	$358	$358
2021	$236	$47	$364	$647
2022	$220	$45	$348	$613
2023	$206	$43	$331	$580
2024	$196	$40	$313	$549
2025	$186	$39	$301	$525
2026	$176	$37	$287	$500
2027	$166	$35	$266	$466
2028	$158	$33	$254	$445
2029	$151	$32	$244	$427
Sum	$1,694	$351	$3,671	$5,715

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

8.8 Petroleum, Energy and National Security Impacts

8.8.1 Energy Security Impacts

The Phase 2 standards are designed to require improvements in the fuel efficiency of medium- and heavy-duty vehicles and, thereby, reduce fuel consumption and GHG emissions. In turn, the Phase 2 standards help to reduce U.S. petroleum imports. A reduction of U.S. petroleum imports reduces both financial and strategic risks caused by potential sudden disruptions in the supply of imported petroleum to the U.S. This reduction in risk increases U.S. energy security. This section summarizes the agency's estimates of U.S. oil import reductions and energy security benefits of the final Phase 2 standards. Additional discussion of this issue can be found in Section IX.I of the Preamble.

The U.S., as a large oil importer and oil consumer, is economically vulnerable to outcomes in a volatile global oil market that relies on oil supplies from potentially unstable sources. Much of the world's oil and gas supplies are located in countries facing social, economic, and demographic challenges, thus making them vulnerable to potential local instability. In 2010, just over 40 percent of world oil supply came from OPEC (e.g., Organization of Petroleum Exporting Countries) nations and the Annual Energy Outlook 2015 projects that that this share will stay high; dipping slightly from 37 percent by 2020 and then rising gradually to over 40 percent by 2035 and thereafter.[RR]

Approximately 30 percent of global supply is from Middle East and North African countries alone, a share that is expected to grow.[SS] Measured in terms of the share of world oil resources or the share of global oil export supply, rather than oil production, the concentration of global petroleum resources in OPEC nations is even larger. As another measure of concentration, of the 137 countries/principalities that export either crude or product, the top 12 have recently accounted for over 55 percent of exports.[61] Eight of these countries are members of OPEC, and a ninth is Russia.[TT] In a market where even a 1-2 percent supply loss raises prices noticeably, and where a 10 percent supply loss could lead to an unprecedented price shock, this regional concentration is of concern.[UU] Historically, the countries of the Middle East have been

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[RR] The agencies used the AEO 2015 since this version of AEO was available at the time that fuel savings from the rule were being estimated.
[SS] Middle East and North African oil supply share reaches over 40 percent in 2040 in the AEO 2015 Reference Case.
[TT] The other three are Norway, Canada, and the EU, an exporter of product.
[UU] For example, the 2005 Hurricanes Katrina/Rita and the 2011 Libyan conflict both led to a 1.8 percent reduction in global crude supply. While the price impact of the latter is not easily distinguished given the rapidly rising post-recession prices, the former event was associated with a 10-15 percent world oil price increase. There are a range of smaller events with smaller but noticeable impacts. Somewhat larger events, such as the 2002/3 Venezuelan Strike and the War in Iraq, corresponded to about a 2.9 percent sustained loss of supply, and was associated with a 28 percent world oil price increase. (Compiled from EIA oil price data, IEA2012 [IEA Response System for Oil Supply Emergencies] (http://www.iea.org/publications/freepublications/publication/EPPD_Brochure_English_2012_02.pdf) See table on P. 11. and Hamilton 2011 "Historical Oil Shocks,"(http://econweb.ucsd.edu/~jhamilto/oil_history.pdf) in *Routledge Handbook of Major Events in Economic History*, pp. 239-265, edited by Randall E. Parker and Robert Whaples, New York: Routledge Taylor and Francis Group, 2013).

the source of eight of the ten major world oil disruptions, with the ninth originating in Venezuela, an OPEC country, and the tenth being Hurricanes Katrina and Rita.[VV]

One impact of the final Phase 2 program is that it promotes more efficient use of transportation fuels in the U.S. The result is that it reduces U.S. oil consumption and imports, which reduces both financial and strategic risks associated with a potential disruption in supply or a spike in the cost of a particular energy source. This reduction in risks increases U.S. energy security. For this rule, an "oil premium" approach is utilized that identifies those energy security related economic costs which are not reflected in the market price of oil, and which are expected to change in response to an incremental change in the level of U.S. oil imports.

8.8.2 Impact on U.S. Petroleum Imports

U.S. energy security is generally considered as the continued availability of energy sources at an acceptable price. Most discussion of U.S. energy security revolves around the topic of the economic costs of U.S. dependence on oil imports. The U.S.'s energy security problem is that the U.S. relies on imported oil from potentially unstable sources. In addition, oil exporters have the ability to raise the price of oil by exerting monopoly power through the formation of a cartel, the Organization of Petroleum Exporting Countries (OPEC). These factors contribute to the vulnerability of the U.S. economy to episodic oil supply shocks and price spikes. In 2014, U.S. expenditures for imports of crude oil and petroleum products, net of revenues for exports, were $178 billion, and total consumption expenditure was $469 billion (in 2013$) (see Figure 8-3).[62] Recently, as a result of strong growth in domestic oil production mainly from tight shale formations, U.S. production of oil has increased while U.S. oil imports have decreased. For example, from 2012 to 2015, domestic oil production increased by 44 percent while oil net imports and products decreased by 38 percent. While U.S. oil import costs have declined since 2011, total oil expenditures (domestic and imported) remained near historical highs through 2014. Post-2015 oil expenditures are projected (AEO 2015) to remain between double and triple the inflation-adjusted levels experienced by the U.S. from 1986 to 2002.

[VV] The events IEA categorized as oil supply disruptions all had a gross peak oil supply loss of at least 1.5 million barrels a day as a result of wars, revolutions, embargoes or strikes involving major oil exporting nations or from major storm events or disasters (like the double Hurricane Katrina/Rita) affecting oil producing/processing regions. IEA 2011 "IEA Response System for Oil Supply Emergencies."

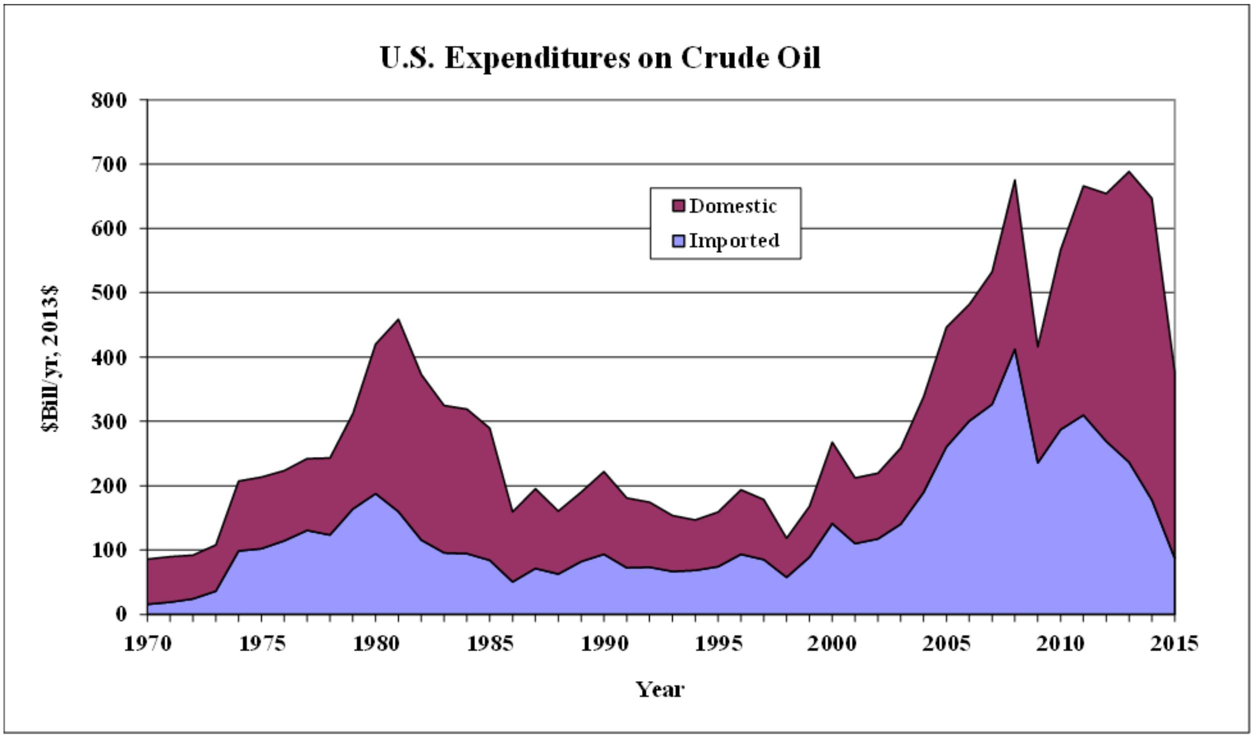

Figure 8-3 U.S. Expenditures on Crude Oil from 1970 through 2015[63]

The agencies used EPA's MOVES model to estimate the reductions in U.S. fuel consumption due to this final rule for vocational vehicles and tractors. For HD pickups and vans, the agencies used both DOT's CAFE model and EPA's MOVES model to estimate the fuel consumption impacts. (Detailed explanations of the MOVES and CAFE models can be found in Chapter 5 of the RIA. See IX.C of the Preamble for estimates of reduced fuel consumption from the final rules). Based on a detailed analysis of differences in U.S. fuel consumption, petroleum imports, and imports of petroleum products, the agencies estimate that approximately 90 percent of the reduction in fuel consumption resulting from adopting improved GHG emissions standards and fuel efficiency standards is likely to be reflected in reduced U.S. imports of crude oil and net imported petroleum products.[WW] Thus, on balance, each gallon of fuel saved as a consequence of the HD GHG and fuel efficiency standards is anticipated to reduce total U.S. imports of petroleum by 0.90 gallons. Based upon the fuel savings estimated by the MOVES/CAFE models and the 90 percent oil import factor, the reduction in U.S. oil imports from this rule are estimated for the years 2020, 2025, 2030, 2040, and 2050 (in millions of barrels per day (MMBD)) in

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[WW] We looked at changes in U.S. crude oil imports and net petroleum products in the AEO 2015 Reference Case in comparison the Low (i.e., Economic Growth) Demand Case to undertake this analysis. See the spreadsheet "Impact of Fuel Demand on Imports AEO2015.xlsx." We also considered a paper entitled "Effect of a U.S. Demand Reduction on Imports and Domestic Supply Levels" by Paul Leiby, 4/16/2013. This paper suggests that "Given a particular reduction in oil demand stemming from a policy or significant technology change, the fraction of oil use savings that shows up as reduced U.S. imports, rather than reduced U.S. supply, is actually quite close to 90 percent, and probably close to 95 percent."

Table 8-25 below. For comparison purposes, Table 8-25 also shows U.S. imports and exports of crude oil in 2020, 2025, 2030 and 2040 as projected by DOE in the Annual Energy Outlook 2015 (Reference Case). U.S. Gross Domestic Product (GDP) is projected to grow by roughly 48 percent (2009$) between 2020-2040 in the AEO 2015 projections.

Table 8-25 Projected U.S. Exports and Imports of Oil and U.S. Oil Import Reductions in 2020, 2025, 2030, 2040 and 2050 for the Final Program Relative to the Flat Baseline and using Method B (Millions of barrels per day (MMBD))[a]

YEAR	U.S OIL EXPORTS	U.S. OIL IMPORTS	U.S. NET PRODUCT IMPORTS*	U.S. NET CRUDE & PRODUCT IMPORTS	REDUCTIONS FROM HD RULES
2020	0.63	6.14	-2.80	2.71	0.007
2025	0.63	6.72	-3.24	2.85	0.162
2030	0.63	7.07	-3.56	2.88	0.405
2040	0.63	8.21	-4.26	3.32	0.721
2050	**	**	**	**	0.861

Notes:
* Negative U.S. Net Product Imports imply positive exports.
** The AEO 2015 only projects energy market and economic trends through 2040.

8.8.3 Methodology Used to Estimate U.S. Energy Security Benefits

In order to understand the energy security implications of reducing U.S. oil imports, EPA has worked with Oak Ridge National Laboratory (ORNL), which has developed approaches for evaluating the social costs and energy security implications of oil use. The energy security estimates provided below are based upon a methodology developed in a peer-reviewed study entitled, "*The Energy Security Benefits of Reduced Oil Use, 2006-2015*", completed in March 2008. This ORNL study is an updated version of the approach used for estimating the energy security benefits of U.S. oil import reductions developed in a 1997 ORNL Report.[64] For EPA and NHTSA rulemakings, the ORNL methodology is updated periodically to account for forecasts of future energy market and economic trends reported in the U.S. Energy Information Administration's Annual Energy Outlook.

As part of the process for developing the ORNL energy security estimates, EPA sponsored an independent, expert peer review of the 2008 ORNL study.[65] In addition, EPA worked with ORNL to address comments raised in the peer review and to develop estimates of the energy security benefits associated with a reduction in U.S. oil imports. In response to peer reviewer comments, ORNL modified its model by changing several key parameters involving OPEC supply behavior, the responsiveness of oil demand and supply to a change in the world oil price, and the responsiveness of U.S. economic output to a change in the world oil price.

When conducting this analysis, ORNL considered the full cost of importing petroleum into the U.S. The full economic cost is defined to include two components in addition to the purchase price of petroleum itself. These are: (1) the higher costs for oil imports resulting from the effect of U.S. demand on the world oil price (i.e., the "demand" or "monopsony" costs); and

(2) the risk of reductions in U.S. economic output and disruption to the U.S. economy caused by sudden disruptions in the supply of imported oil to the U.S. (i.e., macroeconomic disruption/adjustment costs).

The literature on energy security for the last two decades has routinely combined the monopsony and the macroeconomic disruption components when calculating the total value of the energy security premium. However, in the context of using a global value for the Social Cost of Carbon (SCC) the question arises: how should the energy security premium be used when some benefits from the rule, such as the benefits of reducing greenhouse gas emissions, are calculated from a global perspective? Monopsony benefits represent avoided payments by U.S. consumers to oil producers that result from a decrease in the world oil price as the U.S. decreases its demand for oil. Although there is clearly an overall benefit to the U.S. when considered from a domestic perspective, the decrease in price due to decreased demand in the U.S. also represents a loss to oil producing countries, one of which is the U.S. Given the redistributive nature of this monopsony effect from a global perspective, it is excluded in the energy security benefits calculations for this final program.

In contrast, the other portion of the energy security premium, the avoided U.S. macroeconomic disruption and adjustment cost that arises from reductions in U.S. petroleum imports, does not have offsetting impacts outside of the U.S., and, thus, is included in the energy security benefits estimated for these final rules. To summarize, the agencies have included only the avoided macroeconomic disruption portion of the energy security benefits to estimate the monetary value of the total energy security benefits of these final rules.

For this rulemaking, ORNL updated the energy security premiums by incorporating the most recent oil price forecast and energy market trends, particularly regional oil supplies and demands, from the AEO 2015 into its model.[66] Table 8-26 provides estimates for energy security premiums for the years 2020, 2025, 2030 and 2040[XX], as well as a breakdown of the components of the energy security premiums for each year. The components of the energy security premiums and their values are discussed below.

[XX] AEO 2015 forecasts energy market trends and values only to 2040. The post-2040 energy security premium values are assumed to be equal to the 2040 estimate.

Table 8-26 Energy Security Premiums in 2020, 2025, 2030 and 2040 (2013$/Barrel)*

YEAR (RANGE)	MONOPSONY (RANGE)	AVOIDED MACROECONOMIC DISRUPTION/ADJUSTMENT COSTS (RANGE)	TOTAL MID-POINT (RANGE)
2020	$2.21 ($0.65 - $3.59)	$5.48 ($2.51 - $8.92)	$7.69 ($4.54 - $11.14)
2025	$2.59 ($0.76 - $4.14)	$6.30 ($2.92 - $10.22)	$8.89 ($5.22 - $12.83)
2030	$2.83 ($0.83 - $4.56)	$7.26 ($3.40 - $11.73)	$10.09 ($5.90 - $14.59)
2040	$4.09 ($1.19 - $6.67)	$9.61 ($4.54 - $15.39)	$13.69 ($8.12 - $19.64)

Note:
*Top values in each cell are the midpoints, the values in parentheses are the 90 percent confidence intervals.

8.8.3.1 Effect of Oil Use on the Long-Run Oil Price

The first component of the full economic costs of importing petroleum into the U.S. follows from the effect of U.S. import demand on the world oil price over the long-run. Because the U.S. is a sufficiently large purchaser of global oil supplies, its purchases can affect the world oil price. This monopsony power means that increases in U.S. petroleum demand can cause the world price of crude oil to rise, and conversely, that reduced U.S. petroleum demand can reduce the world price of crude oil. Thus, one benefit of decreasing U.S. oil purchases, due to improvements in the fuel efficiency of medium- and heavy-duty vehicles is the potential decrease in the crude oil price paid for all crude oil purchased.

The demand or monopsony effect can be readily illustrated with an example. If the U.S. imports 10 million barrels per day at a world oil price of $50 per barrel, its total daily bill for oil imports is 500 million dollars. If a 10 percent decrease in U.S. imports to 9 million barrels per day causes the world oil price to drop to $49 per barrel, the daily U.S. oil import bill drops to $441 million (9 million barrels times $49 per barrel). While the world oil price only declines $1, the resulting decrease in oil purchase payments of $59 million per day (500 million dollars minus $441 million) is equivalent to an incremental benefit of $59 per barrel of oil imports reduced ($59 million/1 million barrels per day reduced), or $10 more than the newly-decreased world price of $49 per barrel. This additional $10 per barrel “import cost premium” represents the incremental external benefits to the U.S. for avoided import costs beyond the price paid for oil purchases. This additional benefit from import reduction arises only to the extent that a reduction in U.S. oil imports affects the world oil price. ORNL estimates this component of the energy security benefit in 2020 to be $2.21/barrel (2013$), with a range of $0.65/barrel to $3.59/barrel of imported oil reduced.

There is disagreement in the literature about the magnitude of the monopsony component, and its relevance for policy analysis. Brown and Huntington (2013)[67], for example, argue that the United States’ refusal to exercise its market power to reduce the world oil price does not represent a proper externality, and that the monopsony component should not be considered in calculations of the energy security externality. However, they also note in their earlier discussion paper (Brown and Huntington 2010)[68] that this is a departure from the traditional energy security literature, which includes sustained wealth transfers associated with stable but higher-price oil markets. On the other hand, Greene (2010)[69] and others in prior literature (e.g., Toman 1993)[70] have emphasized that the monopsony cost component is policy-relevant because the world oil market is non-competitive and strongly influenced by cartelized and government-controlled supply decisions. Thus, while sometimes couched as an externality, Greene notes that the monopsony component is best viewed as stemming from a completely different market failure than an externality (Ledyard 2008)[71], yet still implying marginal social costs to importers.

Recently, the Council on Foreign Relations (i.e., "the Council") (2015)[72] released a discussion paper that assesses NHTSA's analysis of the benefits and costs of CAFE in a lower-oil-price world. In this paper, the Council notes that while NHTSA cites the monopsony effect of the CAFE standards for 2017–2025, NHTSA does not include it when calculating the cost-benefit calculation for the rule. The Council argues that the monopsony benefit should be included in the CAFE cost-benefit analysis and that including the monopsony benefit is more consistent with the legislators' intent in mandating CAFE standards in the first place.

The recent National Academy of Science (NAS 2015) Report, "Cost, Effectiveness and the Deployment of Fuel Economy Technologies for Light-Duty Vehicles,"[73] suggests that the agencies' logic about not accounting for monopsony benefits is inaccurate. According to the NAS, the fallacy lies in treating the two problems, oil dependence and climate change, similarly. According to the NAS, "Like national defense, it [oil dependence] is inherently adversarial (i.e., oil consumers against producers using monopoly power to raise prices). The problem of climate change is inherently global and requires global action. If each nation considered only the benefits to itself in determining what actions to take to mitigate climate change, an adequate solution could not be achieved. Likewise, if the U.S. considers the economic harm its reduced petroleum use will do to monopolistic oil producers it will not adequately address its oil dependence problem. Thus, if the United States is to solve both of these problems it must take full account of the costs and benefits of each, using the appropriate scope for each problem." At this point in time, we are continuing to exclude monopsony premiums for the cost benefit analysis of this final rule, but we will be taking comment on this issue in a near term future rulemaking.

There is also a question about the ability of gradual, long-term reductions, such as those resulting from these final rules, to reduce the world oil price in the presence of OPEC's monopoly power. OPEC is currently the world's marginal petroleum supplier, and could conceivably respond to gradual reductions in U.S. demand with gradual reductions in supply over the course of several years as the fuel savings resulting from this rule grow. However, if OPEC opts for a long-term strategy to preserve its market share, rather than maintain a particular price level (as they have done recently in response to increasing U.S. petroleum production), reduced demand would create downward pressure on the global price. The Oak Ridge analysis assumes that OPEC does respond to demand reductions over the long run, but there is still a price effect in the model. Under the mid-case behavioral assumption used in the premium calculations, OPEC responds by gradually reducing supply to maintain *market share* (consistent with the long-term self-interested strategy suggested by Gately (2004, 2007)).[74]

One potential result of the potential decline in the world price of oil as a result of these rules would be an increase in the consumption of petroleum products, particularly outside the U.S. In addition, other fuels could be displaced from the increasing use of oil worldwide. For example, if a decline in the world oil price causes an increase in oil use in China, India, or another country's industrial sector, this increase in oil consumption may displace natural gas usage. Alternatively, the increased oil use could result in a decrease in coal used to produce electricity. An increase in the consumption of petroleum products particularly outside the U.S., could lead to a modest increase in emissions of GHGs, criteria air pollutants, and airborne toxics from their refining and use. However, lower usage of, for example, displaced coal would result in a decrease in GHG emissions. Therefore, any assessment of the impacts on GHG emissions and other pollutants from a potential increase in world oil demand would need to take into account the impacts on all portions of global energy sector.

8.8.3.2 Macroeconomic Disruption Adjustment Costs

The second component of the oil import premium, "avoided macroeconomic disruption/adjustment costs," arises from the effect of oil imports on the expected cost of supply disruptions and accompanying price increases. A sudden increase in oil prices triggered by a disruption in world oil supplies has two main effects: (1) it increases the costs of oil imports in the short-run, and (2) it can lead to macroeconomic contraction, dislocation and Gross Domestic Product (GDP) losses. For example, ORNL estimates the combine value of these two factors in to be $5.48/barrel (2013$) when U.S. oil imports are reduced in 2020, with a range from $2.51/barrel to $8.92/barrel of imported oil reduced.

There are two main effects of macroeconomic disruption/adjustment costs. The first is the aggregate effect of the short-run price increase from an oil shock. The oil price shock results in a combination of real resource shortages, costly short-run shifts in energy supply, behavioral and demand adjustments by energy users, and other response costs. Unlike pure transfers, the root cause of the disruption price increase is a real resource supply reduction due, for example, to disaster or war. Regions where supplies are disrupted, such as the U.S., suffer high costs. Businesses' and households' emergency responses to supply disruptions and rapid price increases consume real economic resources.

When households and businesses make decisions related to their oil consumption, such as whether to invest in fuel-saving technologies or use futures markets, they are unlikely to account for the effect of their petroleum consumption on the magnitude of costs that supply interruptions and accompanying price shocks impose on others. As a consequence, the U.S. economy as a whole will not make sufficient use of these mechanisms to insulate itself from the real costs of rapid increases in energy prices and outlays that usually accompany oil supply interruptions. Therefore, the ORNL estimate of avoided macroeconomic disruption/adjustment costs that the agencies use to value energy security benefits includes the increased oil import costs stemming from oil price shocks that are unanticipated and not internalized by advance actions of U.S. consumers and businesses. This aggregate output effect will last as long as the oil price is elevated. It depends on the extent and duration of any disruption in the world supply of oil, since these factors determine the magnitude of the resulting increases in prices for petroleum products, as well as how rapidly these prices return to their pre-disruption level.

The second main effect of macroeconomic disruption/adjustment costs is the macroeconomic losses due to "allocative" losses. These are the costs of temporary dislocation and underutilization of available resources due to the oil shock, such as labor unemployment and idle plant capacity. Because supply disruptions and resulting price increases occur suddenly, empirical evidence shows they impose additional costs on businesses and households that must adjust their use of petroleum and other productive factors more rapidly than if the same price increase had occurred gradually. Dislocational effects include the unemployment of workers and other resources during the time needed for their intersectoral or interregional reallocation, and pauses in capital investment due to uncertainty. These adjustments temporarily reduce the level of economic output that can be achieved even below the "potential" output level that would ultimately be reached once the economy's adaptation to higher petroleum prices is complete. The additional costs imposed on businesses and households for making these adjustments reflect their limited ability to adjust prices, output levels, and their use of energy, labor and other inputs quickly and smoothly in response to rapid changes in prices for petroleum products.

Since future disruptions in foreign oil supplies are an uncertain prospect, each of the disruption cost components must be weighted by the probability that the supply of petroleum to the U.S. will actually be disrupted. Thus, the "expected value" of these costs – the product of the probability that a supply disruption will occur and the sum of costs from reduced economic output and the economy's abrupt adjustment to sharply higher petroleum prices – is the relevant measure of their magnitude. Further, when assessing the energy security value of a policy to reduce oil use, it is only the change in the expected costs of disruption that results from the policy that is relevant. The expected costs of disruption may change from lowering the normal (*i.e.*, pre-disruption) level of domestic petroleum use and imports, from any induced alteration in the likelihood or size of disruption, or from altering the short-run flexibility (*e.g.*, elasticity) of petroleum use.

By late 2015/early 2016, world oil prices were sharply lower than in 2014. Future prices remain uncertain, but sustained markedly lower oil prices can have mixed implications for U.S. energy security. Under lower prices U.S. expenditures on oil consumption are lower, and they are a less prominent component of the U.S. economy. This would lessen the issue of imported oil as an energy security problem for the U.S. On the other hand, sustained lower oil prices encourage greater oil consumption, and reduce the competitiveness of new U.S. oil supplies and alternative fuels. The AEO 2015 low-oil price outlook, for example, projects that by 2030 total U.S. petroleum supply would be 10 percent lower and imports would be 78 percent higher than the AEO Reference Case. Under the low-price case, 2030 prices are 35 percent lower, so that import expenditures are 16 percent higher.

A second potential proposed energy security effect of lower oil prices is increased instability of supply, due to greater global reliance on fewer suppling nations,[75] and because lower prices may increase economic and geopolitical instability in some supplier nations.[76,77,78] The International Monetary Fund reported that low oil prices are creating substantial economic tension in the Middle East oil producers on top of the economic costs of ongoing conflicts, and noted the risk that Middle East countries including Saudi Arabia could run out of financial assets without substantial change in policy.[79] The concern raised is that oil revenues are essential for some exporting nations to fund domestic programs and avoid domestic unrest.

The energy security costs estimated here follow the oil security premium framework, which is well established in the energy economics literature. The oil import premium gained attention as a guiding concept for energy policy around the time of the second and third major post-war oil shocks (Bohi and Montgomery 1982, EMF 1982) .[80] Plummer (1982)[81] provided valuable discussion of many of the key issues related to the oil import premium as well as the analogous oil stockpiling premium. Bohi and Montgomery (1982)[82] detailed the theoretical foundations of the oil import premium established many of the critical analytic relationships through their thoughtful analysis. Hogan (1981)[83] and Broadman and Hogan (1986, 1988)[84] revised and extended the established analytical framework to estimate optimal oil import premia with a more detailed accounting of macroeconomic effects.

Since the original work on energy security was undertaken in the 1980's, there have been several reviews on this topic. For example, Leiby, Jones, Curlee and Lee (1997)[85] provided an extended review of the literature and issues regarding the estimation of the premium. Parry and Darmstadter (2004)[86] also provided an overview of extant oil security premium estimates and they estimated some premium components.

The recent economics literature on whether oil shocks are a threat to economic stability that they once were is mixed. Some of the current literature asserts that the macroeconomic component of the energy security externality is small. For example, the National Research Council (2009) argued that the non-environmental externalities associated with dependence on foreign oil are small, and potentially trivial.[87] Analyses by Nordhaus (2007) and Blanchard and Gali (2010) question the impact of more recent oil price shocks on the economy.[88] They were motivated by attempts to explain why the economy actually expanded immediately after the last shocks, and why there was no evidence of higher energy prices being passed on through higher wage inflation. Using different methodologies, they conclude that the economy has largely gotten over its concern with dramatic swings in oil prices.

One reason, according to Nordhaus, is that monetary policy has become more accommodating to the price impacts of oil shocks. Another is that consumers have simply decided that such movements are temporary, and have noted that price impacts are not passed on as inflation in other parts of the economy. He also notes that real changes to productivity due to oil price increases are incredibly modest,[89] and that the general direction of the economy matters a great deal regarding how the economy responds to a shock. Estimates of the impact of a price shock on aggregate demand are insignificantly different from zero.

Blanchard and Gali (2010) contend that improvements in monetary policy (as noted above), more flexible labor markets, and lessening of energy intensity in the economy, combined with an absence of concurrent shocks, all contributed to lessen the impact of oil shocks after 1980. They find "… the effects of oil price shocks have changed over time, with steadily smaller effects on prices and wages, as well as on output and employment."[90] In a comment at the chapter's end, this work is summarized as follows: "The message of this chapter is thus optimistic in that it suggests a transformation in U.S. institutions has inoculated the economy against the responses that we saw in the past."

At the same time, the implications of the "Shale Oil Revolution" are now being felt in the international markets, with current prices at four year lows. Analysts generally attribute this result in part to the significant increase in supply resulting from U.S. production, which has put liquid petroleum production on par with Saudi Arabia. The price decline is also attributed to the sustained reductions in U.S. consumption and global demand growth from fuel efficiency policies and high oil prices. The resulting decrease in foreign imports, down to about one-third of domestic consumption (from 60 percent in 2005, for example[91]), effectively permits U.S. supply to act as a buffer against artificial or other supply restrictions (the latter due to conflict or natural disaster, for example).

However, other papers suggest that oil shocks, particularly sudden supply shocks, remain a concern. Both Blanchard and Gali's and Nordhaus work were based on data and analysis through 2006, ending with a period of strong global economic growth and growing global oil demand. The Nordhaus work particularly stressed the effects of the price increase from 2002-2006 that were comparatively gradual (about half the growth rate of the 1973 event and one-third that of the 1990 event). The Nordhaus study emphasizes the robustness of the U.S. economy during a time period through 2006. This time period was just before rapid further increases in the price of oil and other commodities with oil prices more-than-doubling to over $130/barrel by mid-2008, only to drop after the onset of the largest recession since the Great Depression.

Hamilton (2012)[92] reviewed the empirical literature on oil shocks and suggested that the results are mixed, noting that some work (e.g. Rasmussen and Roitman (2011) finds less evidence for economic effects of oil shocks, or declining effects of shocks (Blanchard and Gali 2010), while other work continues to find evidence regarding the economic importance of oil shocks. For example, Baumeister and Peersman (2011) found that an oil price increase of a given size seems to have a decreasing effect over time, but noted that the declining price-elasticity of demand meant that a given physical disruption had a bigger effect on price and turned out to have a similar effect on output as in the earlier data." Hamilton observes that "a negative effect of oil prices on real output has also been reported for a number of other countries, particularly when nonlinear functional forms have been employed". Alternatively, rather than a declining effect, Ramey and Vine (2010) [93] found "remarkable stability in the response of aggregate real variables to oil shocks once we account for the extra costs imposed on the economy in the 1970s by price controls and a complex system of entitlements that led to some rationing and shortages."

Some of the recent literature on oil price shocks has emphasized that economic impacts depend on the nature of the oil shock, with differences between price increases caused by sudden supply loss and those caused by rapidly growing demand. Most recent analyses of oil price shocks have confirmed that "demand-driven" oil price shocks have greater effects on oil prices and tend to have positive effects on the economy while "supply-driven" oil shocks still have negative economic impacts (Baumeister, Peersman and Van Robays, 2010).[94] A recent paper by Kilian and Vigfusson (2014),[95] for example, assigned a more prominent role to the effects of price increases that are unusual, in the sense of being beyond range of recent experience. Kilian and Vigfussen also conclude that the difference in response to oil shocks may well stem from the different effects of demand- and supply-based price increases: “One explanation is that oil price shocks are associated with a range of oil demand and oil supply shocks, some of which stimulate the U.S. economy in the short run and some of which slow down U.S. growth (see Kilian 2009). How recessionary the response to an oil price shock is thus depends on the average composition of oil demand and oil supply shocks over the sample period.”

The general conclusion that oil supply-driven shocks reduce economic output is also reached in a recently published paper by Cashin et al. (2014)[96] for 38 countries from 1979-2011. “The results indicate that the economic consequences of a supply-driven oil-price shock are very different from those of an oil-demand shock driven by global economic activity, and vary for oil-importing countries compared to energy exporters,” and “oil importers [including the U.S.] typically face a long-lived fall in economic activity in response to a supply-driven surge in oil prices” but almost all countries see an increase in real output for an oil-demand disturbance. Note that the energy security premium calculation in this analysis is based on price shocks from potential future supply events only.

Despite continuing uncertainty about oil market behavior and outcomes and the sensitivity of the U.S. economy to oil shocks, it is generally agreed that it is beneficial to reduce petroleum fuel consumption from an energy security standpoint. Reducing fuel consumption reduces the amount of domestic economic activity associated with a commodity whose price depends on volatile international markets. Also, reducing U.S. oil import levels reduces the likelihood and significance of supply disruptions.

The Competitive Enterprise Institute (CEI) and others argue that there are little, if any, energy security benefits associated with this rule. In large part CEI argues that oil supplies are plentiful and that current oil prices are low so that reduced consumption of petroleum products due to these rules would have no effect on energy security. However, the discussion of current low oil prices ("lowest Labor Day gasoline prices in a decade") does not assure the absence of future oil supply shocks or price shocks, or even speak to their reduced likelihood. CEI points out that the current low oil prices have been observed before as recently as a decade ago, as they have in more than one instance before that. For example, oil prices were even lower in 1999. But in the intervening periods, oil supply and price shocks have continued to recur, and the recent price record only amplifies oil's high historical price volatility.

Also, sharply lower world oil prices do not clearly imply greater energy security for the U.S. Current low world oil prices may reduce the U.S.’s fracking industry's tight oil production (as CEI points out), or other sources of oil supplies around the world. Some have hypothesized that reduction in oil production outside of OPEC may be the objective of some OPEC producers. With low oil prices, U.S.’s oil import share over time might be larger, increasing the U.S.’s dependence on imported oil.

Securing America’s Future Energy (SAFE), Operation Free and the Investor Network on Climate Risk agree that this rule does improve America’s energy security. SAFE goes on to state that several policy options should be included in this rule to further enhance energy security. The agencies agree that these rules enhances America’s energy security, but does not have information to evaluate the policy options that SAFE proposes.

8.8.3.3 Cost of Existing U.S. Energy Security Policies

The last often-identified component of the full economic costs of U.S. oil imports are the costs to the U.S. taxpayers of existing U.S. energy security policies. The two primary examples are maintaining the Strategic Petroleum Reserve (SPR) and maintaining a military presence to help secure a stable oil supply from potentially vulnerable regions of the world. The SPR is the largest stockpile of government-owned emergency crude oil in the world. Established in the aftermath of the 1973/74 oil embargo, the SPR provides the U.S. with a response option should a disruption in commercial oil supplies threaten the U.S. economy. It also allows the U.S. to meet part of its International Energy Agency obligation to maintain emergency oil stocks, and it provides a national defense fuel reserve. While the costs for building and maintaining the SPR are more clearly related to U.S. oil use and imports, historically these costs have not varied in response to changes in U.S. oil import levels. Thus, while the effect of the SPR in moderating price shocks is factored into the ORNL analysis, the cost of maintaining the SPR is excluded.

U.S. military costs are excluded from the analysis performed by ORNL because their attribution to particular missions or activities is difficult, and because it is not clear that these outlays would decline in response to incremental reductions in U.S. oil imports. Most military forces serve a broad range of security and foreign policy objectives. Attempts to attribute some share of U.S. military costs to oil imports are further challenged by the need to estimate how those costs might vary with incremental variations in U.S. oil imports.

In the proposal to this rule, the agencies solicited comments on quantifying the military benefits from reduced U.S. imports of oil. The California Air Resources Board (CARB) notes that the National Research Council (NRC)[97] attempted to estimate the military costs associated with U.S. imports and consumption of petroleum. The NRC cited estimates of the national defense costs of oil dependence from the literature that range from less than $5 to $50 billion per year or more. Assuming a range of approximate range of $10 to $50 billion per year, the NRC divided national defense costs by a projected U.S. consumption rate of approximately 6.4 billion barrels per year (EIA, 2012). This procedure yielded a range of average national defense cost of $1.50 - $8.00 per barrel (rounded to the nearest $0.50), with a mid-point of $5/barrel (in 2009$). The agencies acknowledge this NRC study, but have not included the estimates as part of the cost-benefit analysis for this rule.

8.8.4 Energy Security Benefits of this Program

Using the ORNL “oil premium” methodology, updating world oil price values and energy trends using AEO 2015 and using the estimated fuel savings from the final rule estimated from the MOVES/CAFE models, the agencies have calculated the energy security benefits of these final rules for different classes for medium- and heavy-duty vehicles for the various years up to 2050.[YY] Since the agencies are taking a global perspective with respect to valuing greenhouse gas benefits from the rule, only the avoided macroeconomic adjustment/disruption

[YY] In order to determine the energy security benefits beyond 2040, we use the 2040 energy security premium multiplied by the estimate fuel savings from the final program. Since the AEO 2015 only goes to 2040, we only calculate energy security premiums to 2040.

portion of the energy security premium is used in the energy security benefits estimates present below. These results are shown below in Table 8-27, Table 8-28 and Table 8-29 show discounted model year lifetime energy security benefits for different classes of heavy-duty vehicles using a three and seven percent discount rate.

Table 8-27 Annual U.S. Energy Security Benefits and Net Present Values at 3% and 7% Discount Rates for the Final Program (Millions of 2013$) [a]

CALENDAR YEAR	HD PICKUP & VANS	VOCATIONAL	TRACTOR/ TRAILER	SUM
2018	$0	$0	$4	$4
2019	$0	$0	$9	$9
2020	$0	$0	$14	$14
2021	$2	$9	$44	$55
2022	$8	$18	$83	$109
2023	$18	$27	$125	$171
2024	$32	$43	$193	$268
2025	$51	$58	$263	$372
2026	$74	$74	$335	$482
2027	$101	$95	$431	$627
2028	$129	$117	$528	$775
2029	$157	$140	$626	$923
2030	$186	$162	$726	$1,074
2035	$327	$274	$1,246	$1,847
2040	$438	$370	$1,725	$2,533
2050	$489	$435	$2,101	$3,025
NPV, 3%	$4,166	$3,633	$16,916	$24,716
NPV, 7%	$1,684	$1,485	$6,881	$10,050

Table 8-28 Discounted Model Year Lifetime Energy Security Benefits at a 3% Discount Rate for the Final Program (Millions of 2013$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/ TRAILER	SUM
2018	$0	$0	$30	$30
2019	$0	$0	$29	$29
2020	$0	$0	$28	$28
2021	$21	$85	$379	$485
2022	$56	$85	$380	$520
2023	$90	$84	$378	$552
2024	$124	$130	$595	$849
2025	$157	$131	$598	$886
2026	$190	$131	$596	$917
2027	$221	$174	$788	$1,183
2028	$220	$175	$787	$1,182
2029	$219	$175	$790	$1,184
Sum	$1,296	$1,169	$5,379	$7,844

Table 8-29 Discounted Model Year Lifetime Energy Security Benefits at 7% Discount Rate due to the Final Program (Millions of 2013$) [a]

MODEL YEAR	HD PICKUP AND VANS	VOCATIONAL	TRACTOR/ TRAILER	SUM
2018	$0	$0	$21	$21
2019	$0	$0	$20	$20
2020	$0	$0	$18	$18
2021	$13	$52	$230	$294
2022	$33	$50	$222	$304
2023	$51	$47	$213	$311
2024	$67	$71	$323	$461
2025	$83	$69	$313	$464
2026	$96	$66	$301	$463
2027	$108	$85	$384	$577
2028	$104	$82	$369	$555
2029	$99	$80	$358	$536
Sum	$653	$602	$2,771	$4,026

8.9 Summary of Benefits and Costs

This section presents the costs, benefits, and other economic impacts of the Phase 2 standards. It is important to note that NHTSA's fuel consumption standards and EPA's GHG standards will both be in effect, and will jointly lead to increased fuel efficiency and reductions in GHG and non-GHG emissions. The individual categories of benefits and costs presented in the tables below include:

- the vehicle program costs (costs of complying with the vehicle CO_2 and fuel consumption standards),
- changes in fuel expenditures associated with reduced fuel use by more efficient vehicles and increased fuel use associated with the "rebound" effect, both of which result from the program,
- the global economic value of reductions in GHGs,
- the economic value of reductions in non-GHG pollutants,
- costs associated with increases in noise, congestion, and crashes resulting from increased vehicle use,
- savings in drivers' time from less frequent refueling,
- benefits of increased vehicle use associated with the "rebound" effect, and
- the economic value of improvements in U.S. energy security impacts.

For a discussion of the cost of ownership and the agencies' payback analysis of vehicles covered by these final rules, please see Chapter 7 of this RIA.

The agencies separate analyses using two analytical methods referred to as Method A and Method B. For an explanation of these methods, please see Section I.D for the Preamble. And as discussed in Preamble Section X.A.1, the agencies present estimates of benefits and costs that are measured against two different assumptions about improvements in fuel efficiency that might occur in the absence of the Phase 2 standards. The first case (Alternative 1a) uses a baseline that projects very little improvement in new vehicles in the absence of new Phase 2 standards, and the second (Alternative 1b) uses a more dynamic baseline that projects more significant improvements in vehicle fuel efficiency.

Table 8-30 shows benefits and costs for the standards from the perspective of a program designed to improve the nation's energy security and conserve energy by improving fuel efficiency. From this viewpoint, technology costs occur when the vehicle is purchased. Fuel savings are counted as benefits that occur over the lifetimes of the vehicles produced during the model years subject to the Phase 2 standards as they consume less fuel. The table shows that benefits far outweigh the costs, and the final program is anticipated to result in large net benefits to the U.S economy.

Table 8-30 Lifetime Benefits & Costs of the Final Program for Model Years 2018 - 2029 Vehicles Using Analysis Method A (Billions of 2013$ discounted at 3% and 7%)

CATEGORY	BASELINE 1A		BASELINE 1B	
	3%	**7%**	**3%**	**7%**
Vehicle Program: Technology and Indirect Costs, Normal Profit on Additional Investments	24.4	16.6	23.7	16.1
Additional Routine Maintenance	1.7	0.9	1.7	0.9
Congestion, Crashes, Fatalities and Noise from Increased Vehicle Use [a]	3.2	1.9	3.1	1.8
Total Costs	**29.3**	**19.4**	**28.5**	**18.8**
Fuel Savings (valued at pre-tax prices)	163.0	87.0	149.1	79.7
Savings from Less Frequent Refueling	3.2	1.7	3.0	1.6
Economic Benefits from Additional Vehicle Use	5.5	3.5	5.4	3.4
Reduced Climate Damages from GHG Emissions [b]	36.0		33.0	
Reduced Health Damages from Non-GHG Emissions	30.0	16.1	27.2	14.5
Increased U.S. Energy Security	7.9	4.2	7.3	3.9
Total Benefits	**246**	**149**	**225**	**136**
Net Benefits	**216**	**129**	**197**	**117**

Note:

Benefits and net benefits use the 3 percent average global SC-CO_2, SC-CH_4, and SC-N_2O value applied to CO_2, CH_4, and N_2O emissions, respectively; GHG reductions also include HFC reductions, and include benefits to other nations as well as the U.S. See RIA Chapter 8.5 and Preamble Section IX.G for further discussion.

[b] "Congestion, Crashes, Fatalities and Noise from Increased Vehicle Use" includes NHTSA's monetized value of estimated reductions in the incidence of highway fatalities associated with mass reduction in HD pickup and vans, but this does not include these reductions from tractor-trailers or vocational vehicles. This likely results in a conservative overestimate of these costs.

Table 8-30, Table 8-31 and Table 8-33 report benefits and cost from the perspective of reducing GHG. Table 8-31 shows the annual impacts and net benefits of the final program for selected future years, together with the net present values of cumulative annual impacts from 2018 through 2050, discounted at 3 percent and 7 percent rates. Table 8-31 and Table 8-33 show the discounted lifetime costs and benefits for each model year affected by the Phase 2 standards at 3 percent and 7 percent discount rates, respectively.

Table 8-31 Annual Benefits & Costs and Net Present Values for the Final Program Relative to the Flat Baseline and using Method B (Billions of 2013$)[a,b,c]

	2018	2021	2024	2030	2035	2040	2050	NPV, 3%	NPV, 7%
Vehicle program	-$0.2	-$2.5	-$4.2	-$5.2	-$5.7	-$6.3	-$7.3	-$87.8	-$41.9
Maintenance	$0.0	$0.0	-$0.1	-$0.2	-$0.2	-$0.2	-$0.2	-$3.2	-$1.5
Pre-tax Fuel	$0.1	$1.3	$6.1	$23.4	$38.9	$53.1	$63.4	$523.3	$213.8
Energy security	$0.0	$0.1	$0.3	$1.1	$1.8	$2.5	$3.0	$24.7	$10.1
Crashes/ Congestion/ Noise	$0.0	-$0.1	-$0.2	-$0.4	-$0.5	-$0.5	-$0.6	-$6.8	-$3.1
Refueling	$0.0	$0.0	$0.1	$0.6	$0.9	$1.1	$1.5	$12.0	$4.9
Travel value	$0.0	$0.3	$0.6	$1.2	$1.7	$2.0	$2.3	$23.4	$10.3
Non-GHG	$0.0 to $0.0	$0.2 to $0.5	$0.7 to $1.8	$2.7 to $6.8	$4.1 to $10.1	$5.0 to $12.5	$6.0 to $15.0	$58.8 to $132.0	$22.1 to $49.7
GHG									
SC-GHG; 5% avg	$0.0	$0.1	$0.4	$1.7	$2.8	$3.9	$5.8	$25.1	$25.1
SC-GHG; 3% avg	$0.0	$0.3	$1.4	$5.2	$8.4	$11.1	$15.2	$115.4	$115.4
SC-GHG; 2.5% avg	$0.0	$0.4	$2.0	$7.5	$11.9	$15.5	$20.9	$183.1	$183.1
SC-GHG; 3% 95th	$0.1	$0.9	$4.1	$15.6	$25.5	$33.6	$46.6	$351.0	$351.0
Net benefits									
SC-GHG; 5% avg	-$0.1	-$0.6	$4.3	$26.7	$46.6	$64.3	$78.2	$606.2	$253.8
SC-GHG; 3% avg	-$0.1	-$0.4	$5.2	$30.2	$52.2	$71.4	$87.6	$696.4	$344.0
SC-GHG; 2.5% avg	-$0.1	-$0.3	$5.9	$32.6	$55.7	$75.8	$93.3	$764.2	$411.8
SC-GHG; 3% 95th	$0.0	$0.2	$8.0	$40.7	$69.4	$94.0	$119.0	$932.1	$579.7

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] GHG benefit estimates include reductions in CO_2, CH_4, and N_2O but do not include the HFC reductions. Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CO_2, SC-CH_4, and SC-N_2O, each discounted at rates of at 5, 3, 2.5 percent) is used to calculate net present value of SC-CO2, SC-CH4, and SC-N2O, respectively, for internal consistency. Refer to the SC-CO2 TSD for more detail.

[c] Chapter 8.5 of the RIA notes that SC-GHGs increases over time. Corresponding to the years in this table (2020-2050), the SC-CO_2 estimates range as follows: for Average SC-CO_2 at 5%: $7-$16; for Average SC-CO_2 at 3%: $27-$46; for Average SC-CO_2 at 2.5%: $43-$67; and for 95th percentile SC-CO_2 at 3%: $83-$140. For the years 2012-2050, the SC-CH4 estimates range as follows: for Average SC-CH4 at 5%: $440-$1,400; for Average SC-CH4 at 3%: $1,000-$2,700; for Average SC-CH4 at 2.5%: $1,400-$3,400; and for 95th percentile SC-CH4 at 3%: $2,800-$7,400. For the years 2012-2050, the SC-N2O estimates range as follows: for Average SC-N2O at 5%:

$4,000-$12,000; for Average SC-N2O at 3%: $14,000-$30,000; for Average SC-N2O at 2.5%: $21,000-$41,000; and for 95th percentile SC-N2O at 3%: $36,000-$79,000. Chapter 8.5 also presents these SC-GHG estimates.

The table shows the benefits of reduced CO_2, CH_4, and N_2O emissions—and consequently the annual quantified benefits (*i.e.*, total benefits)—for each of four SC-CO_2, SC-CH_4, and SC-N_2O values, respectively. As discussed in Chapter 8.5, there are some limitations to the SC-CO_2, SC-CH_4, and SC-N_2O analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion.

In addition, these monetized GHG benefits exclude the value of reductions in HFC emissions expected under this program. Although EPA has not included monetized estimates of benefits of reductions in HFC emissions in this Chapter 8.9, the value of these reductions should not be interpreted as zero. The reader is referred to Chapter 8.5.2.2 of this RIA to see the sensitivity analysis that approximates the value of HFC benefits.

The agencies have also conducted a separate analysis of the total benefits over the model year lifetimes of 2018 through 2029 model year vehicles. In contrast to the calendar year analysis presented in Table 8-31, the model year lifetime analysis shows the impacts of the program on vehicles produced during each of the affected model years over the course of their expected lifetimes. The net societal benefits over the full lifetimes of vehicles produced during each of the model years are shown in Table 8-31 and Table 8-32 at both 3 percent and 7 percent discount rates, respectively.

Table 8-32 Discounted Model Year Lifetime Impacts for the Final Program Relative to the Flat Baseline and using Method B (Billions of 2013$; 3% Discount Rate)[a,b,c]

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	SUM
Vehicle Program	-$0.2	-$0.2	-$0.2	-$2.1	-$2.0	-$2.1	-$3.1	-$3.0	-$3.0	-$3.6	-$3.5	-$3.4	-$26.5
Maintenance	-$0.01	-$0.01	-$0.01	-$0.15	-$0.16	-$0.16	-$0.18	-$0.18	-$0.17	-$0.30	-$0.29	-$0.29	-$1.9
Pre-tax Fuel	$0.7	$0.7	$0.6	$10.7	$11.4	$12.0	$18.5	$19.1	$19.7	$25.3	$25.2	$25.1	$169.1
Energy Security	$0.0	$0.0	$0.0	$0.5	$0.5	$0.6	$0.8	$0.9	$0.9	$1.2	$1.2	$1.2	$7.8
Crashes, Noise, Congestion	-$0.1	-$0.1	-$0.2	-$0.3	-$0.3	-$0.3	-$0.3	-$0.3	-$0.3	-$0.3	-$0.3	-$0.3	-$3.2
Refueling	$0.0	$0.0	$0.0	$0.2	$0.3	$0.3	$0.4	$0.5	$0.5	$0.6	$0.6	$0.6	$4.0
Travel value	$0.5	$0.5	$0.6	$1.1	$1.0	$1.0	$1.0	$1.0	$1.0	$1.0	$0.9	$0.9	$10.5
Non-GHG	$0.1 to $0.3	$0.1 to $0.2	$0.1 to $0.2	$1.4 to $3.2	$1.4 to $3.2	$1.5 to $3.3	$2.3 to $5.2	$2.3 to $5.3	$2.2 to $4.8	$2.8 to $6.2	$2.7 to $6.1	$2.7 to $6.0	$19.6 to $44.1
GHG													
SC-GHG; 5% avg	$0.0	$0.0	$0.0	$0.6	$0.6	$0.6	$1.0	$1.0	$1.0	$1.3	$1.2	$1.2	$8.6
SC-GHG; 3% avg	$0.2	$0.1	$0.1	$2.4	$2.6	$2.7	$4.1	$4.2	$4.3	$5.5	$5.5	$5.5	$37.2
SC-GHG; 2.5% avg	$0.2	$0.2	$0.2	$3.7	$4.0	$4.2	$6.4	$6.6	$6.8	$8.7	$8.6	$8.6	$58.3
SC-GHG; 3% 95th	$0.5	$0.4	$0.4	$7.2	$7.7	$8.0	$12.3	$12.7	$13.1	$16.8	$16.7	$16.6	$112.5
Net benefits													
SC-GHG; 5% avg	$1.1	$1.1	$1.1	$12.8	$13.7	$14.3	$21.8	$22.7	$23.1	$29.6	$29.5	$29.5	$200.2
SC-GHG; 3% avg	$1.2	$1.2	$1.2	$14.6	$15.6	$16.3	$24.9	$26.0	$26.4	$33.9	$33.8	$33.7	$228.8
SC-GHG; 2.5% avg	$1.3	$1.3	$1.3	$16.0	$17.1	$17.8	$27.2	$28.4	$28.9	$37.0	$36.9	$36.9	$249.9
SC-GHG; 3% 95th	$1.5	$1.5	$1.5	$19.5	$20.8	$21.7	$33.2	$34.5	$35.2	$45.1	$44.9	$44.9	$304.1

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The monetized GHG benefits presented in this analysis exclude the value of changes in HFC emissions expected under this program (see RIA Chapter 8.5). Although EPA has not monetized changes in HFCs in the main benefits analysis, the value of any increases or reductions should not be interpreted as zero.

[c] GHG benefit estimates include reductions in CO_2, CH_4, and N_2O but do not include the HFC reductions. Note that net present value of reduced CO_2 GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CO_2 , SC-CH_4, and SC-N_2O, each discounted at rates of at 5, 3, 2.5 percent) is used to calculate net present value of SC-CO_2, SC-CH_4, and SC-N_2O, respectively, SC-CO_2 for internal consistency. Refer to the SC-CO_2 TSD for more detail.

Table 8-33 Discounted Model Year Lifetime Impacts for the Final Program Relative to the Flat Baseline and using Method B (Billions of 2013$; 7% Discount Rate) [a,b,c]

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	SUM
Vehicle Program	-$0.2	-$0.2	-$0.2	-$1.6	-$1.5	-$1.5	-$2.2	-$2.0	-$1.9	-$2.2	-$2.1	-$2.0	-$17.6
Maintenance	$0.00	$0.00	$0.00	-$0.10	-$0.09	-$0.09	-$0.10	-$0.10	-$0.09	-$0.15	-$0.14	-$0.13	-$1.0
Pre-tax Fuel	$0.5	$0.4	$0.4	$6.6	$6.7	$6.8	$10.1	$10.1	$10.0	$12.4	$11.9	$11.4	$87.2
Energy Security	$0.0	$0.0	$0.0	$0.3	$0.3	$0.3	$0.5	$0.5	$0.5	$0.6	$0.6	$0.5	$4.0
Crashes, Noise, Congestion	-$0.1	-$0.1	-$0.1	-$0.2	-$0.2	-$0.2	-$0.2	-$0.2	-$0.2	-$0.1	-$0.1	-$0.1	-$1.8
Refueling	$0.0	$0.0	$0.0	$0.1	$0.2	$0.2	$0.2	$0.2	$0.3	$0.3	$0.3	$0.3	$2.1
Travel value	$0.3	$0.3	$0.4	$0.6	$0.6	$0.6	$0.5	$0.5	$0.5	$0.5	$0.4	$0.4	$5.7
Non-GHG	$0.1 to $0.2	$0.1 to $0.1	$0.1 to $0.1	$0.8 to $1.8	$0.8 to $1.7	$0.8 to $1.7	$1.1 to $2.6	$1.1 to $2.5	$1.0 to $2.2	$1.2 to $2.7	$1.2 to $2.6	$1.1 to $2.5	$9.2 to $20.8
GHG													
SC-GHG; 5% avg	$0.0	$0.0	$0.0	$0.6	$0.6	$0.6	$1.0	$1.0	$1.0	$1.3	$1.2	$1.2	$8.6
SC-GHG; 3% avg	$0.2	$0.1	$0.1	$2.4	$2.6	$2.7	$4.1	$4.2	$4.3	$5.5	$5.5	$5.5	$37.2
SC-GHG; 2.5% avg	$0.2	$0.2	$0.2	$3.7	$4.0	$4.2	$6.4	$6.6	$6.8	$8.7	$8.6	$8.6	$58.3
SC-GHG; 3% 95th	$0.5	$0.4	$0.4	$7.2	$7.7	$8.0	$12.3	$12.7	$13.1	$16.8	$16.7	$16.6	$112.5
Net benefits													
SC-GHG; 5% avg	$0.7	$0.7	$0.6	$7.6	$7.9	$7.9	$11.7	$11.8	$11.6	$14.4	$13.9	$13.5	$102.3
SC-GHG; 3% avg	$0.8	$0.8	$0.8	$9.4	$9.8	$10.0	$14.8	$15.1	$15.0	$18.7	$18.2	$17.7	$130.9
SC-GHG; 2.5% avg	$0.9	$0.9	$0.8	$10.7	$11.2	$11.4	$17.1	$17.4	$17.4	$21.9	$21.3	$20.9	$151.9
SC-GHG; 3% 95th	$1.1	$1.1	$1.0	$14.2	$14.9	$15.3	$23.0	$23.6	$23.7	$29.9	$29.3	$28.9	$206.1

Notes:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Preamble Section X.A.1

[b] The monetized GHG benefits presented in this analysis exclude the value of changes in HFC emissions expected under this program (see RIA Chapter 8.5). Although EPA has not monetized changes in HFC s in the main benefits analysis, the value of any increases or reductions should not be interpreted as zero.

[c] GHG benefit estimates include reductions in CO_2, CH_4, and N_2O but do not include the HFC reductions. Note that net present value of reduced CO_2 GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SC-CO_2 , SC-CH_4, and SC-N_2O, each discounted at rates of at 5, 3, 2.5 percent) is used to calculate net present value of SC-CO_2, SC-CH_4, and SC-N_2O, respectively, SC-CO_2 for internal consistency. Refer to the SC-CO_2 TSD for more detail.

8.10 Employment Impacts

8.10.1 Introduction

Executive Order 13563 (January 18, 2011) directs federal agencies to consider regulatory impacts on, among other criteria, job creation.[98] According to the Executive Order "Our regulatory system must protect public health, welfare, safety, and our environment while promoting economic growth, innovation, competitiveness, and job creation. It must be based on the best available science" (emphasis added). Analysis of employment impacts of a regulation is not part of a standard benefit-cost analysis (except to the extent that labor costs contribute to costs). Employment impacts of federal rules are of general interest, however, and have been particularly so, historically, in the auto sector during periods of challenging labor market conditions. For this reason, we are describing the connections of these standards to employment in the regulated sector, the motor vehicle manufacturing sector, as well as the motor vehicle body and trailer and motor vehicle parts manufacturing sectors.[ZZ]

The overall effect of the final rules on motor vehicle sector employment depends on the relative magnitude of output and substitution effects, described below. Because we do not have quantitative estimates of the output effect, and only a partial estimate of the substitution effect, we cannot reach a quantitative estimate of the overall employment effects of the final rules on motor vehicle sector employment or even whether the total effect will be positive or negative.

According to the U.S. Bureau of Labor Statistics, in 2014, about 850,000 people in the U.S. were employed in the Motor Vehicle and Parts Manufacturing Sector (NAICS 3361, 3362, and 3363),[99] the directly regulated sector. The employment effects of these final rules are expected to expand beyond the regulated sector. Though some of the parts used to achieve the standards are likely to be built by motor vehicle manufacturers (including trailer manufacturers) themselves, the motor vehicle parts manufacturing sector also plays a significant role in providing those parts, and will also be affected by changes in vehicle sales. Changes in truck sales, discussed in Chapter 8.4.2, could also affect employment for truck and trailer vendors. As discussed in Chapter 7, the final rules are expected to reduce the amount of fuel these vehicles use, and thus affect the petroleum refinery and supply industries as well. Finally, since the net reduction in cost associated with these final rules is expected to lead to lower transportation and shipping costs, in a competitive market a substantial portion of those cost savings will be passed along to consumers, who then will have additional discretionary income (how much of the cost is passed along to consumers depends on market structure and the relative price elasticities). The final rules are not expected to have any notable inflationary or recessionary effect.

The employment effects of environmental regulation are difficult to disentangle from other economic changes and business decisions that affect employment, over time and across

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[ZZ] The employment analysis in this RIA is part of EPA's ongoing effort to "conduct continuing evaluations of potential loss or shifts of employment which may result from the administration or enforcement of [the Act]" pursuant to CAA section 321(a).

regions and industries. In light of these difficulties, we lean on economic theory to provide a constructive framework for approaching these assessments and for better understanding the inherent complexities in such assessments. Neoclassical microeconomic theory describes how profit-maximizing firms adjust their use of productive inputs in response to changes in their economic conditions.[100] Berman and Bui (2001, pp. 274-75) model two components that drive changes in firm-level labor demand: output effects and substitution effects.[101,AAA] Regulation can affect the profit-maximizing quantity of output by changing the marginal cost of production. If regulation causes marginal cost to increase, it will place upward pressure on output prices, leading to a decrease in the quantity demanded, and resulting in a decrease in production. The output effect describes how, holding labor intensity constant, a decrease in production causes a decrease in labor demand. As noted by Berman and Bui, although many assume that regulation increases marginal cost, it need not be the case. A regulation could induce a firm to upgrade to less polluting and more efficient equipment that lowers marginal production costs, or it may induce use of technologies that may prove popular with buyers or provide positive network externalities (see Chapter 8.2 for discussion of this effect). In such a case, output could increase.

The substitution effect describes how, holding output constant, regulation affects labor intensity of production. Although increased environmental regulation may increase use of pollution control equipment and energy to operate that equipment, the impact on labor demand is ambiguous. For example, equipment inspection requirements, specialized waste handling, or pollution technologies that alter the production process may affect the number of workers necessary to produce a unit of output. Berman and Bui (2001) model the substitution effect as the effect of regulation on pollution control equipment and expenditures required by the regulation and the corresponding change in labor intensity of production.

In summary, as output and substitution effects may be positive or negative, theory alone cannot predict the direction of the net effect of regulation on labor demand at the level of the regulated firm. Operating within the bounds of standard economic theory, empirical estimation of net employment effects on regulated firms is possible when data and methods of sufficient detail and quality are available. The literature, however, illustrates difficulties with empirical estimation. For example, studies sometimes rely on confidential plant-level employment data from the U.S. Census Bureau, possibly combined with pollution abatement expenditure data that are too dated to be reliably informative. In addition, the most commonly used empirical methods do not permit estimation of net effects.

The conceptual framework described thus far focused on regulatory effects on plant-level decisions within a regulated industry. Employment impacts at an individual plant do not necessarily represent impacts for the sector as a whole. The approach must be modified when applied at the industry level.

[AAA] Berman and Bui also discuss a third component, the impact of regulation on factor prices, but conclude that this effect is unlikely to be important for large competitive factor markets, such as labor and capital. Morgenstern, Pizer and Shih (2002) use a very similar model, but they break the employment effect into three parts: 1) a demand effect; 2) a cost effect; and 3) a factor-shift effect.

At the industry level, labor demand is more responsive if: (1) the price elasticity of demand for the product is high, (2) other factors of production can be easily substituted for labor, (3) the supply of other factors is highly elastic, or (4) labor costs are a large share of total production costs.[102] For example, if all firms in an industry are faced with the same regulatory compliance costs and product demand is inelastic, then industry output may not change much, and output of individual firms may change slightly.[103] In this case, the output effect may be small, while the substitution effect depends on input substitutability. Suppose, for example, that new equipment for fuel efficiency improvements requires labor to install and operate. In this case, the substitution effect may be positive, and with a small output effect, the total effect may be positive. As with potential effects for an individual firm, theory cannot determine the sign or magnitude of industry-level regulatory effects on labor demand. Determining these signs and magnitudes requires additional sector-specific empirical study. For environmental rules, much of the data needed for these empirical studies is not publicly available, would require significant time and resources in order to access confidential U.S. Census data for research, and also would not be necessary for other components of a typical RIA.

In addition to changes to labor demand in the regulated industry, net employment impacts encompass changes in other related sectors. For example, the standards are expected to increase demand for fuel-saving technologies. This increased demand may increase revenue and employment in the firms providing these technologies. At the same time, the regulated industry is purchasing the equipment, and these costs may impact labor demand at regulated firms. Therefore, it is important to consider the net effect of compliance actions on employment across multiple sectors or industries.

If the U.S. economy is at full employment, even a large-scale environmental regulation is unlikely to have a noticeable impact on aggregate net employment.[BBB] Instead, labor would primarily be reallocated from one productive use to another, and net national employment effects from environmental regulation will be small and transitory (e.g., as workers move from one job to another).[104]

Affected sectors may experience transitory effects as workers change jobs. Some workers may retrain or relocate in anticipation of new requirements or require time to search for new jobs, while shortages in some sectors or regions could bid up wages to attract workers. These adjustment costs can lead to local labor disruptions. Although the net change in the national workforce is expected to be small, localized reductions in employment may adversely impact individuals and communities just as localized increases may have positive impacts.

If the economy is operating at less than full employment, economic theory does not clearly indicate the direction or magnitude of the net impact of environmental regulation on employment; it could cause either a short-run net increase or short-run net decrease.[105] An important research question is how to accommodate unemployment as a structural feature in

[BBB] Full employment is a conceptual target for the economy where everyone who wants to work and is available to do so at prevailing wages is actively employed. The unemployment rate at full employment is not zero.

economic models. This feature may be important in assessing large-scale regulatory impacts on employment.[106]

Environmental regulation may also affect labor supply. In particular, pollution and other environmental risks may impact labor productivity or employees' ability to work.[107] While the theoretical framework for analyzing labor supply effects is analogous to that for labor demand, it is more difficult to study empirically. There is a small emerging literature described in the next section that uses detailed labor and environmental data to assess these impacts.

To summarize, economic theory provides a framework for analyzing the impacts of environmental regulation on employment. The net employment effect incorporates expected employment changes (both positive and negative) in the regulated sector and elsewhere. Labor demand impacts for regulated firms, and also for the regulated industry, can be decomposed into output and substitution effects which may be either negative or positive. Estimation of net employment effects for regulated sectors is possible when data of sufficient detail and quality are available. Finally, economic theory suggests that labor supply effects are also possible. In the next section, we discuss the empirical literature.

8.10.1.1 Current State of Knowledge Based on the Peer-Reviewed Literature

In the labor economics literature there is an extensive body of peer-reviewed empirical work analyzing various aspects of labor demand, relying on the above theoretical framework.[108] This work focuses primarily on the effects of employment policies, e.g. labor taxes, minimum wage, etc.[109] In contrast, the peer-reviewed empirical literature specifically estimating employment effects of environmental regulations is very limited. Several empirical studies, including Berman and Bui (2001),[110] Morgenstern, Pizer and Shih (2002),[111] Gray et al (2014),[112] and Ferris, Shadbegian and Wolverton (2014)[113] suggest that net employment impacts may be zero or slightly positive but small even in the regulated sector. Other research suggests that more highly regulated counties may generate fewer jobs than less regulated ones.[114] However, since these latter studies compare more regulated to less regulated counties, they overstate the net national impact of regulation to the extent that regulation causes plants to locate in one area of the country rather than another. List et al. (2003)[115] find some evidence that this type of geographic relocation may be occurring. Overall, the peer-reviewed literature does not contain evidence that environmental regulation has a large impact on net employment (either negative or positive) in the long run across the whole economy.

Analytic challenges make it very difficult to accurately produce net employment estimates for the whole economy that would appropriately capture the way in which costs, compliance spending, and environmental benefits propagate through the macro-economy. Quantitative estimates are further complicated by the fact that macroeconomic models often have very little sectoral detail and usually assume that the economy is at full employment. EPA is currently in the process of seeking input from an independent expert panel on modeling economy-wide impacts, including employment effects. For more information, see: https://federalregister.gov/a/2014-02471.

8.10.2 Employment Impacts in the Motor Vehicle and Parts Manufacturing Sector

This chapter describes changes in employment in the motor vehicle, trailer, and parts (hence, motor vehicle) manufacturing sectors due to these final rules. We focus on the motor vehicle manufacturing sector because it is directly regulated, and because it is likely to bear a substantial share of changes in employment due to these final rules. We include discussion of effects on the parts manufacturing sector, because the motor vehicle manufacturing sector can either produce parts internally or buy them from an external supplier, and we do not have estimates of the likely breakdown of effort between the two sectors.

We follow the theoretical structure of Berman and Bui [116] of the impacts of regulation in employment in the regulated sectors. In Berman and Bui's (2001, p. 274-75) theoretical model, as described above, the change in a firm's labor demand arising from a change in regulation is decomposed into two main components: output and substitution effects.[CCC] As the output and substitution effects may be both positive, both negative, or some combination, standard neoclassical theory alone does not point to a definitive net effect of regulation on labor demand at regulated firms.

Following the Berman and Bui framework for the impacts of regulation on employment in the regulated sector, we consider two effects for the motor vehicle sector: the output effect and the substitution effect.

8.10.2.1 The Output Effect

If truck or trailer sales increase, then more people will be required to assemble trucks, trailers, and their components. If truck or trailer sales decrease, employment associated with these activities will decrease. The effects of this final rulemaking on HD vehicle sales thus depend on the perceived desirability of the new vehicles. On one hand, this final rulemaking will increase truck and trailer costs; by itself, this effect would reduce truck and trailer sales. In addition, while decreases in truck performance would also decrease sales, this program is not expected to have any negative effect on truck performance. On the other hand, this final rulemaking will reduce the fuel costs of operating the trucks; by itself, this effect would increase truck sales, especially if potential buyers have an expectation of higher fuel prices. The agencies have not made an estimate of the potential change in truck or trailer sales. However, as discussed in Chapter 8.3, the agencies have estimated an increase in vehicle miles traveled (*i.e.*, VMT rebound) due to the reduced operating costs of trucks meeting these standards. Since increased VMT is most likely to be met with more drivers and more trucks, our projection of VMT rebound is suggestive of an increase in vehicle sales and truck driver employment

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[CCC] The authors also discuss a third component, the impact of regulation on factor prices, but conclude that this effect is unlikely to be important for large competitive factor markets, such as labor and capital. Morgenstern, Pizer and Shih (2002) use a very similar model, but they break the employment effect into three parts: 1) the demand effect; 2) the cost effect; and 3) the factor-shift effect. See Morgenstern, Richard D., William A. Pizer, and Jhih-Shyang Shih. "Jobs Versus the Environment: An Industry-Level Perspective." Journal of Environmental Economics and Management 43 (2002): 412-436 (Docket EPA-HQ-OAR).

(recognizing that these increases may be partially offset by a decrease in manufacturing and sales for equipment of other modes of transportation such as rail cars or barges).

8.10.2.2 The Substitution Effect

The output effect, above, measures the effect due to new truck and trailer sales only. The substitution effect includes the impacts due to the changes in technologies needed for vehicles to meet these standards, separate from the effect on output (that is, as though holding output constant). This effect includes both changes in employment due to incorporation of abatement technologies and overall changes in the labor intensity of manufacturing. We present estimates for this effect to provide a sense of the order of magnitude of expected impacts on employment, which we expect to be small in the automotive sector, and to repeat that regulations may have positive as well as negative effects on employment.

One way to estimate this effect, given the cost estimates for complying with the final rules, is to use the ratio of workers to each $1 million of expenditures in that sector. The use of these ratios has both advantages and limitations. It is often possible to estimate these ratios for quite specific sectors of the economy: for instance, it is possible to estimate the average number of workers in the motor vehicle body and trailer manufacturing sector per $1 million spent in the sector, rather than use the ratio from another, more aggregated sector, such as motor vehicle manufacturing. As a result, it is not necessary to extrapolate employment ratios from possibly unrelated sectors. On the other hand, these estimates are averages for the sectors, covering all the activities in those sectors; they may not be representative of the labor required when expenditures are required on specific activities, or when manufacturing processes change sufficiently that labor intensity changes. For instance, the ratio for the motor vehicle manufacturing sector represents the ratio for all vehicle manufacturing, not just for emissions reductions associated with compliance activities. In addition, these estimates do not include changes in sectors that supply these sectors, such as steel or electronics producers. They thus may best be viewed as the effects on employment in the motor vehicle sector due to the changes in expenditures in that sector, rather than as an assessment of all employment changes due to these changes in expenditures. In addition, this approach estimates the effects of increased expenditures while holding constant the labor intensity of manufacturing; it does not take into account changes in labor intensity due to changes in the nature of production. This latter effect could either increase or decrease the employment impacts estimated here.[DDD]

Some of the costs of these final rules will be spent directly in the motor vehicle manufacturing sector, but it is also likely that some of the costs will be spent in the motor vehicle body and trailer and motor vehicle parts manufacturing sectors. The analysis here draws on estimates of workers per $1 million of expenditures for each of these sectors.

There are several public sources for estimates of employment per $1 million expenditures. The U.S. Bureau of Labor Statistics (BLS) provides its Employment

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[DDD] As noted above, Morgenstern et al. (2002) separate the effect of holding output constant into two effects: the cost effect, which holds labor intensity constant, and the factor shift effect, which estimates those changes in labor intensity.

Requirements Matrix (ERM),[117] which provides direct estimates of the employment per $1 million in sales of goods in 202 sectors. The values considered here are for Motor Vehicle Manufacturing (NAICS 3361), Motor Vehicle Body and Trailer Manufacturing (NAICS 3362), and Motor Vehicle Parts Manufacturing (NAICS 3363) for 2014.

The Census Bureau provides the Annual Survey of Manufacturers[118] (ASM), a subset of the Economic Census (EC), based on a sample of establishments; though the EC itself is more complete, it is conducted only every 5 years, while the ASM is annual. Both include more sectoral detail than the BLS ERM: for instance, while the ERM includes the Motor Vehicle Manufacturing sector, the ASM and EC have detail at the 6-digit NAICS code level (e.g., light truck and utility vehicle manufacturing). While the ERM provides direct estimates of employees/$1 million in expenditures, the ASM and EC separately provide number of employees and value of shipments; the direct employment estimates here are the ratio of those values. The values reported are for Motor Vehicle Manufacturing (NAICS 3361), Light Truck and Utility Vehicle Manufacturing (NAICS 336112), Heavy Duty Truck Manufacturing (33612), Motor Vehicle Body and Trailer Manufacturing (3362), and Motor Vehicle Parts Manufacturing (NAICS 3363). The values used here are adjusted to remove the employment effects of imports through use of a ratio of domestic production to domestic sales of 0.78.[EEE]

Table 8-34 provides the values, either given (BLS) or calculated (ASM and EC) for employment per $1 million of expenditures in 2014 (2012 for EC), all adjusted to 2013 dollars using the Bureau of Economic Analysis's Implicit GDP Price Deflators.[FFF] The different data sources provide similar patterns for the estimates for the sectors. Body and trailer manufacturing and parts manufacturing appear to be more labor-intensive than vehicle manufacturing; light truck and utility vehicle manufacturing appears to be less, and heavy duty truck manufacturing appears to be more, labor-intensive than motor vehicle manufacturing as a whole.

[EEE] To estimate the proportion of domestic production affected by the change in sales, we use data from Ward's Automotive Group for total truck production in the U.S. compared to total truck sales in the U.S. For the period 2006-2015, the proportion is 78 percent (Docket EPA-HQ-OAR-), ranging from 68 percent (2009) to 83 percent (2012) over that time.

[FFF] At the time of access, the EC data was only available by 2-, 3-, or 6-digit NAICS industry code. To construct the 4- and 5-digit numbers, we separately summed total employees and total expenditure for each 6-digit subcategory.

Table 8-34 Employment per $1 Million Expenditures (2013$) in the Motor Vehicle Manufacturing Sector[a]

SOURCE	SECTOR	RATIO OF WORKERS PER $1 MILLION EXPENDITURES	RATIO OF WORKERS PER $1 MILLION EXPENDITURES, ADJUSTED FOR DOMESTIC VS. FOREIGN PRODUCTION
BLS ERM	Motor vehicle mfg (3361)	0.393	0.306
BLS ERM	Motor vehicle body & trailer mfg (3362)	0.991	0.773
BLS ERM	Motor vehicle parts mfg (3363)	1.709	1.334
ASM	Motor vehicle mfg (3361)	0.582	0.454
ASM	Light truck & utility vehicle mfg (336112)	0.468	0.365
ASM	Heavy duty truck mfg (33612)	1.018	0.794
ASM	Motor vehicle body & trailer mfg (3362)	3.189	2.489
ASM	Motor vehicle parts mfg (3363)	2.081	1.624
EC	Motor vehicle mfg (3361)	0.594	0.463
EC	Light truck & utility vehicle mfg (336112)	0.472	0.369
EC	Heavy duty truck mfg (33612)	0.975	0.760
EC	Motor vehicle body & trailer mfg (3362)	3.502	2.733
EC	Motor vehicle parts mfg (3363)	2.126	1.659

Note:
[a] BLS ERM refers to the U.S. Bureau of Labor Statistics' Employment Requirement Matrix, 2014 values. ASM refers to the U.S. Census Bureau's Annual Survey of Manufactures, 2014 values. EC refers to the U.S. Census Bureau's Economic Census, 2012 values.

Over time, the amount of labor needed in the motor vehicle industry has changed: automation and improved methods have led to significant productivity increases. The BLS ERM, for instance, provided estimates that, in 1997, 1.09 workers in the Motor Vehicle Manufacturing sector were needed per $1 million, but only 0.39 workers by 2014 (in 2013$).[119] Because the ERM is available annually for 1997-2014, we used these data to estimate productivity improvements over time. We regressed logged ERM values on a year trend for the Motor Vehicle Manufacturing, Motor Vehicle Body and Trailer Manufacturing, and Motor Vehicle Parts Manufacturing sectors. We used this approach because the coefficient describing the relationship between time and productivity is a direct measure of the average percent change in productivity per year. The results suggest a 6.6 percent per year productivity improvement in the Motor Vehicle Manufacturing Sector, and a 4.9 percent per year improvement in the Motor Vehicle Parts Manufacturing Sector. The Motor Vehicle Body and Trailer Manufacturing Sector results were more complex: the workers/$1 million values before 2010 are substantially higher (averaging 3.98 in 2013$) than those in 2010 and after (averaging 1.28 in 2013$); we used dummy variables to account for this shift, and estimate productivity gains of 1 percent per year before 2010, and 14 percent after. This dramatic difference may suggest taking care when relying on the data for this sector. As discussed further below, we only report maximum and minimum employment impacts, and the Motor Vehicle Body and Trailer Manufacturing estimates provide the maximum values in all but one year; they may therefore create greater uncertainty about the upper bound of the substitution-effect employment.

We then used the regression results to project the number of workers per $1 million through 2027. We calculated separate sets of projections (adjusted to 2013$) for the BLS ERM data as well as the EC and ASM for all three sectors discussed above. The BLS ERM projections were calculated directly from the fitted regression equations since the regressions themselves used ERM data. For the ASM and EC projections, we used the ERM's ratio of the projected value in each future year to the projected value in 2014 for ASM and 2012 for EC (the base years in our data) to determine how many workers will be needed per $1 million of 2013$. In other words, we apply the projected productivity growth estimated using the ERM data to the ASM and EC numbers.

Finally, to simplify the presentation and give a range of estimates, we compared the projected employment among the 3 sectors for the ERM, EC, and ASM, and we provide only the maximum and minimum employment effects estimated for the three data sources. We provide the range rather than a point estimate because of the inherent difficulties in estimating employment impacts; the range gives an estimate of the expected magnitude. The details of the calculations may be found in the docket. The ERM estimates in the Motor Vehicle Manufacturing Sector are consistently the minimum values. The ASM estimates in the Motor Vehicle Body and Trailer Manufacturing Sector are the maximum values for all years but 2027, where the ASM value for Motor Vehicle Parts Manufacturing provides the maximum value.

Chapter 7 of the RIA discusses the vehicle cost estimates developed for these final rules. The final step in estimating employment impacts is to multiply costs (in $ millions) by workers per $1 million in costs, to estimate employment impacts in the regulated and parts manufacturing sectors. Increased costs of vehicles and parts would, by itself, and holding labor intensity constant, be expected to increase employment between 2018 and 2027 between zero and 4.5 thousand each year.

While we estimate employment impacts, measured in job-years, beginning with program implementation, some of these employment gains may occur earlier as motor vehicle manufacturers and parts suppliers hire staff in anticipation of compliance with the standards. A job-year is a way to calculate the amount of work needed to complete a specific task. For example, a job-year is one year of work for one person.

Table 8-35 Employment Effects due to Increased Costs of Vehicles and Parts (Substitution Effect), in Job-years

YEAR	COSTS (MILLIONS OF 2012$)	MINIMUM EMPLOYMENT DUE TO SUBSTITUTION EFFECT (ERM ESTIMATES, EXPENDITURES IN THE MOTOR VEHICLES MFG SECTOR)	MAXIMUM EMPLOYMENT DUE TO SUBSTITUTION EFFECT (ASM ESTIMATES, EXPENDITURES IN THE BODY AND TRAILER MFG SECTOR[A])
2018	$227	0	400
2019	$215	0	400
2020	$220	0	300
2021	$2,270	300	3,100
2022	$2,243	300	2,900
2023	$2,485	300	2,900
2024	$3,890	400	4,200
2025	$4,146	400	4,100
2026	$4,203	400	3,800
2027	$5,219	500	4,500

Note:
[a] For 2027, the maximum employment effects are associated with ASM's Motor Vehicle Parts Manufacturing sector.

8.10.2.3 Summary of Employment Effects in the Motor Vehicle Sector

The overall effect of these final rules on motor vehicle sector employment depends on the relative magnitude of the output effect and the substitution effect. Because we do not have quantitative estimates of the output effect, and only a partial estimate of the substitution effect, we cannot reach a quantitative estimate of the overall employment effects of these final rules on motor vehicle sector employment or even whether the total effect will be positive or negative.

The standards are not expected to provide incentives for manufacturers to shift employment between domestic and foreign production. This is because the standards will apply to vehicles sold in the U.S. regardless of where they are produced. If foreign manufacturers already have increased expertise in satisfying the requirements of the standards, there may be some initial incentive for foreign production, but the opportunity for domestic manufacturers to sell in other markets might increase. To the extent that the requirements of these final rules might lead to installation and use of technologies that other countries may seek now or in the future, developing this capacity for domestic production now may provide some additional ability to serve those markets.

Some vehicle parts are made in-house and would be included directly in the regulated sector. Others are made by independent suppliers and are not directly regulated, but they will be affected by the rules as well. The parts manufacturing sector will be involved primarily in providing "add-on" parts, or components for replacement parts built internally. If demand for these parts increases due to the increased use of these parts, employment effects in this sector are expected to be positive. If the demand effect in the regulated sectors is significantly negative enough, it is possible that demand for other parts may decrease. As noted, the agencies do not predict a direction for the demand effect.

8.10.3 Employment Impacts in Other Affected Sectors

8.10.3.1 Transport and Shipping Sectors

Although not directly regulated by these final rules, employment effects in the transport and shipping sector are likely to result from these regulations. If the overall cost of shipping a ton of freight decreases because of increased fuel efficiency (taking into account the increase in upfront purchasing costs), in a perfectly competitive industry these costs savings, depending on the relative elasticities of supply and demand, will be passed along to customers. With lower prices, demand for shipping would lead to an increase in demand for truck shipping services (consistent with the VMT rebound effect analysis) and therefore an increase in employment in the truck shipping sector. In addition, if the relative cost of shipping freight via trucks becomes cheaper than shipping by other modes (*e.g.*, rail or barge), then employment in the truck transport industry is likely to increase. If the trucking industry is more labor intensive than other modes, we would expect this effect to lead to an overall increase in employment in the transport and shipping sectors.[120,121] Such a shift would, however, be at the expense of employment in the sectors that are losing business to trucking. The first effect – a gain due to lower shipping costs – is likely to lead to a net increase in employment. The second effect, due to mode-shifting, may increase employment in trucking, but decrease employment in other shipping sectors (e.g., rail or barge), with the net effects dependent on the labor-intensity of the sectors and the volumes.

8.10.3.2 Fuel Suppliers

In addition to the effects on the trucking industry and related truck parts sector, these final rules will result in reductions in fuel use that lower GHG emissions. Fuel saving, principally reductions in liquid fuels such as diesel and gasoline, will affect employment in the fuel suppliers industry sectors, principally the Petroleum Refinery sector.

Chapter 7 of this RIA provides estimates of the effects of these standards on expected fuel consumption. While reduced fuel consumption represents savings for purchasers of fuel, it also represents a loss in value of output for the petroleum refinery industry, which will result in reduced sectoral employment. Because this sector is material-intensive, the employment effect is not expected to be large.[GGG]

8.10.3.3 Fuel Savings

As a result of this rulemaking, it is anticipated that trucking firms will experience fuel savings. Fuel savings lower the costs of transportation goods and services. In a competitive market, some of the fuel savings that initially accrue to trucking firms are likely to be passed along as lower transportation costs that, in turn, could result in lower prices for final goods and services. Some of the savings might also be retained by firms for investments or for distributions to firm owners. Again, how much accrues to customers versus firm owners will depend on the relative elasticities of supply and demand. Regardless, the savings will accrue to some segment

[GGG] In the 2014 BLS ERM cited above, the Petroleum and Coal Products Manufacturing sector has a ratio of workers per $1 million of 0.215, lower than all but two of the 181 sectors with non-zero employment per $1 million.

of consumers: either owners of trucking firms or the general public, and the effect will be increased spending by consumers in other sectors of the economy, creating jobs in a diverse set of sectors, including retail and service industries.

As described in Preamble Section IX.C.(2), the value of fuel savings from this rulemaking is projected to be $15.8 billion (2013$) in 2027, according to Table IX-6. If all those savings are spent, the fuel savings will stimulate increased employment in the economy through those expenditures. If the fuel savings accrue primarily to firm owners, they may either reinvest the money or take it as profit. Reinvesting the money in firm operations could increase employment directly. If they take the money as profit, to the extent that these owners are wealthier than the general public, they may spend less of the savings, and the resulting employment impacts would be smaller than if the savings went to the public. Thus, while fuel savings are expected to decrease employment in the refinery sector, they are expected to increase employment through increased consumer expenditures.

8.10.4 Summary of Employment Impacts

The primary employment effects of these rules are expected to be found throughout several key sectors: truck and engine manufacturers, the trucking industry, truck parts manufacturing, fuel production, and consumers. These rules initially take effect in model year 2018; the unemployment rate at that time is unknowable. In an economy with full employment, the primary employment effect of a rulemaking is likely to be to move employment from one sector to another, rather than to increase or decrease employment. For that reason, we focus our partial quantitative analysis on employment in the regulated sector, to examine the impacts on that sector directly. We discuss the likely direction of other impacts in the regulated sector as well as in other directly related sectors, but we do not quantify those impacts, because they are more difficult to quantify with reasonable accuracy, particularly so far into the future.

For the regulated sector, we have not quantified the output effect. The substitution effect is associated with potential increased employment between zero and 4.5 thousand jobs per year between 2018 and 2027, depending on the share of employment impacts in the affected sectors (Motor Vehicle Manufacturing, Motor Vehicle Body and Trailer Manufacturing, and Motor Vehicle Parts Manufacturing). These estimates do not include potential changes, either greater or less, in labor intensity of production. As mentioned above, some of these job gains may occur earlier as auto manufacturers and parts suppliers hire staff to prepare to comply with the standard.

Lower prices for shipping are expected to lead to an increase in demand for truck shipping services and, therefore, an increase in employment in that sector, though this effect may be offset somewhat by changes in employment in other shipping sectors. Reduced fuel production implies less employment in the fuel provision sectors. Finally, any net cost savings are expected to be passed along to some segment of consumers: either the general public or the owners of trucking firms, who are expected then to increase employment through their expenditures. Under conditions of full employment, any changes in employment levels in the regulated sector due to this program are mostly expected to be offset by changes in employment in other sectors.

8.11 Oil Price Sensitivity Analysis using Method B

In this section, EPA presents a sensitivity analysis examining the impact on net benefits using AEO's "low oil price" and "high oil price" cases. The sensitivity analysis is based on the final program relative to the flat baseline as the "primary" case using Method B. Fuel price changes were not used as an input to technology application rates (i.e., a constant $/vehicle has been used throughout this sensitivity analysis). The primary analysis (presented earlier in this chapter) uses the AEO reference case oil prices. The primary case and both high and low oil price case $/gallon values are shown in Table 8-36.

Table 8-36 AEO2015 Fuel Prices in the Low Oil Price Case, our Primary Analysis Case, and the AEO High Oil Price Case (2013$)

YEAR	RETAIL						UNTAXED					
	Diesel			Gasoline			Diesel			Gasoline		
	Low	Primary	High	Low	Primary	High	Low	Primary	High	Low	Primary	High
2018	$2.50	$3.08	$4.79	$2.21	$2.70	$4.04	$2.04	$2.62	$4.33	$1.81	$2.30	$3.62
2019	$2.55	$3.12	$4.88	$2.28	$2.70	$4.11	$2.09	$2.66	$4.42	$1.88	$2.30	$3.69
2020	$2.61	$3.17	$4.97	$2.33	$2.74	$4.17	$2.16	$2.72	$4.52	$1.94	$2.35	$3.75
2021	$2.65	$3.23	$5.07	$2.35	$2.78	$4.26	$2.20	$2.78	$4.62	$1.96	$2.39	$3.85
2022	$2.70	$3.31	$5.18	$2.37	$2.82	$4.33	$2.25	$2.86	$4.73	$1.98	$2.43	$3.92
2023	$2.73	$3.37	$5.27	$2.39	$2.86	$4.41	$2.29	$2.93	$4.83	$2.00	$2.47	$4.00
2024	$2.76	$3.43	$5.42	$2.40	$2.90	$4.49	$2.32	$2.99	$4.98	$2.01	$2.52	$4.08
2025	$2.82	$3.49	$5.54	$2.40	$2.95	$4.56	$2.38	$3.05	$5.10	$2.02	$2.57	$4.16
2026	$2.86	$3.56	$5.66	$2.42	$3.00	$4.65	$2.43	$3.13	$5.23	$2.04	$2.62	$4.25
2027	$2.89	$3.63	$5.78	$2.43	$3.04	$4.74	$2.46	$3.20	$5.35	$2.05	$2.66	$4.34
2028	$2.90	$3.70	$5.92	$2.44	$3.09	$4.85	$2.47	$3.27	$5.49	$2.06	$2.71	$4.46
2029	$2.91	$3.77	$6.05	$2.45	$3.14	$4.96	$2.48	$3.35	$5.63	$2.08	$2.76	$4.57
2030	$2.91	$3.84	$6.17	$2.45	$3.20	$5.05	$2.49	$3.42	$5.75	$2.08	$2.82	$4.66
2031	$2.93	$3.92	$6.30	$2.47	$3.26	$5.16	$2.51	$3.50	$5.89	$2.10	$2.88	$4.76
2032	$2.93	$4.00	$6.43	$2.47	$3.33	$5.27	$2.51	$3.59	$6.02	$2.10	$2.95	$4.88
2033	$2.94	$4.09	$6.60	$2.49	$3.39	$5.40	$2.53	$3.68	$6.19	$2.12	$3.02	$5.01
2034	$2.95	$4.17	$6.74	$2.50	$3.46	$5.53	$2.54	$3.76	$6.34	$2.14	$3.09	$5.14
2035	$2.96	$4.26	$6.84	$2.52	$3.53	$5.64	$2.55	$3.86	$6.44	$2.16	$3.16	$5.25
2036	$2.98	$4.35	$6.99	$2.54	$3.60	$5.78	$2.58	$3.95	$6.59	$2.18	$3.23	$5.40
2037	$2.99	$4.45	$7.14	$2.55	$3.66	$5.89	$2.59	$4.05	$6.75	$2.19	$3.30	$5.51
2038	$3.00	$4.55	$7.29	$2.56	$3.74	$6.04	$2.60	$4.16	$6.90	$2.21	$3.38	$5.66
2039	$3.02	$4.65	$7.44	$2.58	$3.83	$6.17	$2.63	$4.26	$7.05	$2.23	$3.47	$5.79
2040	$3.03	$4.75	$7.61	$2.60	$3.90	$6.33	$2.64	$4.36	$7.22	$2.25	$3.54	$5.94

Note:
Our Primary case values are the AEO reference fuel price case values and are taken from AEO2015.

The impacts of using the low and high oil price cases on our estimated fuel savings and net benefits are shown in Table 8-37.

Table 8-37 MY2018-2029 Lifetime Sensitivity on Net Benefits using AEO2014 Low and High Oil Price Cases for the Final Program Relative to the Flat Baseline and using Method B (Billions of 2013$; 3% Discounting) [a]

	LOW OIL PRICE CASE	PRIMARY CASE	HIGH OIL PRICE CASE
Vehicle program	-$27	-$27	-$27
Maintenance	-$1.9	-$1.9	-$1.9
Fuel	$119	$169	$282
Benefits	$86	$88	$94
Net benefits	$176	$229	$348

Note:

[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1

Appendix 8.A to Chapter 8 - Supplemental Analysis of Quantified and Monetized Non-GHG Health and Environmental Impacts

This appendix presents the results of our quantified and monetized criteria pollutant health impacts analysis due to the Phase 2 standards compared to a future-year reference scenario without the standards in place. Specifically, we present $PM_{2.5}$- and ozone-related health benefits of the standards for calendar year (CY) 2040.

As described in Chapter 8.6, we consider this analysis to be supplemental to the primary analysis because, out of necessity, the air quality modeling was based on emissions inventories that reflected the form of the standards as they were proposed, not finalized (air quality modeling results are presented in Appendix 6A). The length of time needed to prepare the inventories and run the air quality model requires EPA to make air quality modeling input decisions early in the analytical process, and therefore made it impossible to base the health impacts analysis on the emissions changes associated with the final rulemaking.

The chief limitation when using air quality inventories based on emissions from the proposal is that they can diverge from the estimated emissions of the final rulemaking. How much the emissions might diverge and how that difference would impact the air quality modeling and health benefit results is difficult to anticipate. For the FRM, EPA concluded that when comparing the proposal and final rule inventories, the differences were enough to justify the move of the typical CY benefits analysis (based on air quality modeling) from the primary estimate of costs and benefits to a supplemental analysis presented in this Chapter.[HHH] While we believe this supplemental analysis is still illustrative of the standard's potential benefits, EPA has instead chosen to characterize the CY benefits in the primary analysis in a manner consistent with the MY lifetime analysis. That is, we apply PM-related "benefits per-ton" values to the CY final rule emission reductions to estimate the PM-related benefits of the final rule.

8A.1 Quantified and Monetized Non-GHG Human Health Benefits of the 2040 Calendar Year (CY) Analysis

8A.1.1 Overview

This section presents EPA's analysis of the criteria pollutant related health impacts resulting from non-GHG emission reductions that can be expected to occur as a result of the Phase 2 standards. CO_2 emissions are predominantly the byproduct of fossil fuel combustion processes that also produce criteria and hazardous air pollutant emissions. The vehicles that are subject to the Phase 2 standards are also significant sources of mobile source air pollution such as direct PM, NO_X, VOCs and air toxics. The standards will affect exhaust emissions of these pollutants from vehicles and will also affect emissions from upstream sources that occur during

[HHH] See Chapter 5 for a presentation and discussion of the differences between the proposal inventories used to conduct the air quality modeling and the final rule inventories.

the refining and distribution of fuel. Changes in ambient concentrations of ozone, $PM_{2.5}$, and air toxics that will result from the Phase 2 standards are expected to affect human health by reducing premature deaths and other serious human health effects, as well as other important improvements in public health and welfare. Children especially benefit from reduced exposures to criteria and toxic pollutants, because they tend to be more sensitive to the effects of these respiratory pollutants. Ozone and particulate matter have been associated with increased incidence of asthma and other respiratory effects in children, and particulate matter has been associated with a decrease in lung maturation. Some minority groups and children living under the poverty line are even more vulnerable with higher prevalence of asthma.

The analysis in this section aims to characterize the benefits of the standards by answering two key questions:

1. What are the health and welfare effects of changes in ambient particulate matter ($PM_{2.5}$) and ozone air quality resulting from reductions in precursors including NO_X and SO_2?

2. What is the economic value of these effects?

For the supplemental health benefits analysis, we have quantified and monetized the health and environmental impacts in 2040, representing projected impacts associated with a year when most of the fleet is turned over. Overall, we estimate that the standards will lead to a net decrease in $PM_{2.5}$- and ozone-related health impacts in 2040. The estimated decrease in population-weighted national average $PM_{2.5}$ exposure results in a net decrease in adverse PM-related human health impacts (the decrease in national population-weighted annual average $PM_{2.5}$ is 0.01 $\mu g/m^3$ in 2040).[III] The estimated decrease in population-weighted national average ozone exposure results in a net decrease in ozone-related health impacts (population-weighted maximum 8-hour average ozone decreases by 0.21 ppb in 2040).

Using the lower end of EPA's range of preferred premature mortality estimates (Krewski et al., 2009 for $PM_{2.5}$ and Smith et al., 2009 for ozone),[122,123] we estimate that by 2040, implementation of the standards will reduce approximately 310 premature mortalities annually and will yield between $2.8 and $3.0 billion in total annual benefits, depending on the discount rate used.[JJJ] The upper end of the range of avoided premature mortality estimates associated with the standards (based on Lepeule et al., 2012 for $PM_{2.5}$ and Zanobetti and Schwartz, 2008 for ozone)[124,125] results in approximately 640 premature mortalities avoided in 2040 and will yield between $5.9 and $6.4 billion in total benefits. Thus, even using the lower end of the range of

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[III] Note that the national, population-weighted $PM_{2.5}$ and ozone air quality metrics presented in this Chapter represent an average for the entire, gridded U.S. CMAQ domain. These are different than the population-weighted $PM_{2.5}$ and ozone design value metrics presented in Chapter 7, which represent the average for areas with a current air quality monitor.

[JJJ] The monetized value of $PM_{2.5}$-related mortality accounts for a twenty-year segmented cessation lag. To discount the value of premature mortality that occurs at different points in the future, we apply both a 3 and 7 percent discount rate. We also use both a 3 and 7 percent discount rate to value PM-related nonfatal heart attacks (myocardial infarctions). Nonfatal myocardial infarctions (MI) are valued using age-specific cost-of-illness values that reflect lost earnings and direct medical costs over a 5-year period following a nonfatal MI.

premature mortality estimates, the criteria pollutant-related health benefits of the standards presented in this rule are projected to be substantial.

We base our analysis of the rule's impact on human health and the environment on peer-reviewed studies of air quality and human health effects.[126,127] To model the ozone and PM air quality impacts of the standards, we used the Community Multiscale Air Quality (CMAQ) model (see Appendix 6A). The modeled ambient air quality data serves as an input to the Environmental Benefits Mapping and Analysis Program – Community Edition version 1.1 (BenMAP-CE).[KKK] BenMAP-CE is a computer program developed by the U.S. EPA that integrates a number of the modeling elements used in previous analyses (*e.g.*, interpolation functions, population projections, health impact functions, valuation functions, analysis and pooling methods) to translate modeled air concentration estimates into health effects incidence estimates and monetized benefits estimates.

The range of total monetized ozone- and PM-related health impacts in 2040 is presented in Table 8A.1. We present total benefits (the sum of morbidity-related benefits and mortality-related benefits) based on the PM- and ozone-related premature mortality function used. These estimates represent EPA's preferred approach to characterizing a best estimate of benefits.

Table 8A-1 Estimated 2040 Monetized PM-and Ozone-Related Health Benefits (billions, 2013$)[a]

	Discount Rate	Benefits
Ozone Benefits [c]	[b]	$1.0 to $1.8
$PM_{2.5}$ Benefits [d]	3%	$2.0 to $4.6
	7%	$1.8 to $4.2
Total Benefits	3%	$3.0 to $6.4[e]
	7%	$2.8 to $5.9 [e]

Notes:
[a] Rounded to two significant figures. These estimates reflect the economic value of avoided morbidities and premature deaths using risk coefficients from the studies noted in Table 8A-8.
[b] Ozone-only benefits reflect short-term exposure impacts and as such are assumed to occur in the same year as ambient ozone reductions. Consequently, social discounting is not applied to the benefits for this category.
[c] Range reflects application of effect estimates from Smith et al. (2009) and Zanobetti and Schwartz (2008).
[d] Range reflects application of effect estimates from Krewski et al. (2009) and Lepeule et al. (2012).
[e] Excludes additional health and welfare benefits which could not be quantified (see Table 8A-2).

The benefits in Table 8A-1 include all of the human health impacts we are able to quantify and monetize at this time. However, the full complement of human health and welfare effects associated with PM, ozone, and other criteria pollutants remain unquantified because of current limitations in methods or available data. We have not quantified a number of known or suspected health effects linked with ozone, PM, and other criteria pollutants for which appropriate health impact functions are not available or which do not provide easily interpretable outcomes (*e.g.*, changes in heart rate variability). Additionally, we are unable to quantify a number of known welfare effects, including reduced acid and particulate deposition damage to

[KKK] Information on BenMAP, including downloads of the software, can be found at https://www3.epa.gov/benmap.

cultural monuments and other materials, and environmental benefits due to reductions of impacts of eutrophication in coastal areas. These are listed in Table 8A-2. As a result, the health benefits quantified in this section are likely underestimates of the total benefits attributable to the standards.

Table 8A-2 lists the PM- and ozone-related benefits categories we will use to quantify the non-GHG incidence impacts associated with the standards. Table 8A-2 also lists non-GHG-related endpoints we are currently unable to quantify and/or monetize.

Table 8A-2 Estimated Quantified and Unquantified Health Effects

Benefits Category	*Specific Effect*	*Effect Has Been Quantified*	*Effect Has Been Monetized*	*More Information*
Improved Human Health				
Reduced incidence of premature mortality and morbidity from exposure to $PM_{2.5}$	Adult premature mortality based on cohort study estimates and expert elicitation estimates (age >25 or age >30)	✓	✓	PM NAAQS RIA,[128] Section 5.6
	Infant mortality (age <1)	✓	✓	PM NAAQS RIA, Section 5.6
	Non-fatal heart attacks (age > 18)	✓	✓	PM NAAQS RIA, Section 5.6
	Hospital admissions—respiratory (all ages)	✓	✓	PM NAAQS RIA, Section 5.6
	Hospital admissions—cardiovascular (age >20)	✓	✓	PM NAAQS RIA, Section 5.6
	Emergency department visits for asthma (all ages)	✓	✓	PM NAAQS RIA, Section 5.6
	Acute bronchitis (age 8–12)	✓	✓	PM NAAQS RIA, Section 5.6
	Lower respiratory symptoms (age 7–14)	✓	✓	PM NAAQS RIA, Section 5.6
	Upper respiratory symptoms (asthmatics age 9–11)	✓	✓	PM NAAQS RIA, Section 5.6
	Asthma exacerbation (asthmatics age 6–18)	✓	✓	PM NAAQS RIA, Section 5.6
	Lost work days (age 18–65)	✓	✓	PM NAAQS RIA, Section 5.6
	Minor restricted-activity days (age 18–65)	✓	✓	PM NAAQS RIA, Section 5.6
	Chronic Bronchitis (age >26)	—	—	PM NAAQS RIA, Section 5.6[c]
	Emergency department visits for cardiovascular effects (all ages)	—	—	PM NAAQS RIA, Section 5.6[c]
	Strokes and cerebrovascular disease (age 50–79)	—	—	PM NAAQS RIA, Section 5.6[c]
	Other cardiovascular effects (e.g., other ages)	—	—	PM ISA[a,129]
	Other respiratory effects (e.g., pulmonary function, non-asthma ER visits, non-bronchitis chronic diseases, other ages and populations)	—	—	PM ISA[a]

Benefits Category	*Specific Effect*	*Effect Has Been Quantified*	*Effect Has Been Monetized*	*More Information*
	Reproductive and developmental effects (e.g., low birth weight, pre-term births, etc.)	—	—	PM ISA[a,b]
	Cancer, mutagenicity, and genotoxicity effects	—	—	PM ISA[a,b]
Reduced incidence of premature mortality and morbidity from exposure to ozone	Premature mortality based on short-term study estimates (all ages)	✓	✓	Ozone NAAQS RIA,[130] Section 6.6
	Premature mortality based on long-term study estimates (age 30–99)	d	d	Ozone NAAQS RIA, Section 6.6
	Hospital admissions—respiratory causes (age > 65)	✓	✓	Ozone NAAQS RIA, Section 6.6
	Emergency department visits for asthma (all ages)	✓	✓	Ozone NAAQS RIA, Section 6.6
	Asthma exacerbation (age 6-18)	✓	✓	Ozone NAAQS RIA, Section 6.6
	Minor restricted-activity days (age 18–65)	✓	✓	Ozone NAAQS RIA, Section 6.6
	School absence days (age 5–17)	✓	✓	Ozone NAAQS RIA, Section 6.6
	Decreased outdoor worker productivity (age 18–65)	d	d	Ozone NAAQS RIA, Section 6.6
	Other respiratory effects (e.g., premature aging of lungs)	—	—	Ozone ISA[a,131]
	Cardiovascular and nervous system effects	—	—	Ozone ISA[b]
	Reproductive and developmental effects	—	—	Ozone ISA[b]

Benefits Category	*Specific Effect*	*Effect Has Been Quantified*	*Effect Has Been Monetized*	*More Information*
Reduced incidence of morbidity from exposure to air toxics	Cancer (benzene, 1,3-butadiene, formaldehyde, acetaldehyde) Anemia (benzene) Disruption of production of blood components (benzene) Reduction in the number of blood platelets (benzene) Excessive bone marrow formation (benzene) Depression of lymphocyte counts (benzene) Reproductive and developmental effects (1,3-butadiene) Irritation of eyes and mucus membranes (formaldehyde) Respiratory irritation (formaldehyde) Asthma attacks in asthmatics (formaldehyde) Asthma-like symptoms in non-asthmatics (formaldehyde) Irritation of the eyes, skin, and respiratory tract (acetaldehyde) Upper respiratory tract irritation and congestion (acrolein)	—	—	IRIS[a,b,132]

Notes:

[a] We assess these benefits qualitatively because we do not have sufficient confidence in available data or methods.

[b] We assess these benefits qualitatively because current evidence is only suggestive of causality or there are other significant concerns over the strength of the association.

[c] We assess these benefits qualitatively due to time and resource limitations for this analysis.

[d] We quantified these benefits, but they are not part of the core monetized benefits.

While there will be impacts associated with air toxic pollutant emission changes that result from the standards, we do not attempt to monetize those impacts. This is primarily because currently available tools and methods to assess air toxics risk from mobile sources at the national scale are not adequate for extrapolation to incidence estimations or benefits assessment. The best suite of tools and methods currently available for assessment at the national scale are those used in the National-Scale Air Toxics Assessment (NATA). The EPA Science Advisory Board specifically commented in their review of the 1996 NATA that these tools were not yet ready for use in a national-scale benefits analysis, because they did not consider the full distribution of exposure and risk, or address sub-chronic health effects.[133] While EPA has since improved these tools, there remain critical limitations for estimating incidence and assessing benefits of reducing mobile source air toxics.

As part of the second prospective analysis of the benefits and costs of the Clean Air Act,[134] EPA conducted a case study analysis of the health effects associated with reducing exposure to benzene in Houston from implementation of the Clean Air Act. While reviewing the draft report, EPA's Advisory Council on Clean Air Compliance Analysis concluded that "the challenges for assessing progress in health improvement as a result of reductions in emissions of hazardous air pollutants (HAPs) are daunting...due to a lack of exposure-response functions, uncertainties in emissions inventories and background levels, the difficulty of extrapolating risk estimates to low doses and the challenges of tracking health progress for diseases, such as cancer, that have long latency periods."[135] EPA continues to work to address these limitations; however, we did not have the methods and tools available for national-scale application in time for the analysis of the standards.[LLL]

The reduction in air pollution emissions that will result from the standards is projected to have "welfare" co-benefits in addition to human health benefits, including changes in visibility, materials damage, ecological effects from PM deposition, ecological effects from nitrogen and sulfur emissions, vegetation effects from ozone exposure, and climate effects. Despite our goal to quantify and monetize as many of the benefits as possible for the standards, the welfare co-benefits of the standards remain unquantified and non-monetized in this RIA due to data, methodology, and resource limitations. As a result, the benefits quantified in this analysis are likely underestimates of the total benefits attributable to the standards. We refer the reader to Chapter 6 of the PM NAAQS RIA for a complete discussion of these welfare co-benefits. [136]

8A.1.2 Human Health Impacts

Table 8A-3 and Table 8A-4 present the annual $PM_{2.5}$ and ozone health impacts in the 48 contiguous U.S. states associated with the standards. For each endpoint presented in the tables, we provide both the point estimate and the 90 percent confidence interval.

Using EPA's preferred estimates, based on the American Cancer Society (ACS) and Six-Cities studies and a no threshold assumption in the model of mortality, we estimate that the standards will result in between 210 and 480 cases of avoided $PM_{2.5}$-related premature deaths annually in 2040. For ozone, changes in mortality risk are estimated using two ozone-related short-term effect estimates, Smith et al., 2009 and Zanobetti and Schwartz, 2008, consistent with the 2015 Ozone NAAQS RIA. We estimate that the standards will result in between 99 and 210 cases of avoided ozone-related premature mortalities.

[LLL] In April, 2009, EPA hosted a workshop on estimating the benefits or reducing hazardous air pollutants. This workshop built upon the work accomplished in the June 2000 Science Advisory Board/EPA Workshop on the Benefits of Reductions in Exposure to Hazardous Air Pollutants, which generated thoughtful discussion on approaches to estimating human health benefits from reductions in air toxics exposure, but no consensus was reached on methods that could be implemented in the near term for a broad selection of air toxics. Please visit http://epa.gov/air/toxicair/2009workshop.html for more information about the workshop and its associated materials.

Table 8A-3 Estimated $PM_{2.5}$-Related Health Impacts[a]

Health Effect	2040 Annual Reduction in Incidence (5th - 95th percentile)
Premature Mortality – Derived from epidemiology literature[b]	
Adult, age 30+, ACS Cohort Study (Krewski et al., 2009)	210 (150 – 270)
Adult, age 25+, Six-Cities Study (Lepeule et al., 2012)	480 (280 – 680)
Infant, age <1 year (Woodruff et al., 1997)	0.29 (0.14 – 0.44)
Non-fatal myocardial infarction (adult, age 18 and over)	
Peters et al. (2001)	260 (93 – 420)
Pooled estimate of 4 studies	27 (13 – 60)
Hospital admissions - respiratory (all ages)[c, e]	66 (-15 – 120)
Hospital admissions - cardiovascular (adults, age >18)[d]	56 (25 – 110)
Emergency room visits for asthma (age 18 years and younger)[e]	96 (-17 – 190)
Acute bronchitis, (children, age 8-12)[e]	280 (-10 – 580)
Lower respiratory symptoms (children, age 7-14)	3,600 (1,700 – 5,500)
Upper respiratory symptoms (asthmatic children, age 9-18)	5,200 (1,600 – 8,700)
Asthma exacerbation (asthmatic children, age 6-18)	5,400 (680 – 11,000)
Work loss days	23,000 (20,000 – 26,000)
Minor restricted activity days (adults age 18-65)	140,000 (120,000 – 160,000)

Notes:

[a] Incidence is rounded to two significant digits. Estimates represent incidence within the 48 contiguous United States.

[b] PM-related adult mortality based upon the most recent American Cancer Society (ACS) Cohort Study (Krewski et al., 2009) and the most recent Six-Cities Study (Lepeule et al., 2012). Note that these are two alternative estimates of adult mortality and should not be summed. PM-related infant mortality based upon a study by Woodruff, Grillo, and Schoendorf, (1997).[137]

[c] Respiratory hospital admissions for PM include admissions for chronic obstructive pulmonary disease (COPD), pneumonia and asthma.

[d] Cardiovascular hospital admissions for PM include total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

[e] The negative estimates at the 5th percentile confidence estimates for these morbidity endpoints reflect the statistical power of the study used to calculate these health impacts. These results do not suggest that reducing air pollution results in additional health impacts.

Table 8A-4 Estimated Ozone-Related Health Impacts[a,b]

Health Effect	2040 Annual Reduction in Incidence (5th - 95th percentile)
Short-Term Premature Mortality, All ages[b] Multi-City Analyses Smith et al. (2009) Zanobetti and Schwartz (2008)	 99 (55 – 140) 160 (98 – 230)
Hospital admissions- respiratory causes (adult, 65 and older)[c]	200 (-14 – 410)
Emergency room visit for asthma (all ages)	510 (84 – 1,200)
Asthma exacerbation (age 6-18)[c]	170,000 (-96,000 – 390,000)
Minor restricted activity days (adults, age 18-65)	410,000 (200,000 – 620,000)
School absence days	140,000 (62,000 – 270,000)

Notes:
[a] All incidence estimates are rounded to whole numbers with a maximum of two significant digits.
[b] All incidence estimates are based on ozone-only models unless otherwise noted.
[c] The negative estimates at the 5th percentile confidence estimates for these morbidity endpoints reflect the statistical power of the studies used to calculate these health impacts. These results do not suggest that reducing air pollution results will adversely affect health, but rather, that we are less confident in the magnitude of the expected benefits for this endpoint.

8A.1.3 Monetized Estimates of Human Health and Environmental Impacts

Table 8A-5 presents the estimated monetary value of changes in the incidence of ozone and $PM_{2.5}$-related health and environmental effects. Total aggregate monetized benefits are presented in Table 8A-6. All monetized estimates are presented in 2013 dollars. Where appropriate, estimates account for growth in real gross domestic product (GDP) per capita between 2000 and 2040.[MMM] The monetized value of $PM_{2.5}$-related mortality also accounts for a twenty-year segmented cessation lag.[NNN] To discount the value of premature mortality that

[MMM] Our analysis accounts for expected growth in real income over time. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real incomes increase. Benefits are therefore adjusted by multiplying the unadjusted benefits by the appropriate adjustment factor to account for income growth over time. For growth between 2000 and 2040, this factor is 1.23 for long-term mortality, 1.27 for chronic health impacts, and 1.08 for minor health impacts. For a complete discussion of how these adjustment factors were derived, we refer the reader to the PM NAAQS regulatory impact analysis. Note that similar adjustments do not exist for cost-of-illness-based unit values. For these, we apply the same unit value regardless of the future year of analysis.
[NNN] Based in part on prior SAB advice, EPA has typically assumed that there is a time lag between changes in pollution exposures and the total realization of changes in health effects. Within the context of benefits analyses, this term is often referred to as "cessation lag." The existence of such a lag is important for the valuation of premature mortality incidence because economic theory suggests that benefits occurring in the future should be discounted. In this analysis, we apply a twenty-year distributed lag to PM mortality reductions. This method is consistent with the most recent recommendation by the EPA's Science Advisory Board. Refer to: EPA – Science

occurs at different points in the future, we apply both a 3 and 7 percent discount rate. We also use both a 3 and 7 percent discount rate to value PM-related nonfatal heart attacks (myocardial infarctions).[OOO]

In addition to omitted benefits categories such as air toxics and various welfare effects, not all known $PM_{2.5}$- and ozone-related health and welfare effects could be quantified or monetized. The estimate of total monetized health benefits of the standards is thus equal to the subset of monetized $PM_{2.5}$- and ozone-related health impacts we are able to quantify plus the sum of the non-monetized health and welfare benefits. Our estimate of total monetized benefits in 2040 for the standards, using the ACS and Six-Cities PM mortality studies and the two ozone mortality studies, is between \$3.0 and \$6.4 billion, assuming a 3 percent discount rate, or between \$2.8 and \$5.9 billion, assuming a 7 percent discount rate. As the results indicate, total benefits are driven primarily by the reduction in $PM_{2.5}$- and ozone-related premature fatalities each year.

The next largest benefit is for reductions in nonfatal heart attacks, although this value is more than an order of magnitude lower than for premature mortality. Hospital admissions for respiratory and cardiovascular causes, minor restricted activity days, and work loss days account for the majority of the remaining benefits. The remaining categories each account for a small percentage of total benefit; however, they represent a large number of avoided incidences affecting many individuals. A comparison of the incidence table to the monetary benefits table reveals that there is not always a close correspondence between the number of incidences avoided for a given endpoint and the monetary value associated with that endpoint. For example, there are many more work loss days than PM-related premature mortalities, yet work loss days account for only a very small fraction of total monetized benefits. This reflects the fact that many of the less severe health effects, while more common, are valued at a lower level than the more severe health effects. Also, some effects, such as hospital admissions, are valued using a proxy measure of willingness-to-pay (*e.g.*, cost-of-illness). As such, the true value of these effects may be higher than that reported here.

Advisory Board, 2004. Advisory Council on Clean Air Compliance Analysis Response to Agency Request on Cessation Lag. Letter from the Health Effects Subcommittee to the U.S. Environmental Protection Agency Administrator, December.

[OOO] Nonfatal myocardial infarctions (MI) are valued using age-specific cost-of-illness values that reflect lost earnings and direct medical costs over a 5-year period following a nonfatal MI.

Table 8A-5 Estimated Monetary Value of Changes in Incidence of Health and Welfare Effects (millions of 2013$) [a,b]

		2040
$PM_{2.5}$-Related Health Effect		(5th and 95th Percentile)
Premature Mortality – Derived from Epidemiology Studies[c,d]	Adult, age 30+ - ACS study (Krewski et al., 2009)	
	3% discount rate	$2,000 ($300 - $4,700)
	7% discount rate	$1,800 ($270 - $4,200)
	Adult, age 25+ - Six-Cities study (Lepeule et al., 2012)	
	3% discount rate	$4,500 ($650 - $11,000)
	7% discount rate	$4,100 ($580 - $9,900)
	Infant Mortality, <1 year – (Woodruff et al. 1997)	$3.1 ($0.41 - $7.6)
Non-fatal myocardial infarction (adult, age 18 and over)		
Peters et al. (2001)		
3% Discount Rate		$31 ($6.6 - $74)
7% Discount Rate		$31 ($6.1 - $74)
Pooled estimate of 4 studies		
3% Discount Rate		$3.4 ($0.83 - $9.0)
7% Discount Rate		$3.3 ($0.77 - $8.9)
Hospital admissions for respiratory causes[d]		$2.0 (-$0.61 - $3.8)
Hospital admissions for cardiovascular causes		$3.2 ($1.6 - $5.7)
Emergency room visits for asthma[d]		$0.04 (-$0.007 - $0.09)
Acute bronchitis (children, age 8–12)[d]		$0.15 (-$0.005 - $0.36)
Lower respiratory symptoms (children, 7–14)		$0.08 ($0.03 - $0.15)
Upper respiratory symptoms (asthma, 9–11)		$0.19 ($0.05 - $0.41)
Asthma exacerbations		$0.34 ($0.04 - $0.80)
Work loss days		$4.0 ($3.5 - $4.6)
Minor restricted-activity days (MRADs)		$10 ($5.9 - $15)
Ozone-Related Health Effects		
Premature Mortality, All ages – Derived from Multi-city analyses	Smith et al., 2009	$940 ($47 - $2,500)
	Zanobetti & Schwartz, 2008	$1,700 ($250 - $4,200)
Hospital admissions- respiratory causes (adult, 65 and older)[d]		$6.7 (-$0.48 - $14)

Emergency room visit for asthma (all ages)	$0.23 ($0.04 - $0.53)
Asthma exacerbation (age 6-18)[d]	$11 (-$4.2 - $29)
Minor restricted activity days (adults, age 18-65)	$30 ($13 - $52)
School absence days	$15 ($6.5 - $28)

Notes:
[a] Monetary benefits are rounded to two significant digits for ease of presentation and computation. PM and ozone benefits are nationwide.
[b] Monetary benefits adjusted to account for growth in real GDP per capita between 1990 and the analysis year (2040).
[c] Valuation assumes discounting over the SAB recommended 20 year segmented lag structure. Results reflect the use of 3 percent and 7 percent discount rates consistent with EPA and OMB guidelines for preparing economic analyses.
[d] The negative estimate at the 5th percentile confidence estimate for this morbidity endpoint reflects the statistical power of the study used to calculate this health impact. This result does not suggest that reducing air pollution results in additional health impacts.

Table 8A-6 Estimated 2040 Monetized PM-and Ozone-Related Health Benefits[a]

	Discount Rate	Benefits
Ozone Benefits [c]	[b]	$1.0 to $1.8
$PM_{2.5}$ Benefits [d]	3%	$2.0 to $4.6
	7%	$1.8 to $4.2
Total Benefits	3%	$3.0 to $6.4[e]
	7%	$2.8 to $5.9 [e]

Notes:
[a] Rounded to two significant figures. These estimates reflect the economic value of avoided morbidities and premature deaths using risk coefficients from the studies noted in Table 8A-8.
[b] Ozone-only benefits reflect short-term exposure impacts and as such are assumed to occur in the same year as ambient ozone reductions. Consequently, social discounting is not applied to the benefits for this category.
[c] Range reflects application of effect estimates from Smith et al. (2009) and Zanobetti and Schwartz (2008).
[d] Range reflects application of effect estimates from Krewski et al. (2009) and Lepeule et al. (2012).
[e] Excludes additional health and welfare benefits which could not be quantified (see Table 8A-2).

8A.1.4 Methodology

We follow a "damage-function" approach in calculating total benefits of the modeled changes in environmental quality. This approach estimates changes in individual health endpoints (specific effects that can be associated with changes in air quality) and assigns values to those changes assuming independence of the values for those individual endpoints. Total benefits are calculated simply as the sum of the values for all non-overlapping health endpoints. The "damage-function" approach is the standard method for assessing costs and benefits of environmental quality programs and has been used in several recent published analyses.[138,139,140]

To assess economic value in a damage-function framework, the changes in environmental quality must be translated into effects on people or on the things that people value. In some cases, the changes in environmental quality can be directly valued. In other cases, such as for changes in ozone and PM, an impact analysis must first be conducted to convert air quality changes into effects that can be assigned dollar values. For the purposes of this RIA, the health impacts analysis (HIA) includes those health effects that are directly linked to ambient levels of air pollution and specifically to those linked to ozone and $PM_{2.5}$.

We note at the outset that the EPA rarely has the time or resources to perform extensive new research to measure directly either the health outcomes or their values for regulatory analyses. Thus, similar to Kunzli et al. (2000)[141] and other, more recent health impact analyses, our estimates are based on the best available methods of benefits transfer. Benefits transfer is the science and art of adapting primary research from similar contexts to obtain the most accurate measure of benefits for the environmental quality change under analysis. Adjustments are made for the level of environmental quality change, the socio-demographic and economic characteristics of the affected population, and other factors to improve the accuracy and robustness of benefits estimates.

8A.1.4.1 Human Health Impact Assessment

The health impact assessment (HIA) quantifies the changes in the incidence of adverse health impacts resulting from changes in human exposure to $PM_{2.5}$ and ozone air quality. HIAs are a well-established approach for estimating the retrospective or prospective change in adverse health impacts expected to result from population-level changes in exposure to pollutants.[142] PC-based tools such as the environmental ***Ben***efits ***M***apping and ***A***nalysis ***P***rogram (BenMAP) can systematize health impact analyses by applying a database of key input parameters, including health impact functions and population projections—provided that key input data are available, including air quality estimates and risk coefficients.[143] Analysts have applied the HIA approach to estimate human health impacts resulting from hypothetical changes in pollutant levels.[144, 145],[146] The EPA and others have relied upon this method to predict future changes in health impacts expected to result from the implementation of regulations affecting air quality.[147] For this assessment, the HIA is limited to those health effects that are directly linked to ambient ozone and $PM_{2.5}$ concentrations.

The HIA approach used in this analysis involves three basic steps: (1) utilizing projections of $PM_{2.5}$ air quality[PPP] and estimating the change in the spatial distribution of the ambient air quality; (2) determining the subsequent change in population-level exposure; (3) calculating health impacts by applying concentration-response relationships drawn from the epidemiological literature to this change in population exposure.

A typical health impact function might look like:

$$\Delta y = y_0 \cdot \left(e^{\beta \cdot \Delta x} - 1\right),$$

[PPP] Projections of ambient $PM_{2.5}$ concentrations for this analysis were generated using the Community Multiscale Air Quality model (CMAQ). See Chapter 7 of this RIA for more information on the air quality modeling.

where y_0 is the baseline incidence (the product of the baseline incidence rate times the potentially affected population), β is the effect estimate, and Δx is the estimated change in the summary pollutant measure. There are other functional forms, but the basic elements remain the same. The following subsections describe the sources for each of the first three elements: size of the potentially affected populations; $PM_{2.5}$ and ozone effect estimates; and baseline incidence rates. We also describe the treatment of potential thresholds in PM-related health impact functions in Chapter 8.1.2.5.3. Chapter 8.1.2.4.6 describes the ozone and PM air quality inputs to the health impact functions.

Potentially Affected Populations

Quantified and monetized human health impacts depend on the demographic characteristics of the population, including age, location, and income. We use population projections based on economic forecasting models developed by Woods and Poole, Inc.[148] The Woods and Poole (WP) database contains county-level projections of population by age, sex, and race out to 2040, relative to a baseline using the 2010 Census data. Projections in each county are determined simultaneously with every other county in the United States to take into account patterns of economic growth and migration. The sum of growth in county-level populations is constrained to equal a previously determined national population growth, based on Bureau of Census estimates.[149] According to WP, linking county-level growth projections together and constraining to a national-level total growth avoids potential errors introduced by forecasting each county independently. County projections are developed in a four-stage process:

- First, national-level variables such as income, employment, and populations are forecasted.
- Second, employment projections are made for 179 economic areas defined by the Bureau of Economic Analysis,[150] using an "export-base" approach, which relies on linking industrial-sector production of non-locally consumed production items, such as outputs from mining, agriculture, and manufacturing with the national economy. The export-based approach requires estimation of demand equations or calculation of historical growth rates for output and employment by sector.
- Third, population is projected for each economic area based on net migration rates derived from employment opportunities and following a cohort-component method based on fertility and mortality in each area.
- Fourth, employment and population projections are repeated for counties, using the economic region totals as bounds. The age, sex, and race distributions for each region or county are determined by aging the population by single year of age by sex and race for each year through 2040 based on historical rates of mortality, fertility, and migration.

Effect Estimate Sources

The first step in selecting effect coefficients is to identify the health endpoints to be quantified. We base our selection of health endpoints on consistency with the EPA's Integrated Science Assessments (which replace previous Criteria Documents), with input and advice from the SAB-HES, a scientific review panel specifically established to provide advice on the use of the scientific literature in developing benefits analyses for the EPA's Report to Congress on *The Benefits and Costs of the Clean Air Act 1990 to 2020*.[151] In addition, we included more recent epidemiology studies from the ozone ISA, PM ISA, and the PM Provisional Assessment. [152,153,154] In general, we follow a weight of evidence approach, based on the biological plausibility of effects, availability of concentration-response functions from well conducted peer-reviewed epidemiological studies, cohesiveness of results across studies, and a focus on endpoints reflecting public health impacts (like hospital admissions) rather than physiological responses (such as changes in clinical measures like Forced Expiratory Volume [FEV1]).

There are several types of data that can support the determination of types and magnitude of health effects associated with air pollution exposures. These sources of data include toxicological studies (including animal and cellular studies), human clinical trials, and observational epidemiology studies. All of these data sources provide important contributions to the weight of evidence surrounding a particular health impact. However, only epidemiology studies provide direct concentration-response relationships that can be used to evaluate population-level impacts of reductions in ambient pollution levels in a health impact assessment.

For the data-derived estimates, we relied on the published scientific literature to ascertain the relationship between $PM_{2.5}$, ozone, and adverse human health effects. We evaluated epidemiological studies using the selection criteria summarized in Table 8A-7. These criteria include consideration of whether the study was peer-reviewed, the match between the pollutant studied and the pollutant of interest, the study design and location, and characteristics of the study population, among other considerations. In general, the use of concentration-response functions from more than a single study can provide a more representative distribution of the effect estimate. However, there are often differences between studies examining the same endpoint, making it difficult to pool the results in a consistent manner. For example, studies may examine different pollutants or different age groups. For this reason, we consider very carefully the set of studies available examining each endpoint and select a consistent subset that provides a good balance of population coverage and match with the pollutant of interest. In many cases, either because of a lack of multiple studies, consistency problems, or clear superiority in the quality or comprehensiveness of one study over others, a single published study is selected as the basis of the effect estimate.

When several effect estimates for a pollutant and a given health endpoint have been selected (with the exception of mortality), they are quantitatively combined or pooled to derive a more robust estimate of the relationship. The BenMAP Manual Technical Appendices provides details of the procedures used to combine multiple impact functions.[155] In general, we used fixed or random effects models to pool estimates from different single city studies of the same endpoint. Fixed effects pooling simply weights each study's estimate by the inverse variance, giving more weight to studies with greater statistical power (lower variance). Random effects pooling accounts for both within-study variance and between-study variability, due, for example, to differences in population susceptibility. We used the fixed effects model as our null hypothesis and then determined whether the data suggest that we should reject this null hypothesis, in which case we would use the random effects model.[QQQ] Pooled impact functions are used to estimate hospital admissions and asthma exacerbations. When combining evidence across multi-city studies (e.g., cardiovascular hospital admission studies), we use equal weights pooling. The effect estimates drawn from each multi-city study are themselves pooled across a large number of urban areas. For this reason, we elected to give each study an equal weight rather than weighting by the inverse of the variance reported in each study. For more details on methods used to pool incidence estimates, see the BenMAP Manual Appendices.

Effect estimates selected for a given health endpoint were applied consistently across all locations nationwide. This applies to both impact functions defined by a single effect estimate and those defined by a pooling of multiple effect estimates. Although the effect estimate may, in fact, vary from one location to another (e.g., because of differences in population susceptibilities or differences in the composition of PM), location-specific effect estimates are generally not available.

[QQQ] EPA recently changed the algorithm BenMAP uses to calculate study variance, which is used in the pooling process. Prior versions of the model calculated population variance, while the version used here calculated sample variance. This change did not affect the selection of random or fixed effects for the pooled incidence estimates between the proposal and final RIA.

Table 8A-7 Criteria Used When Selecting C-R Function

Consideration	*Comments*
Peer-Reviewed Research	Peer-reviewed research is preferred to research that has not undergone the peer-review process.
Study Type	Among studies that consider chronic exposure (e.g., over a year or longer), prospective cohort studies are preferred over ecological studies because they control for important individual-level confounding variables that cannot be controlled for in ecological studies.
Study Period	Studies examining a relatively longer period of time (and therefore having more data) are preferred, because they have greater statistical power to detect effects. Studies that are more recent are also preferred because of possible changes in pollution mixes, medical care, and lifestyle over time. However, when there are only a few studies available, studies from all years will be included.
Population Attributes	The most technically appropriate measures of benefits would be based on impact functions that cover the entire sensitive population but allow for heterogeneity across age or other relevant demographic factors. In the absence of effect estimates specific to age, sex, preexisting condition status, or other relevant factors, it may be appropriate to select effect estimates that cover the broadest population to match with the desired outcome of the analysis, which is total national-level health impacts. When available, multi-city studies are preferred to single city studies because they provide a more generalizable representation of the concentration-response function.
Study Size	Studies examining a relatively large sample are preferred because they generally have more power to detect small magnitude effects. A large sample can be obtained in several ways, including through a large population or through repeated observations on a smaller population (e.g., through a symptom diary recorded for a panel of asthmatic children).
Study Location	U.S. studies are more desirable than non-U.S. studies because of potential differences in pollution characteristics, exposure patterns, medical care system, population behavior, and lifestyle. National estimates are most appropriate when benefits are nationally distributed; the impact of regional differences may be important when benefits only accrue to a single area.
Pollutants Included in Model	When modeling the effects of ozone and PM (or other pollutant combinations) jointly, it is important to use properly specified impact functions that include both pollutants. Using single-pollutant models in cases where both pollutants are expected to affect a health outcome can lead to double-counting when pollutants are correlated.
Measure of PM	For this analysis, impact functions based on $PM_{2.5}$ are preferred to PM_{10} because of the focus on reducing emissions of $PM_{2.5}$ precursors, and because air quality modeling was conducted for this size fraction of PM. Where $PM_{2.5}$ functions are not available, PM_{10} functions are used as surrogates, recognizing that there will be potential downward (upward) biases if the fine fraction of PM_{10} is more (less) toxic than the coarse fraction.
Economically Valuable Health Effects	Some health effects, such as forced expiratory volume and other technical measurements of lung function, are difficult to value in monetary terms. These health effects are not quantified in this analysis.
Non-overlapping Endpoints	Although the benefits associated with each individual health endpoint may be analyzed separately, care must be exercised in selecting health endpoints to include in the overall benefits analysis because of the possibility of double-counting of benefits.

It is important to note that we are unable to separately quantify all of the possible PM and ozone health effects that have been reported in the literature for three reasons: (1) the possibility of double counting (such as hospital admissions for specific respiratory diseases versus hospital admissions for all or a sub-set of respiratory diseases); (2) uncertainties in applying effect relationships that are based on clinical studies to the potentially affected population; or (3) the lack of an established concentration-response (CR) relationship. Table 8A-8 lists the health endpoints included in this analysis.

Table 8A-8 Health Impact Functions Used in BenMAP to Estimate Impacts of $PM_{2.5}$ and Ozone Reductions

Endpoint	Study	Study Population	Relative Risk or Effect Estimate (β) (with 95th Percentile Confidence Interval or SE)
PM-related Health Impacts			
Premature Mortality			
Premature mortality—cohort study, all-cause	*Krewski et al. (2009)*[156]	> 29 years	RR = 1.06 (1.04–1.06) per 10 μg/m^3
	Lepeule et al. (2012)[157]	> 24 years	RR = 1.14 (1.07–1.22) per 10 μg/m^3
Premature mortality—all-cause	Woodruff et al. (1997)[158]	Infant (< 1 year)	OR = 1.04 (1.02–1.07) per 10 μg/m^3
Chronic Illness			
Nonfatal heart attacks	Peters et al. (2001)[159]	Adults (> 18 years)	OR = 1.62 (1.13–2.34) per 20 μg/m^3
	Pooled estimate:		
	Pope et al. (2006)[160]		β = 0.00481 (0.00199)
	Sullivan et al. (2005)[161]		β = 0.00198 (0.00224)
	Zanobetti et al. (2009)		β = 0.00225 (0.000591)
	Zanobetti and Schwartz (2006)[162]		β = 0.0053 (0.00221)
Hospital Admissions			
Respiratory	*Zanobetti et al. (2009)*—ICD 460-519 (All respiratory)	> 64 years	β=0.00207 (0.00446)
	Kloog et al. (2012)[163]—ICD 460-519 (All Respiratory		β=0.0007 (0.000961)
	Moolgavkar (2000)[164]—ICD 490–496 (Chronic lung disease)	18–64 years	1.02 (1.01–1.03) per 36 μg/m^3
	Babin et al. (2007)[165]—ICD 493 (asthma)	< 19 years	β=0.002 (0.004337)
	Sheppard (2003)[166]—ICD 493 (asthma)	< 18	RR = 1.04 (1.01–1.06) per 11.8 μg/m^3
Cardiovascular	Pooled estimate:	> 64 years	
	Zanobetti et al. (2009)—ICD 390-459 (all cardiovascular)		β=0.00189 (0.000283)
	Peng et al. (2009)[167]—ICD 426-427; 428; 430-438; 410-414; 429; 440-449 (Cardio-, cerebro- and peripheral vascular disease)		β=0.00068 (0.000214)
	Peng et al. (2008)[168]—ICD 426-427; 428; 430-438; 410-414; 429; 440-449 (Cardio-, cerebro- and peripheral vascular disease)		β=0.00071 (0.00013)
	Bell et al. (2008)[169]—ICD 426-427; 428; 430-438; 410-414; 429; 440-449 (Cardio-, cerebro- and peripheral vascular disease)		β=0.0008 (0.000107)
	Moolgavkar (2000)[170]—ICD 390–429 (all cardiovascular)	20–64 years	RR=1.04 (t statistic: 4.1) per 10 μg/m^3
Asthma-related emergency department visits	Pooled estimate:	All ages	
	Mar et al. (2010)[171]		RR = 1.04 (1.01–1.07) per 7 μg/m^3
	Slaughter et al. (2005)[172]		RR = 1.03 (0.98–1.09) per 10 μg/m^3
	Glad et al. (2012)[173]		β=0.00392 (0.002843)
Other Health Endpoints			

Acute bronchitis	Dockery et al. (1996)[174]	8–12 years	OR = 1.50 (0.91–2.47) per 14.9 µg/m[3]
Asthma exacerbations	Pooled estimate: Ostro et al. (2001)[175] (cough, wheeze, shortness of breath) [b] Mar et al. (2004)[176] (cough, shortness of breath)	6–18 years [b]	OR = 1.03 (0.98–1.07) OR = 1.06 (1.01–1.11) OR = 1.08 (1.00–1.17) per 30 µg/m[3] RR = 1.21 (1–1.47) per RR = 1.13 (0.86–1.48) per 10 µg/m[3]
Work loss days	Ostro (1987)[177]	18–65 years	β=0.0046 (0.00036)
Acute respiratory symptoms (MRAD)	Ostro and Rothschild (1989)[178] (Minor restricted activity days)	18–65 years	β=0.00220 (0.000658)
Upper respiratory symptoms	Pope et al. (1991)[179]	Asthmatics, 9–11 years	1.003 (1–1.006) per 10 µg/m[3]
Lower respiratory symptoms	Schwartz and Neas (2000)[180]	7–14 years	OR = 1.33 (1.11–1.58) per 15 µg/m[3]
Ozone-related Health Impacts			
Premature Mortality			
Premature mortality—short-term	*Smith et al. (2009)*[181] *Zanobetti and Schwartz (2008)*[182]	All ages	β = 0.00032 (0.00008) β = 0.00051 (0.00012)
Hospital Admissions			
Respiratory	Pooled estimate: *Katsouyanni et al. (2009)*[183]	> 65 years	β = 0.00064 (0.00040) penalized splines
Asthma-related emergency department visits	Pooled estimate: *Glad et al. (2012)*[184] *Ito et al. (2007)*[185] *Mar and Koenig (2009)*[186] Peel et al. (2005)[187] *Sarnat et al. (2013)*[188] Wilson et al. (2005)[189]	0-99 years	β = 0.00306 (0.00117) β = 0.00521 (0.00091) β = 0.01044 (0.00436) (0-17 yr olds) β = 0.00770 (0.00284) (18-99 yr olds) β = 0.00087 (0.00053) β = 0.00111 (0.00028) RR = 1.022 (0.996 – 1.049) per 25
Other Health Endpoints			
Asthma exacerbation	Pooled estimate: [b] *Mortimer et al. (2002)*[190] *Schildcrout et al. (2006)*[191]	6–18 years	β = 0.00929 (0.00387) β = 0.00222 (0.00282)
School loss days	Pooled estimate: Chen et al. (2000)[192] Gilliland et al. (2001)[193]	5-17 years	β = 0.015763 (0.004985) β = 0.007824 (0.004445)
Acute respiratory symptoms (MRAD)	Ostro and Rothschild (1989)[194]	18–65 years	β = 0.002596 (0.000776)

Notes:

[a] For PM, studies highlighted in *red* represent updates incorporated since the ozone NAAQS RIA (U.S. EPA, 2008). These updates were introduced in the PM NAAQS RIA (U.S. EPA, 2012). For ozone, studies highlighted in red represent updates incorporated since the 2008 ozone NAAQS RIA (U.S. EPA, 2008).

[b] The original study populations were 8 to 13 years for the Ostro et al. (2001) study and 7 to 12 years for the Mar et al. (2004) study. Based on advice from the SAB-HES, we extended the applied population to 6-18 years, reflecting the common biological basis for the effect in children in the broader age group. See: U.S. EPA-SAB (2004) and NRC (2002).

In selecting epidemiological studies as sources of effect estimates, we applied several criteria to develop a set of studies that is likely to provide the best estimates of impacts in the U.S. To account for the potential impacts of different health care systems or underlying health status of populations, we give preference to U.S. studies over non-U.S. studies. In addition, due to the potential for confounding by co-pollutants, we give preference to effect estimates from models including both ozone and PM over effect estimates from single-pollutant models.[195,196]

Baseline Incidence Rates

Epidemiological studies of the association between pollution levels and adverse health effects generally provide a direct estimate of the relationship of air quality changes to the *relative risk* of a health effect, rather than estimating the absolute number of avoided cases. For example, a typical result might be that a 100 ppb decrease in daily ozone levels might, in turn, decrease hospital admissions by 3 percent. The baseline incidence of the health effect is necessary to convert this relative change into a number of cases. A baseline incidence rate is the estimate of the number of cases of the health effect per year in the assessment location, as it corresponds to baseline pollutant levels in that location. To derive the total baseline incidence per year, this rate must be multiplied by the corresponding population number. For example, if the baseline incidence rate is the number of cases per year per 100,000 people, that number must be multiplied by the number of 100,000s in the population.

Table 8A-9 summarizes the sources of baseline incidence rates and provides average incidence rates for the endpoints included in the analysis. Table 8A-10 presents the asthma prevalence rates used in this analysis. For both baseline incidence and prevalence data, we used age-specific rates where available. We applied concentration-response functions to individual age groups and then summed over the relevant age range to provide an estimate of total population benefits. In most cases, we used a single national incidence rate, due to a lack of more spatially disaggregated data. Whenever possible, the national rates used are national averages, because these data are most applicable to a national assessment of benefits. For some studies, however, the only available incidence information comes from the studies themselves; in these cases, incidence in the study population is assumed to represent typical incidence at the national level. Regional incidence rates are available for hospital admissions, and county-level data are available for premature mortality. We have projected mortality rates such that future mortality rates are consistent with our projections of population growth.[197]

Table 8A-9 Baseline Incidence Rates and Population Prevalence Rates for Use in Impact Functions, General Population

Endpoint	Parameter	Rates: Value	Rates: Source
Mortality	Daily or annual mortality rate projected to 2025 [a]	Age-, cause-, and county-specific rate	CDC WONDER (2004–2006) U.S. Census bureau, 2000
Hospitalizations	Daily hospitalization rate	Age-, region-, state-, county- and cause-specific rate	2007 HCUP data files [b]
ER Visits	Daily ER visit rate for asthma and cardiovascular events	Age-, region-, state-, county- and cause-specific rate	2007 HCUP data files [b]
Nonfatal Myocardial Infarction (heart attacks)	Daily nonfatal myocardial infarction incidence rate per person, 18+	Age-, region-, state-, and county-specific rate	2007 HCUP data files [b] adjusted by 0.93 for probability of surviving after 28 days (Rosamond et al., 1999)
Asthma Exacerbations[c]	Incidence among asthmatic African-American children		Ostro et al. (2001)
	daily wheeze	0.173	
	daily cough	0.145	
	daily shortness of breath	0.074	
Acute Bronchitis	Annual bronchitis incidence rate, children	0.043	American Lung Association (2002, Table 11)[198]
Lower Respiratory Symptoms	Daily lower respiratory symptom incidence among children [d]	0.0012	Schwartz et al. (1994, Table 2)
Upper Respiratory Symptoms	Daily upper respiratory symptom incidence among asthmatic children	0.3419	Pope et al. (1991, Table 2)
Work Loss Days	Daily WLD incidence rate per person (18–65)		1996 HIS (Adams, Hendershot, and Marano, 1999, Table 41)[199]; U.S. Census Bureau (2000)[200]
	Aged 18–24	0.00540	
	Aged 25–44	0.00678	
	Aged 45–64	0.00492	
School Loss Days	Rate per person per year, assuming 180 school days per year	9.9	National Center for Education Statistics (1996) and 1996 HIS (Adams et al., 1999, Table 47);
Minor Restricted-Activity Days	Daily MRAD incidence rate per person	0.02137	Ostro and Rothschild (1989, p. 243)

Notes:

[a] Mortality rates are only available at 5-year increments.

[b] Healthcare Cost and Utilization Program (HCUP) database contains individual level, state and regional-level hospital and emergency department discharges for a variety of International Classification of Diseases (ICD) codes (AHRQ, 2007). [201]

[c] The incidence of exacerbated asthma was quantified among children of all races, using the baseline incidence rate reported in Ostro et al. (2001).

[d] Lower respiratory symptoms are defined as two or more of the following: cough, chest pain, phlegm, and wheeze.

Table 8A-10 Asthma Prevalence Rates Used for this Analysis

Population Group	Asthma Prevalence Rates	
	Value	Source
All Ages	0.0780	American Lung Association (2010, Table 7)
< 18	0.0941	
5–17	0.1070	
18–44	0.0719	
45–64	0.0745	
65+	0.0716	
African American, 5–17	0.1776	American Lung Association (2010, Table 9)
African American, <18	0.1553	American Lung Association [a]

Note:
[a] Calculated by ALA for U.S. EPA, based on NHIS data (CDC, 2008).[202,203]

Economic Values for Health Outcomes

Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health effects for a large population. Therefore, the appropriate economic measure is willingness-to-pay (WTP) for changes in risk of a health effect rather than WTP for a health effect that would occur with certainty (Freeman, 1993).[204] Epidemiological studies generally provide estimates of the relative risks of a particular health effect that is avoided because of a reduction in air pollution. We converted those to units of avoided statistical incidence for ease of presentation. We calculated the value of avoided statistical incidences by dividing individual WTP for a risk reduction by the related observed change in risk. For example, suppose a pollution-reduction regulation is able to reduce the risk of premature mortality from 2 in 10,000 to 1 in 10,000 (a reduction of 1 in 10,000). If individual WTP for this risk reduction is $100, then the WTP for an avoided statistical premature death is $1 million ($100/0.0001 change in risk).

WTP estimates generally are not available for some health effects, such as hospital admissions. In these cases, we used the cost of treating or mitigating the effect as a primary estimate. These cost-of-illness (COI) estimates generally understate the true value of reducing the risk of a health effect, because they reflect the direct expenditures related to treatment, but not the value of avoided pain and suffering (Harrington and Portney, 1987; Berger, 1987).[205,206] We provide unit values for health endpoints (along with information on the distribution of the unit value) in Table 8A-11. All values are in constant year 2013 dollars, adjusted for growth in real income out to 2024 using projections provided by Standard and Poor's. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real income increases. Many of the valuation studies used in this analysis were conducted in the late 1980s and early 1990s. Because real income has grown since the studies were conducted, people's willingness to pay for reductions in the risk of premature death and disease likely has grown as well. We did not adjust cost of illness-based values because they are based on current costs. Similarly, we did not adjust the value of school absences, because that value is based on current wage rates. For details on valuation estimates for PM-related endpoints, see the 2012 PM NAAQS RIA.[207] For details on valuation estimates for ozone-related endpoints, see the 2015 Ozone NAAQS RIA.[208]

Table 8A-11 Unit Values for Economic Valuation of Health Endpoints (2011$)[a]

Health Endpoint	Central Estimate of Value Per Statistical Incidence: 2000 Income Level	Central Estimate of Value Per Statistical Incidence: 2024 Income Level	Derivation of Distributions of Estimates
Premature Mortality (Value of a Statistical Life)	$8,300,000	$10,000,000	EPA currently recommends a central VSL of $6.3m (2000$) based on a Weibull distribution fitted to 26 published VSL estimates (5 contingent valuation and 21 labor market studies). The underlying studies, the distribution parameters, and other useful information are available in Appendix B of EPA's current Guidelines for Preparing Economic Analyses (U.S. EPA, 2010).[209]
Nonfatal Myocardial Infarction (heart attack) 3% discount rate Age 0–24 Age 25–44 Age 45–54 Age 55–65 Age 66 and over 7% discount rate Age 0–24 Age 25–44 Age 45–54 Age 55–65 Age 66 and over	 $100,000 $110,000 $120,000 $210,000 $100,000 $100,000 $110,000 $120,000 $190,000 $100,000	 $100,000 $110,000 $120,000 $210,000 $100,000 $100,000 $110,000 $120,000 $190,000 $100,000	No distributional information available. Age-specific cost-of-illness values reflect lost earnings and direct medical costs over a 5-year period following a nonfatal MI. Lost earnings estimates are based on Cropper and Krupnick (1990).[210] Direct medical costs are based on simple average of estimates from Russell et al. (1998)[211] and Wittels et al. (1990).[212] Lost earnings: Cropper and Krupnick (1990). Present discounted value of 5 years of lost earnings: age of onset: at 3% at 7% 25–44 $8,774 $7,855 45–54 $12,932 $11,578 55–65 $74,746 $66,920 Direct medical expenses: An average of: 1. Wittels et al. (1990) ($102,658—no discounting) 2. Russell et al. (1998), 5-year period ($22,331 at 3% discount rate; $21,113 at 7% discount rate)
Hospital Admissions			
Chronic Lung Disease (18–64)	$22,000	$22,000	No distributional information available. The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total chronic lung illnesses) reported in Agency for Healthcare Research and Quality (2007) (www.ahrq.gov).[213]
Asthma Admissions (0–64)	$16,000	$16,000	No distributional information available. The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total asthma category illnesses) reported in Agency for Healthcare Research and Quality (2007) (www.ahrq.gov).
All Cardiovascular Age 18–64 Age 65–99	 $44,000 $42,000	 $44,000 $42,000	No distributional information available. The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total cardiovascular category illnesses) reported in Agency for Healthcare Research and Quality (2007) (www.ahrq.gov).

All respiratory (ages 65+)	$37,000	$37,000	No distributions available. The COI point estimates (lost earnings plus direct medical costs) are based on ICD-9 code level information (e.g., average hospital care costs, average length of hospital stay, and weighted share of total respiratory category illnesses) reported in Agency for Healthcare Research and Quality, 2007 (www.ahrq.gov).
Emergency Department Visits for Asthma	$440	$440	No distributional information available. Simple average of two unit COI values (2000$): (1) $310, from Smith et al. (1997)[214] and (2) $260, from Stanford et al. (1999).[215]
Respiratory Ailments Not Requiring Hospitalization			
Upper Respiratory Symptoms (URS)	$35	$32	Combinations of the three symptoms for which WTP estimates are available that closely match those listed by Pope et al. result in seven different "symptom clusters," each describing a "type" of URS. A dollar value was derived for each type of URS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. In the absence of information surrounding the frequency with which each of the seven types of URS occurs within the URS symptom complex, we assumed a uniform distribution between $9.2 and $43 (2000$).
Lower Respiratory Symptoms (LRS)	$22	$21	Combinations of the four symptoms for which WTP estimates are available that closely match those listed by Schwartz et al. result in 11 different "symptom clusters," each describing a "type" of LRS. A dollar value was derived for each type of LRS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for LRS is the average of the dollar values for the 11 different types of LRS. In the absence of information surrounding the frequency with which each of the 11 types of LRS occurs within the LRS symptom complex, we assumed a uniform distribution between $6.9 and $25 (2000$).
Asthma Exacerbations	$56	$60	Asthma exacerbations are valued at $45 per incidence, based on the mean of average WTP estimates for the four severity definitions of a "bad asthma day," described in Rowe and Chestnut (1986).[216] This study surveyed asthmatics to estimate WTP for avoidance of a "bad asthma day," as defined by the subjects. For purposes of valuation, an asthma exacerbation is assumed to be equivalent to a day in which asthma is moderate or worse as reported in the Rowe and Chestnut (1986) study. The value is assumed to have a uniform distribution between $16 and $71 (2000$).
Acute Bronchitis	$460	$500	Assumes a 6-day episode, with the distribution of the daily value specified as uniform with the low and high values based on those recommended for related respiratory symptoms in Neumann et al. (1994). The low daily estimate of $10 is the sum of the mid-range values recommended by IEc (1994) for two symptoms believed to be associated with acute bronchitis: coughing and chest tightness. The high daily estimate was taken to be twice the value of a minor respiratory restricted-activity day, or $110 (2000$).
Work Loss Days (WLDs)	Variable (U.S. median = $150)	Variable (U.S. median = $150)	No distribution available. Point estimate is based on county-specific median annual wages divided by 52 and then by 5—to get median daily wage. U.S. Year 2000 Census, compiled by Geolytics, Inc. (Geolytics, 2002)[217]

Minor Restricted Activity Days (MRADs)	$64	$68	Median WTP estimate to avoid one MRAD from Tolley et al. (1986).[218] Distribution is assumed to be triangular with a minimum of $22 and a maximum of $83, with a most likely value of $52 (2000$). Range is based on assumption that value should exceed WTP for a single mild symptom (the highest estimate for a single symptom—for eye irritation—is $16) and be less than that for a WLD. The triangular distribution acknowledges that the actual value is likely to be closer to the point estimate than either extreme.
School Loss Days	$98	$98	No distribution available. Based on (1) the probability that, if a school child stays home from school, a parent will have to stay home from work to care for the child, and (2) the value of the parent's lost productivity.

Notes:
[a] All estimates are rounded to two significant digits. Unrounded estimates in 2000$ are available in the Appendix J of the BenMAP user manual (U.S. EPA, 2015).[219] Income growth projections are only currently available in BenMAP through 2024, so the 2040 estimates use income growth through 2024 and are therefore likely underestimates. Currently, BenMAP does not have an inflation adjustment to 2013$. We ran BenMAP for a currency year of 2010$ and then adjusted the resulting benefit-per-ton estimates to 2013$ using the Consumer Price Index (CPI-U, all items). This approach slightly underestimates the inflation for medical index and wage index between 2010 and 2013, which affects COI estimates and wage-based estimates.

8A.1.5 Processing Air Quality Modeling Data for Health Impacts Analysis

In the Appendix to Chapter 6, we summarized the methods for and results of estimating air quality for the standards. These air quality results are in turn associated with human populations to estimate changes in health effects. For the purposes of this analysis, we focus on the health effects that have been linked to ambient changes in ozone and $PM_{2.5}$ related to emission reductions estimated to occur due to the implementation of the standards. We estimate ambient $PM_{2.5}$ and ozone concentrations using the Community Multiscale Air Quality model (CMAQ). This section describes how we converted the CMAQ modeling output into full-season profiles suitable for the health impacts analysis.

General Methodology

First, we extracted hourly, surface-layer PM and ozone concentrations for each grid cell from the standard CMAQ output files. For ozone, these model predictions are used in conjunction with the observed concentrations obtained from the Aerometric Information Retrieval System (AIRS) to generate ozone concentrations for the entire ozone season.[RRR,SSS] The predicted changes in ozone concentrations from the future-year base case to future-year control scenario serve as inputs to the health and welfare impact functions of the benefits analysis (*i.e.*, BenMAP).

[RRR] The ozone season for this analysis is defined as the 5-month period from May to September.
[SSS] Based on AIRS, there were 961 ozone monitors with sufficient data (*i.e.*, 50 percent or more days reporting at least nine hourly observations per day [8 am to 8 pm] during the ozone season).

To estimate ozone-related health effects for the contiguous United States, full-season ozone data are required for every BenMAP grid-cell. Given available ozone monitoring data, we generated full-season ozone profiles for each location in two steps: (1) we combined monitored observations and modeled ozone predictions to interpolate hourly ozone concentrations to a grid of 12-km by 12-km population grid cells for the contiguous 48 states, and (2) we converted these full-season hourly ozone profiles to an ozone measure of interest, such as the daily 8-hour maximum.[TTT,UUU]

For $PM_{2.5}$, we also use the model predictions in conjunction with observed monitor data. CMAQ generates predictions of hourly PM species concentrations for every grid. The species include a primary coarse fraction (corresponding to PM in the 2.5 to 10 micron size range), a primary fine fraction (corresponding to PM less than 2.5 microns in diameter), and several secondary particles (*e.g.*, sulfates, nitrates, and organics). $PM_{2.5}$ is calculated as the sum of the primary fine fraction and all of the secondarily formed particles. Future-year estimates of $PM_{2.5}$ were calculated using relative reduction factors (RRFs) applied to 2005 ambient $PM_{2.5}$ and $PM_{2.5}$ species concentrations. A gridded field of $PM_{2.5}$ concentrations was created by interpolating Federal Reference Monitor ambient data and IMPROVE ambient data. Gridded fields of $PM_{2.5}$ species concentrations were created by interpolating EPA speciation network (ESPN) ambient data and IMPROVE data. The ambient data were interpolated to the CMAQ 12 km grid.

The procedures for determining the RRFs are similar to those in EPA's draft guidance for modeling the $PM_{2.5}$ standard (EPA, 2001).[220] The guidance recommends that model predictions be used in a relative sense to estimate changes expected to occur in each major $PM_{2.5}$ species. The procedure for calculating future-year $PM_{2.5}$ design values is called the "Speciated Modeled Attainment Test (SMAT)." EPA used this procedure to estimate the ambient impacts of the final standards.

Table 8A-12 provides those ozone and $PM_{2.5}$ metrics for grid cells in the modeled domain that enter the health impact functions for health benefits endpoints. The population-weighted average reflects the baseline levels and predicted changes for more populated areas of the nation. This measure better reflects the potential benefits through exposure changes to these populations.

[TTT] The 12-km grid squares contain the population data used in the health benefits analysis model, BenMAP.
[UUU] This approach is a generalization of planar interpolation that is technically referred to as enhanced Voronoi Neighbor Averaging (EVNA) spatial interpolation. See the BenMAP manual for technical details, available for download at http://www3.epa.gov/air/benmap.

Table 8A-12 Summary of CMAQ-Derived Population-Weighted Ozone and $PM_{2.5}$ Air Quality Metrics for Health Benefits Endpoints Associated with the Standards

	2040	
Statistic[a]	Baseline	Change[b]
Ozone Metric: National Population-Weighted Average (ppb)[c]		
Daily Maximum 8-Hour Average Concentration	41.67	-0.21
$PM_{2.5}$ Metric: National Population-Weighted Average (µg/m^3)		
Annual Average Concentration	7.32	-0.01

Notes:
[a] Ozone and $PM_{2.5}$ metrics are calculated at the CMAQ grid-cell level for use in health effects estimates. Ozone metrics are calculated over relevant time periods during the daylight hours of the "ozone season" (*i.e.*, May through September). Note that the national, population-weighted $PM_{2.5}$ and ozone air quality metrics presented in this chapter represent an average for the entire, gridded U.S. CMAQ domain. These are different than the population-weighted $PM_{2.5}$ and ozone design value metrics presented in Chapter 7, which represent the average for areas with a current air quality monitor.
[b] The change is defined as the control-case value minus the base-case value; a negative value therefore indicates a reduction and a positive value an increase.
[c] Calculated by summing the product of the projected CMAQ grid-cell population and the estimated CMAQ grid cell seasonal ozone concentration and then dividing by the total population.

Emissions and air quality modeling decisions are made early in the analytical process. For this reason, the emission control scenarios used in the air quality and benefits modeling are different than the final emission inventories estimated for the standards. Please refer to Chapter 6 for more information about the inventories used in the air quality modeling that supports the health impacts analysis.

8A.1.6 Methods for Describing Uncertainty

In any complex analysis using estimated parameters and inputs from numerous models, there are likely to be many sources of uncertainty and this analysis is no exception. As outlined both in this and preceding chapters, many inputs were used to derive the estimate of benefits for the standards, including emission inventories, air quality models (with their associated parameters and inputs), epidemiological health effect estimates, estimates of values (both from WTP and COI studies), population estimates, income estimates, and estimates of the future state of the world (*i.e.*, regulations, technology, and human behavior). Each of these inputs may be uncertain and, depending on its role in the benefits analysis, may have a disproportionately large impact on estimates of total benefits. For example, emissions estimates are used in the first stage of the analysis. As such, any uncertainty in emissions estimates will be propagated through the entire analysis. When compounded with uncertainty in later stages, small uncertainties in emission levels can lead to large impacts on total benefits.

The National Research Council (NRC) (2002, 2008)[221,222] highlighted the need for EPA to conduct rigorous quantitative analysis of uncertainty in its benefits estimates and to present these estimates to decision makers in ways that foster an appropriate appreciation of their inherent uncertainty. In general, the NRC concluded that EPA's general methodology for calculating the benefits of reducing air pollution is reasonable and informative in spite of inherent uncertainties. Since the publication of these reports, EPA's Office of Air and Radiation (OAR) continues to make progress toward the goal of characterizing the aggregate impact of uncertainty in key modeling elements on both health incidence and benefits estimates in two key ways: Monte Carlo analysis and expert-derived concentration-response functions. In this analysis, we use both of these two methods to assess uncertainty quantitatively, as well as provide a qualitative assessment for those aspects that we are unable to address quantitatively.

First, we used Monte Carlo methods for characterizing random sampling error associated with the concentration response functions from epidemiological studies and random effects modeling to characterize both sampling error and variability across the economic valuation functions. Monte Carlo simulation uses random sampling from distributions of parameters to characterize the effects of uncertainty on output variables, such as incidence of premature mortality. Specifically, we used Monte Carlo methods to generate confidence intervals around the estimated health impact and dollar benefits. The reported standard errors in the epidemiological studies determined the distributions for individual effect estimates.

In benefit analyses of air pollution regulations conducted to date, the estimated impact of reductions in premature mortality has accounted for 85 to 95 percent of total monetized benefits. Therefore, it is particularly important to attempt to characterize the uncertainties associated with reductions in premature mortality. The health impact functions used to estimate avoided premature deaths associated with reductions in ozone have associated standard errors that represent the statistical errors around the effect estimates in the underlying epidemiological studies. In our results, we report credible intervals based on these standard errors, reflecting the uncertainty in the estimated change in incidence of avoided premature deaths. We also provide multiple estimates, to reflect model uncertainty between alternative study designs.

For premature mortality associated with exposure to PM, we follow the same approach used in the RIA for 2012 PM NAAQS, presenting two empirical estimates of premature deaths avoided. This characterization, including confidence intervals, omit the contribution to overall uncertainty of uncertainty in air quality changes, baseline incidence rates, populations exposed and transferability of the effect estimate to diverse locations. Furthermore, the approach presented here does not yet include methods for addressing correlation between input parameters and the identification of reasonable upper and lower bounds for input distributions characterizing uncertainty in additional model elements. As a result, the reported confidence intervals and range of estimates give an incomplete picture about the overall uncertainty in the estimates. This information should be interpreted within the context of the larger uncertainty surrounding the entire analysis.

Some key sources of uncertainty in each stage of both the PM and ozone health impact assessment are the following:

- gaps in scientific data and inquiry;
- variability in estimated relationships, such as epidemiological effect estimates, introduced through differences in study design and statistical modeling;
- errors in measurement and projection for variables such as population growth rates;

- errors due to misspecification of model structures, including the use of surrogate variables, such as using PM_{10} when $PM_{2.5}$ is not available, excluded variables, and simplification of complex functions; and

- biases due to omissions or other research limitations.

In Table 8A-13 we summarize some of the key uncertainties in the benefits analysis.

Table 8A-13 Primary Sources of Uncertainty in the Benefits Analysis

1. Uncertainties Associated with Impact Functions
- The value of the ozone or PM effect estimate in each impact function. - Application of a single impact function to pollutant changes and populations in all locations. - Similarity of future-year impact functions to current impact functions. - Correct functional form of each impact function. - Extrapolation of effect estimates beyond the range of ozone or PM concentrations observed in the source epidemiological study. - Application of impact functions only to those subpopulations matching the original study population.
2. Uncertainties Associated with CMAQ-Modeled Ozone and PM Concentrations
- Responsiveness of the models to changes in precursor emissions from the control policy. - Projections of future levels of precursor emissions, especially ammonia and crustal materials. - Lack of ozone and $PM_{2.5}$ monitors in all rural areas requires extrapolation of observed ozone data from urban to rural areas.
3. Uncertainties Associated with PM Mortality Risk
- Limited scientific literature supporting a direct biological mechanism for observed epidemiological evidence. - Direct causal agents within the complex mixture of PM have not been identified. - The extent to which adverse health effects are associated with low-level exposures that occur many times in the year versus peak exposures. - The extent to which effects reported in the long-term exposure studies are associated with historically higher levels of PM rather than the levels occurring during the period of study. - Reliability of the $PM_{2.5}$ monitoring data in reflecting actual $PM_{2.5}$ exposures.
4. Uncertainties Associated with Possible Lagged Effects
- The portion of the PM-related long-term exposure mortality effects associated with changes in annual PM levels that would occur in a single year is uncertain as well as the portion that might occur in subsequent years.
5. Uncertainties Associated with Baseline Incidence Rates
- Some baseline incidence rates are not location specific (*e.g.*, those taken from studies) and therefore may not accurately represent the actual location-specific rates. - Current baseline incidence rates may not approximate well baseline incidence rates in 2040. - Projected population and demographics may not represent well future-year population and demographics.
6. Uncertainties Associated with Economic Valuation
- Unit dollar values associated with health and welfare endpoints are only estimates of mean WTP and therefore have uncertainty surrounding them. - Mean WTP (in constant dollars) for each type of risk reduction may differ from current estimates because of differences in income or other factors.
7. Uncertainties Associated with Aggregation of Monetized Benefits
- Health and welfare benefits estimates are limited to the available impact functions. Thus, unquantified or un-monetized benefits are not included.

References

[1] Environmental Protection Agency and Department of Transportation, "Light-Duty Vehicle Greenhouse Gas Emissions Standards and Corporate Average Fuel Economy Standards; Final Rule," Federal Register 75(88) (May 7, 2010), especially Sections III.H.1 (pp. 25510-25513) and IV.G.6 (pp. 25651-25657); Environmental Protection Agency and Department of Transportation, "2017 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions and Corporate Average Fuel Economy Standards; Final Rule," Federal Register 77(199) (October 15, 2012), especially Sections III.H.1 (pp. 62913-62919) and IV.G.5.a (pp. 63102-63104).

[2] *State of Massachusetts v. EPA*, 549 U.S. at 533.

[3] Klemick, Heather, Elizabeth Kopits, Keith Sargent, and Ann Wolverton (2015). "Heavy-Duty Trucking and the Energy Efficiency Paradox: Evidence form Focus Groups and Interviews." Transportation Research Part A 77: 154-166, Docket EPA-HQ-OAR-2014-0827; Roeth, Mike, Dave Kircher, Joel Smith, and Rob Swim (2013). "Barriers to the Increased Adoption of Fuel Efficiency Technologies in the North American On-Road Freight Sector." NACFE report for the International Council on Clean Transportation, Docket EPA-HQ-OAR-2014-0827-0084; Aarnink, Sanne, Jasper Faber, and Eelco den Boer (2012). "Market Barriers to Increased Efficiency in the European On-road Freight Sector." CE Delft report for the International Council on Clean Transportation, Docket EPA-HQ-OAR-2014-0827-0076.

[4] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council; Transportation Research Board (2010). "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles," (hereafter, "NAS 2010"). Washington, D.C. The National Academies Press. Available electronically from the National Academies Press Website at http://www.nap.edu/catalog.php?record_id=12845 (accessed September 10, 2010), Docket EPA-HQ-OAR-2014-0827-0122.

[5] Vernon, David and Alan Meier (2012). "Identification and quantification of principal-agent problems affecting energy efficiency investments and use decisions in the trucking industry." Energy Policy, 49(C), pp. 266-273, Docket EPA-HQ-OAR-2014-0827-0090.

[6] Blumstein, Carl and Margaret Taylor (2013). "Rethinking the Energy-Efficiency Gap: Producers, Intermediaries, and Innovation," Energy Institute at Haas Working Paper 243, University of California at Berkeley, Docket EPA-HQ-OAR-2014-0827-0075; Tirole, Jean (1998). *The Theory of Industrial Organization.* Cambridge, MA: MIT Press, pp.400, 402, Docket EPA-HQ-OAR-2014-0827-0089.

[7] American Transportation Research Institute, *An Analysis of the Operational Costs of Trucking*, September 2013), Docket EPA-HQ-OAR-2014-0827-0512.

[8] Transport Canada, Operating Cost of Trucks, 2005. See http://www.tc.gc.ca/eng/policy/report-acg-operatingcost2005-2005-e-2-1727.htm, accessed on July 16, 2010, Docket EPA-HQ-OAR-2014-0827-0070.

[9] Winebrake, J.J., Green, E.H., Comer, B., Corbett, J.J., Froman, S., 2012. Estimating the direct rebound effect for on-road freight transportation. Energy Policy 48, 252-259.

[10] Greene, D.L., Kahn, J.R., Gibson, R.C., 1999, "Fuel economy rebound effect for U.S. household vehicles," The Energy Journal, 20.

[11] For a discussion of the wide range of definitions found in the literature, see Appendix D: Discrepancy in Rebound Effect Definitions, in EERA (2014), "Research to Inform Analysis of the Heavy-Duty vehicle Rebound Effect," and Excerpts of Draft Final Report of Phase 1 under EPA contract EP-C-13-025. (Docket ID: EPA-HQ-OAR-2014-0827). See also Greening, L.A., Greene, D.L., Difiglio, C., 2000, "Energy efficiency and consumption — the rebound effect — a survey," Energy Policy, 28, 389-401.

[12] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council; Transportation Research Board (2010). "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles," Washington, D.C. The National Academies Press. Available electronically from the National Academies Press Website at http://www.nap.edu/catalog.php?record_id=12845 (last accessed September 10, 2010).

[13] American Transportation Research Institute, *An Analysis of the Operational Costs of Trucking*, September 2013.

[14] Transport Canada, Operating Cost of Trucks, 2005. See http://www.tc.gc.ca/eng/policy/report-acg-operatingcost2005-2005-e-2-1727.htm, accessed on July 16, 2010.

[15] American Transportation Research Institute (ATRI). “An Analysis of the Operational Costs of Trucking: 2015 Update.” Page 17. September 2015.
[16] These factors are discussed more fully in a report to EPA from EERA, which illustrates in a series of diagrams the complex system of decisions and decision-makers that could influence the magnitude and timing of the rebound effect. See Sections 2.2.2, 2.2.3, 2.2.4, and 2.3 in EERA (2014), “Research to Inform Analysis of the Heavy-Duty Vehicle Rebound Effect,” Excerpts of Draft Final Report of Phase 1 under EPA contract EP-C-13-025.
[17] See Chapter 8, Section 3.2 of the “Draft Regulatory Impact Analysis” for the proposal, accessible at http://www3.epa.gov/otaq/climate/regs-heavy-duty.htm (Last Accessed: March 11, 2016).
[18] See Chapter 8, Section 3.2 of the “Draft Regulatory Impact Analysis” for the proposal, accessible at http://www3.epa.gov/otaq/climate/regs-heavy-duty.htm (Last Accessed: March 11, 2016).
[19] EERA (2014), “Research to Inform Analysis of the Heavy-Duty vehicle Rebound Effect,” Excerpts of Draft Final Report of Phase 1 under EPA contract EP-C-13-025.
[20] EERA (2015), “Working Paper on Fuel Price Elasticities for Heavy Duty Vehicles,” Draft Final Report of Phase 2 under EPA contract EP-C-11-046.
[21] Winebrake, J.J., et al., *Fuel price elasticities in the U.S. combination trucking sector.* Transportation Research Part D: Transport and Environment, 2015. 38: p. 166-177.
[22] Leard, B., et al., *Fuel Costs, Economic Activity, and the Rebound Effect for Heavy-Duty Trucks*. September 2015, Resources for the Future: RF DP 15-43, Washington, DC. EPA-HQ-OAR-2014- 0827-1200-A1.
[23] American Transportation Research Institute. An Analysis of the Operational Costs of Trucking: A 2015 Update. Page 17. September 2015.
[24] The new vocational vehicle cost assumed in the VMT rebound analysis is $100,000 based on the average of the vocational vehicle prices listed in the ICF cost report, July 2010, pages 16-17. The combination tractor-trailer costs are $100,000 based on the average price of day cabs and sleeper cabs and $25,000 for each of the three trailers (assumed a trailer-to-tractor ratio of 3:1) as listed in the ICF cost report pages 3 and 16. EPA-HQ-OAR-2010-0162-0044.
[25] U.S. EPA. Motor Vehicle Emission Simulator (MOVES2014a). Last accessed on March 15, 2016 at http://www3.epa.gov/otaq/models/moves/.
[26] U.S. EPA and NHTSA. Draft Regulatory Impact Analysis: Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2. EPA-420-D-15-002. June 2015. Technology package costs for Alternatives 1b, 2, 3, and 4 from Tables 11-21 and 11-22 on pages 11-27 and 11-28.
[27] 80 FR July 13, 2015 at 40494-40495.
[28] U.S. Energy Information Administration. Annual Energy Outlook 2015. Table 12: Petroleum Product Prices.
[29] U.S. EPA and NHTSA. Draft Regulatory Impact Analysis: Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2. EPA-420-D-15-002. June 2015. Technology package effectiveness as discussed in Chapter 11.4, pages 11-73 through 11-85.
[30] Memo from Energy and Environmental Research Associates, LLC Regarding HDV Rebound Effect, dated June 8, 2011.
[31] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council; Transportation Research Board (2010). “Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles,” Washington, D.C., The National Academies Press. Available electronically from the National Academies Press Website at http://www.nap.edu/catalog.php?record_id=12845, page 152.
[32] A baseline tractor price of a new day cab is $89,500 versus $113,000 for a new sleeper cab based on information gathered by ICF in the “Investigation of Costs for Strategies to Reduce Greenhouse Gas Emissions for Heavy-Duty On-Road Vehicles,” July 2010. Page 3. Docket Identification Number EPA-HQ-OAR-2010-0162-0044.
[33] *See* NAS 2010 Report, pp. 150-151, EPA-HQ-OAR-2014-0827-0276.
[34] *See* NAS 2010 Report, page 151, Docket EPA-HQ-OAR-2014-0827-0276.
[35] Source: Table 2.14 (Errata). Lifetimes, radiative efficiencies and direct (except for CH_4) GWPs relative to CO_2. IPCC Fourth Assessment Report "Climate Change 2007: Working Group I: The Physical Science Basis."
[36] West JJ, Fiore AM, Horowitz LW, Mauzerall DL (2006) Global health benefits of mitigating ozone pollution with methane emission controls. Proc Natl Acad Sci USA 103 (11):3988-3993. doi:10.1073/pnas.0600201103
[37] Anenberg, S., Schwartz, J., Shindell, D., Amann, M., Faluvegi, G., Klimont, Z., Vignati, E., (2012) Global air quality and health co-benefits of mitigating near-term climate change through methane and black carbon emission controls. Environ Health Perspect 120 (6):831. doi:10.1289/ehp.1104301.
[38] Shindell, D., Kuylenstierna, JCI., Vignati, E., van Dingenen, R., Amann, M., Klimont, Z., Fowler D (2012) Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security. Science 335 (6065):183-189. doi:10.1126/science.1210026.

[39] Sarofim, M.C., Waldhoff, S.T., Anenberg, S.C., 2015. “Valuing the Ozone-Related Health Benefits of Methane Emission Controls,” Environ. Resource Econ. DOI 10.1007/s10640-015-9937-6.

[40] Fann, N., Baker, K.R., and Fulcher, C.M. (2012). Characterizing the PM2.5-related health benefits of emission reductions for 17 industrial, area and mobile emission sectors across the U.S., Environment International, 49, 241-151, published online September 28, 2012.

[41] U.S. Environmental Protection Agency. (2014). *Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards Final Rule: Regulatory Impact Analysis*, Assessment and Standards Division, Office of Transportation and Air Quality, EPA-420-R-14-005, March 2014. Available on the internet: http://www3.epa.gov/otaq/documents/tier3/420r14005.pdf.

[42] U.S. Environmental Protection Agency. (2012). *Regulatory Impact Analysis for the Final Revisions to the National Ambient Air Quality Standards for Particulate Matter*, Health and Environmental Impacts Division, Office of Air Quality Planning and Standards, EPA-452-R-12-005, December 2012. Available on the internet: http://www3.epa.gov/ttnecas1/regdata/RIAs/finalria.pdf.

[43] U.S. Environmental Protection Agency (U.S. EPA). (2012). *Regulatory Impact Analysis: Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards*, Assessment and Standards Division, Office of Transportation and Air Quality, EPA-420-R-12-016, August 2012. Available on the Internet at: http://www3.epa.gov/otaq/climate/documents/420r12016.pdf.

[44] U.S. Environmental Protection Agency (U.S. EPA). (2012*). Regulatory Impact Analysis: Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards*, Assessment and Standards Division, Office of Transportation and Air Quality, EPA-420-R-12-016, August 2012. Available on the Internet at: http://www3.epa.gov/otaq/climate/documents/420r12016.pdf.

[45] U.S. Environmental Protection Agency (U.S. EPA). (2013). *Regulatory Impact Analysis for the Reconsideration of the Existing Stationary Compression Ignition (CI) Engines NESHAP*, Office of Air Quality Planning and Standards, Research Triangle Park, NC. January. EPA-452/R-13-001. Available at http://www3.epa.gov/ttnecas1/regdata/RIAs/RICE_NESHAPreconsideration_Compression_Ignition_Engines_RIA_final2013_EPA.pdf.

[46] U.S. Environmental Protection Agency (U.S. EPA). (2013). *Regulatory Impact Analysis for Reconsideration of Existing Stationary Spark Ignition (SI) RICE NESHAP*, Office of Air Quality Planning and Standards, Research Triangle Park, NC. January. EPA-452/R-13-002. Available at http://www3.epa.gov/ttnecas1/regdata/RIAs/NESHAP_RICE_Spark_Ignition_RIA_finalreconsideration2013_EPA.pdf.

[47] U.S. Environmental Protection Agency (U.S. EPA). (2015). *Regulatory Impact Analysis for Residential Wood Heaters NSPS Revision*. Office of Air Quality Planning and Standards, Research Triangle Park, NC. February. EPA-452/R-15-001. Available at http://www2.epa.gov/sites/production/files/2015-02/documents/20150204-residential-wood-heaters-ria.pdf.

[48] U.S. Environmental Protection Agency. (2012). *Regulatory Impact Analysis for the Final Revisions to the National Ambient Air Quality Standards for Particulate Matter*, Health and Environmental Impacts Division, Office of Air Quality Planning and Standards, EPA-452-R-12-005, December 2012. Available on the internet: http://www3.epa.gov/ttnecas1/regdata/RIAs/finalria.pdf.

[49] Fann, N., Baker, K.R., and Fulcher, C.M. (2012). *Characterizing the PM2.5-related health benefits of emission reductions for 17 industrial, area and mobile emission sectors across the U.S.*, Environment International, 49, 241-151, Published online September 28, 2012.

[50] Fann, N., Baker, K.R., and Fulcher, C.M. (2012). *Characterizing the PM2.5-related health benefits of emission reductions for 17 industrial, area and mobile emission sectors across the U.S.*, Environment International, 49, 241-151, Published online September 28, 2012.

[51] U.S. Environmental Protection Agency (U.S. EPA). (2009). Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment—RTP Division. December. Available at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.

[52] U.S. Environmental Protection Agency. (2012). *Regulatory Impact Analysis for the Final Revisions to the National Ambient Air Quality Standards for Particulate Matter*, Health and Environmental Impacts Division, Office of Air Quality Planning and Standards, EPA-452-R-12-005, December 2012. Available on the internet: http://www3.epa.gov/ttnecas1/regdata/RIAs/finalria.pdf.

[53] Science Advisory Board. 2001. NATA – Evaluating the National-Scale Air Toxics Assessment for 1996 – an SAB Advisory. http://www3.epa.gov/ttn/atw/sab/sabrev.html.

[54] U.S. Environmental Protection Agency (U.S. EPA). 2011. *The Benefits and Costs of the Clean Air Act from 1990 to 2020*. Office of Air and Radiation, Washington, DC. March. Available on the Internet at <http://www3.epa.gov/air/sect812/feb11/fullreport.pdf>.

[55] U.S. Environmental Protection Agency—Science Advisory Board (U.S. EPA-SAB). 2008. *Benefits of Reducing Benzene Emissions in Houston, 1990–2020*. EPA-COUNCIL-08-001. July. Available at <http://yosemite.epa.gov/sab/sabproduct.nsf/D4D7EC9DAEDA8A548525748600728A83/$File/EPA-COUNCIL-08-001-unsigned.pdf>.

[56] These estimates were developed by FHWA for use in its 1997 *Federal Highway Cost Allocation Study*; *see* http://www.fhwa.dot.gov/policy/hcas/final/index.htm (last accessed July 21, 2010).

[57] *See* Federal Highway Administration, 1997 *Federal Highway Cost Allocation Study*, http://www.fhwa.dot.gov/policy/hcas/final/index.htm, Tables V-22, V-23, and V-24 (last accessed July 8, 2012).

[58] Passenger vehicle fuel dispensing rate per EPA regulations, last viewed on August 4, 2010 at *http://www3.epa.gov/oms/regs/ld-hwy/evap/spitback.txt.*

[59] Survey data results on refueling times for light-duty trucks derived from "Evaluation of the Effectiveness of TPMS in Proper Tire Pressure Maintenance," November 2012. Report No. DOT HS 811 681. http://www-nrd.nhtsa.dot.gov/Pubs/811681.pdf.

[60] U.S. Department of Transportation, Valuation of Travel Guidance, July 9, 2014, at page 14.

[61] Based on data from the CIA, combining various recent years, https://www.cia.gov/library/publications/the-world-factbook/rankorder/2242rank.html.

[62] See EIA Annual Energy Review, various editions. For data 2011-2013, and projected data: EIA Annual Energy Outlook (AEO) 2014 (Reference Case). See Table 11, file "aeotab_11.xls."

[63] For historical data: EIA Annual Energy Review, various editions. For data 2011-2013, and projected data: EIA Annual Energy Outlook (AEO) 2014 (Reference Case). See Table 11, file "aeotab_11.xls."

[64] Leiby, Paul N., Donald W. Jones, T. Randall Curlee, and Russell Lee, *Oil Imports: An Assessment of Benefits and Costs*, ORNL-6851, Oak Ridge National Laboratory, November, 1997.

[65] Peer Review Report Summary: Estimating the Energy Security Benefits of Reduced U.S. Oil Imports, ICF, Inc., September 2007.

[66] Leiby, P., Factors Influencing Estimate of Energy Security Premium for Heavy-Duty Phase II Final Rule**,** 11/18/2014, Oak Ridge National Laboratory.

[67] Brown, Stephen P.A. and Hillard G. Huntington. 2013. Assessing the U.S. Oil Security Premium, Energy Economics, vol. 38, pp 118-127.

[68] Reassessing the Oil Security Premium. RFF Discussion Paper Series, (RFF DP 10-05). doi: RFF DP 10-05

[69] Greene, D. L. 2010. Measuring energy security: Can the United States achieve oil independence? Energy Policy, 38(4), 1614–1621. doi:10.1016/j.enpol.2009.01.041.

[70] Reassessing the Oil Security Premium. RFF Discussion Paper Series, (RFF DP 10-05). doi:RFF DP 10-05

[71] Ledyard, John O. "Market Failure." The New Palgrave Dictionary of Economics. Second Edition. Eds. Steven N. Durlauf and Lawrence E. Blume. Palgrave Macmillan, 2008.

[72] Council on Foreign Relations, "Automobile Fuel Economy Standards in a Lower-Oil-Price World," Sivarm & Levi, November 2015.

[73] Transitions to Alternative Vehicles and Fuels," Committee on Transitions to Alternative Vehicles and Fuels, National Research Council, 2013.

[74] Gately, Dermot 2004. "OPEC's Incentives for Faster Output Growth," The Energy Journal,25(2):75-96; Gately, Dermot 2007. "What Oil Export Levels Should We Expect From OPEC?," The Energy Journal, 28(2):151-173.

[75] Fatih Birol, Executive Director of the International Energy Agency, warns that prolonged lower oil prices would trigger energy-security concerns by increasing reliance on a small number of low-cost producers "or risk a sharp rebound in price if investment falls short." "It would be a grave mistake to index our attention to energy security to changes in the oil price," Birol said. "Now is not the time to relax. Quite the opposite: a period of low oil prices is the moment to reinforce our capacity to deal with future energy security threats." Hussain, Y. (2015). "Grave mistake" to be complacent on energy security, International Energy Agency warns. *Financial Post*, (November 10). Retrieved from http://business.financialpost.com/news/energy/grave-mistake-to-be-complacent-on-energy-security-international-energy-agency-warns.

[76] Batovic, A. (2015). Low oil prices fuel political and economic instability. *Global Risk Insights*, 18–19. Retrieved from http://globalriskinsights.com/2015/09/low-oil-prices-fuel-political-and-economic-instability/.

[77] Monaldi, F. (2015). The Impact of the Decline in Oil Prices on the Economics, Politics and Oil Industry of Venezuela. *Columbia Center on Global Energy Policy Discussion Papers*, (September). Retrieved from

http://energypolicy.columbia.edu/sites/default/files/energy/Impact of the Decline in Oil Prices on Venezuela**,** September 2015.pdf.

[78] Even, S., & Guzansky, Y. (2015). Falling oil prices and Saudi stability - Opinion. *Jerusalem Post*, (September 30). Retrieved from http://www.jpost.com/Opinion/Falling-oil-prices-and-Saudi-stability-419534.

[79] International Monetary Fund (IMF). (2015). *IMF Regional Economic Outlook - Middle East and Central Asia*. *Regional Economic Outlook* (Vol. 33). Tomkiw, L. (2015). Oil Rich Saudi Arabia Running Out Of Assets? IMF Report Says It's Possible In Next 5 Years. *International Business Times*, *October 21*, 19–22. Retrieved from http://www.ibtimes.com/oil-rich-saudi-arabia-running-out-assets-imf-report-says-its-possible-next-5-years-215017.

[80] Bohi, Douglas R. And W. David Montgomery 1982. "Social Cost of Imported and U.S. Import Policy," Annual Review of Energy, 7:37-60. Energy Modeling Forum, 1981. World Oil, EMF Report 6 (Stanford University Press: Stanford 39 CA. https//emf.stanford.edu/publications/emf-6-world-oil.

[81] Plummer, James L. (Ed.) 1982. Energy Vulnerability, "Basic Concepts, Assumptions and Numerical Results," pp. 13-36, (Cambridge MA: Ballinger Publishing Co.).

[82] Bohi, Douglas R. And W. David Montgomery 1982 "Social Cost of Imported and U.S. Import Policy," Annual Review of Energy, 7:37-60.

[83] Hogan, William W., 1981. "Import Management and Oil Emergencies," Chapter 9 in Deese, 5 David and Joseph Nye, eds. Energy and Security. Cambridge, MA: Ballinger Publishing Co.

[84] Broadman, H. G. 1986. "The Social Cost of Imported Oil," Energy Policy 14(3):242-252. Broadman H.G. and W.W. Hogan, 1988. "Is an Oil Import Tariff Justified? An American Debate: The Numbers Say 'Yes' ," The Energy Journal 9: 7-29.

[85] Leiby, Paul N., Donald W. Jones, T. Randall Curlee, and Russell Lee, Oil Imports: An Assessment of Benefits and Costs, ORNL-6851, Oak Ridge National Laboratory, November 1, 1997.

[86] Parry, Ian W.H. and Joel Darmstadter 2004. "The Costs of U.S. Oil Dependency," Resources for the Future, November 17, 2004 (also published as NCEP Technical Appendix Chapter 1: Enhancing Oil Security, the National Commission on Energy Policy 2004 Ending the Energy Stalemate - A Bipartisan Strategy to Meet America's Energy Challenges).

[87] National Research Council, 2009. Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use. National Academy of Science, Washington, DC.

[88] See, William Nordhaus, "Who's Afraid of a Big Bad Oil Shock?," available at http://aida.econ.yale.edu/~nordhaus/homepage/Big_Bad_Oil_Shock_Meeting.pdf , and Olivier Blanchard and Jordi Gali, "The macroeconomic Effects of Oil price Shocks: Why are the 2000s so different from the 1970s?," pp. 373-421, in The International Dimensions of Monetary Policy, Jordi Gali and Mark Gertler, editors, University of Chicago Press, February 2010, available at http://www.nber.org/chapters/c0517.pdf

[89] In fact, "… energy-price changes have no effect on multifactor productivity and very little effect on labor productivity." Page 19. He calculates the productivity effect of a doubling of oil prices as a decrease of 0.11 percent for one year and 0.04 percent a year for ten years. Page 5. (The doubling reflects the historical experience of the post-war shocks, as described in Table 7.1 in Blanchard and Gali, p. 380).

[90] Blanchard and Gali, p. 414.

[91] See, Oil price Drops on Oversupply, http://www.oil-price.net/en/articles/oil-price-drops-on-oversupply.php, 10/6/2014.

[92] Hamilton, J. D., 2012, Oil Prices, Exhaustible Resources, and Economic Growth. In Handbook of Energy and Climate Change. Retrieved from http://econweb.ucsd.edu/~jhamilto/handbook_climate.pdf [EPA-HQ-OAR-2014-0827-0577].

[93] Ramey, V. A., & Vine, D. J. (2010). "Oil, Automobiles, and the U.S. Economy: How Much have Things Really Changed?," National Bureau of Economic Research Working Papers, WP 16067(June). Retrieved from http://www.nber.org/papers/w16067.pdf.

[94] Baumeister, C.; Peersman, G.; Van Robays, I., 2010, "The Economic Consequences of Oil Shocks: Differences across Countries and Time", Workshop and Conference on Inflation Challenges in the Era of Relative Price Shocks.

[95] Kilian, L.; Vigfusson, R.J., 2014,; "The Role of Oil Price Shocks in Causing U.S. Recessions", Board of Governors of the Federal Reserve System. International Finance Discussion Papers.

[96] Cashin, P.,; Mohaddes, K.,; Raissi, Maziar, and Raissi, M.,e2014, " The differential effects of oil demand and supply shocks on the global economy". Energy Economics.

[97] National Research Council, "Transitions to alternative vehicles and fuels," 2013.

[98] http://www.whitehouse.gov/sites/default/files/omb/inforeg/eo12866/eo13563_01182011.pdf.

[99] U.S. Department of Labor, Bureau of Labor Statistics. "Automotive Industry; Employment, Earnings, and Hours," http://www.bls.gov/iag/tgs/iagauto.htm , accessed 8/18/14.
[100] Layard, P.R.G., and A. A. Walters (1978), Microeconomic Theory (McGraw-Hill, Inc.), Chapter 9 (Docket EPA-HQ-OAR-2014-0827-0070).
[101] Berman, E. and L. T. M. Bui (2001). "Environmental Regulation and Labor Demand: Evidence from the South Coast Air Basin." Journal of Public Economics 79(2): 265-295 (Docket EPA-HQ-OAR-2014-0827-0074).
[102] Ehrenberg, Ronald G., and Robert S. Smith (2000), Modern Labor Economics: Theory and Public Policy (Addison Wesley Longman, Inc.), p. 108, Docket EPA-HQ-OAR-2014-0827-0077.
[103] This discussion draws from Berman, E. and L. T. M. Bui (2001). "Environmental Regulation and Labor Demand: Evidence from the South Coast Air Basin." Journal of Public Economics 79(2): 265-295 (Docket EPA-HQ-OAR-2014-0827-0074), p. 293.
[104] Arrow et al. (1996). "Benefit-Cost Analysis in Environmental, Health, and Safety Regulation: A Statement of Principles." American Enterprise Institute, The Annapolis Center, and Resources for the Future, Docket EPA-HQ-OAR-2014-0827-0073. See discussion on bottom of p. 6. In practice, distributional impacts on individual workers can be important, as discussed later in this section.
[105] Schmalensee, Richard, and Robert N. Stavins. "A Guide to Economic and Policy Analysis of EPA's Transport Rule." White paper commissioned by Excelon Corporation, March 2011, Docket EPA-HQ-OAR-2014-0827-0071.
[106] Klaiber, H. Allen, and V. Kerry Smith (2012). "Developing General Equilibrium Benefit Analyses for Social Programs: An Introduction and Example." Journal of Benefit-Cost Analysis 3(2), Docket EPA-HQ-OAR-2014-0827-0085.
[107] Graff Zivin, J., and M. Neidell (2012). "The Impact of Pollution on Worker Productivity." American Economic Review 102: 3652-3673), Docket EPA-HQ-OAR-2014-0827-0092.
[108] Hamermesh (1993), Labor Demand (Princeton, NJ: Princeton University Press), Chapter 2 (Docket EPA-HQ-OAR-2011-0135), Docket EPA-HQ-OAR-2014-0827-0082.
[109] Ehrenberg, Ronald G., and Robert S. Smith (2000), Modern Labor Economics: Theory and Public Policy (Addison Wesley Longman, Inc.), Chapter 4, Docket EPA-HQ-OAR-2014-0827-0077.
[110] Berman, E. and L. T. M. Bui (2001). "Environmental Regulation and Labor Demand: Evidence from the South Coast Air Basin." Journal of Public Economics 79(2): 265-295 (Docket EPA-HQ-OAR-2014-0827-0074).
[111] Morgenstern, Richard D., William A. Pizer, and Jhih-Shyang Shih. "Jobs Versus the Environment: An Industry-Level Perspective." Journal of Environmental Economics and Management 43 (2002): 412-436 (Docket EPA-HQ-OAR-2014-0827-0088).
[112] Gray, Wayne B., Ronald J. Shadbegian, Chunbei Wang, and Merve Meral. "Do EPA Regulations Affect Labor Demand? Evidence from the Pulp and Paper Industry." Journal of Environmental Economics and Management: 68, 2014, 188-202, Docket EPA-HQ-OAR-2014-0827-0080.
[113] Ferris, Ann, Ronald J. Shadbegian and Ann Wolverton. "The Effect of Environmental Regulation on Power Sector Employment: Phase I of the Title IV SO2 Trading Program." Journal of the Association of Environmental and Resource Economists. (Forthcoming 2014), Docket EPA-HQ-OAR-2014-0827-0078.
[114] Greenstone, M. (2002). "The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments and the Census of Manufactures," Journal of Political Economy 110(6): 1175-1219 (Docket EPA-HQ-OAR- 2014-0827-0081); Walker, Reed. (2011)."Environmental Regulation and Labor Reallocation." American Economic Review: Papers and Proceedings 101(3): 442-447 (Docket EPA-HQ-OAR-2014-0827-0091).
[115] List, J. A., D. L. Millimet, P. G. Fredriksson, and W. W. McHone (2003). "Effects of Environmental Regulations on Manufacturing Plant Births: Evidence from a Propensity Score Matching Estimator." The Review of Economics and Statistics 85(4): 944-952 (Docket EPA-HQ-OAR- 2014-0827-0087).
[116] Berman, E. and L. T. M. Bui (2001). "Environmental Regulation and Labor Demand: Evidence from the South Coast Air Basin." *Journal of Public Economics 79*(2): 265-295 (Docket EPA-HQ-OAR-0827-0074).
[117] http://www.bls.gov/emp/ep_data_emp_requirements.htm; see "HD Substitution Effect Employment Impacts,"Docket EPA-HQ-OAR-2014-0827.
[118] http://www.census.gov/manufacturing/asm/index.html; see "HD Substitution Effect Employment Impacts,"Docket EPA-HQ-OAR-2014-0827.
[119] http://www.bls.gov/emp/ep_data_emp_requirements.htm; see "HD Substitution Effect Employment Impacts,"Docket EPA-HQ-OAR-2014-0827. This analysis used data for sectors 80 (Motor Vehicle Manufacturing), 81 (Motor Vehicle Body and Trailer Manufacturing), and 82 (Motor Vehicle Parts Manufacturing) from "Chain-weighted (2009 dollars) real domestic employment requirements tables."

[120] American Transportation Research Institute, “An Analysis of the Operational Costs of Trucking: 2011 Update.” *See* http://www.atri-online.org/research/results/Op_Costs_2011_Update_one_page_summary.pdf, Docket EPA-HQ-OAR-2014-0827-0512.

[121] Association of American Railroads, “All Inclusive Index and Rail Adjustment Factor.” June 3, 2011. *See* http://www.aar.org/~/media/aar/RailCostIndexes/AAR-RCAF-2011-Q3.ashx, Docket EPA-HQ-OAR-2014-0827-0065.

[122] Krewski, D., M. Jerret, R.T. Burnett, R. Ma, E. Hughes, Y. Shi, et al. (2009). Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. *HEI Research Report, 140,* Health Effects Institute, Boston, MA.

[123] Smith, R.L.; B. Xu and P. Switzer. 2009. Reassessing the relationship between ozone and short- term mortality in U.S. urban communities. Inhalation Toxicology. 21:37-61.

[124] Lepeule J, Laden F, Dockery D, Schwartz J (2012). *Chronic Exposure to Fine Particles and Mortality: An Extended Follow-Up of the Harvard Six Cities Study from 1974 to 2009*. Environ Health Perspect. Jul;120(7):965-70.

[125] Zanobetti, A; J. Schwartz. 2008. Mortality displacement in the association of ozone with mortality: an analysis of 48 cities in the United States. American Journal of Respiratory and Critical Care Medicine. 177:184-189.

[126] U.S. Environmental Protection Agency. (2012). *Regulatory Impact Analysis for the Final Revisions to the National Ambient Air Quality Standards for Particulate Matter*. Prepared by: Office of Air and Radiation, Office of Air Quality Planning and Standards. Retrieved April 27, 2016 at http://www3.epa.gov/ttn/ecas/ria.html. EPA-452/R-12-005

[127] U.S. Environmental Protection Agency. (2015). *Regulatory Impact Analysis of the Final Revisions to the National Ambient Air Quality Standards for Ground-Level Ozone*. Prepared by: Office of Air and Radiation, Office of Air Quality Planning and Standards. Retrieved April 27, 2016 at http://www3.epa.gov/ttn/ecas/ria.html. EPA-452/R-15-007.

[128] U.S. Environmental Protection Agency. (2012). *Regulatory Impact Analysis for the Final Revisions to the National Ambient Air Quality Standards for Particulate Matter*. Prepared by: Office of Air and Radiation, Office of Air Quality Planning and Standards. Retrieved April 27, 2016 at http://www3.epa.gov/ttn/ecas/ria.html. EPA-452/R-12-005.

[129] U.S. EPA. 2009 Final Report: Integrated Science Assessment for Particulate Matter. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009.

[130] U.S. Environmental Protection Agency. (2015). *Regulatory Impact Analysis of the Final Revisions to the National Ambient Air Quality Standards for Ground-Level Ozone*. Prepared by: Office of Air and Radiation, Office of Air Quality Planning and Standards. Retrieved April 27, 2016 at http://www3.epa.gov/ttn/ecas/ria.html. EPA-452/R-15-007.

[131] U.S. EPA. 2013 Final Report: Integrated Science Assessment of Ozone and Related Photochemical Oxidants. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-10/076F, 2013.

[132] U.S. Environmental Protection Agency (2016). Integrated Risk Information System. https://www3.epa.gov/iris

[133] Science Advisory Board. 2001. NATA – Evaluating the National-Scale Air Toxics Assessment for 1996 – an SAB Advisory. http://www3.epa.gov/ttn/atw/sab/sabrev.html.

[134] U.S. Environmental Protection Agency (U.S. EPA). 2011. *The Benefits and Costs of the Clean Air Act from 1990 to 2020*. Office of Air and Radiation, Washington, DC. March. Available on the Internet at <http://www3.epa.gov/air/sect812/feb11/fullreport.pdf>.

[135] U.S. Environmental Protection Agency—Science Advisory Board (U.S. EPA-SAB). 2008. *Benefits of Reducing Benzene Emissions in Houston, 1990–2020*. EPA-COUNCIL-08-001. July. Available at <http://yosemite.epa.gov/sab/sabproduct.nsf/D4D7EC9DAEDA8A548525748600728A83/$File/EPA-COUNCIL-08-001-unsigned.pdf>.

[136] U.S. Environmental Protection Agency. (2012). Regulatory Impact Analysis for the Final Revisions to the National Ambient Air Quality Standards for Particulate Matter. Prepared by: Office of Air and Radiation, EPA-452/R-12-005. Retrieved August 14, 2013 at http://www3.epa.gov/ttn/ecas/ria.html.

[137] Woodruff, T.J., J. Grillo, and K.C. Schoendorf. (1997). The Relationship Between Selected Causes of Postneonatal Infant Mortality and Particulate Air Pollution in the United States. *Environmental Health Perspectives* 105(6):608-612.

[138] Levy JI, Baxter LK, Schwartz J. 2009. “Uncertainty and variability in health-related damages from coal-fired power plants in the United States.” Risk Anal. 29(7) 1000-1014.

[139] Fann N, Roman HR, Fulcher CF, Gentile M, Wesson K, Hubbell BJ, Levy JI. 2012. “Maximizing Health Benefits and Minimizing Inequality: Incorporating Local Scale Data in the Design and Evaluation of Air Quality Policies.” Risk Analysis. 32(6): 908—922.
[140] Tagaris E, Liao KJ, Delucia AJ, et al. 2009. “Potential impact of climate change on air-pollution related human health effects.” Environ. Sci. Technol. 43: 4979–4988.
[141] Kunzli, N., R. Kaiser, S. Medina, M. Studnicka, O. Chanel, P. Filliger, M. Herry, F. Horak Jr., V. Puybonnieux-Texier, P. Quenel, J. Schneider, R. Seethaler, J-C Vergnaud, and H. Sommer. 2000. “Public-Health Impact of Outdoor and Traffic-Related Air Pollution: A European Assessment.” The Lancet 356:795-801.
[142] Levy JI, Baxter LK, Schwartz J. 2009. “Uncertainty and variability in health-related damages from coal-fired power plants in the United States.” Risk Anal. 29(7) 1000-1014.
[143] Abt Associates, Inc. 2010. Environmental Benefits and Mapping Program (Version 4.0). Bethesda, MD. Prepared for U.S. Environmental Protection Agency Office of Air Quality Planning and Standards. Research Triangle Park, NC. Available on the Internet at <http://www3.epa.gov/air/benmap>.
[144] Hubbell, B., A. Hallberg, D.R. McCubbin, and E. Post. 2005. “Health-Related Benefits of Attaining the 8-Hr Ozone Standard.” Environmental Health Perspectives 113:73–82. ICD, 1979.
[145] Tagaris E, Liao KJ, Delucia AJ, et al. 2009. “Potential impact of climate change on air-pollution related human health effects.” Environ. Sci. Technol. 43: 4979–4988.
[146] Fann N, Roman HR, Fulcher CF, Gentile M, Wesson K, Hubbell BJ, Levy JI. 2012. “Maximizing Health Benefits and Minimizing Inequality: Incorporating Local Scale Data in the Design and Evaluation of Air Quality Policies.” Risk Analysis. 32(6): 908—922.
[147] U.S. Environmental Protection Agency (U.S. EPA). 2011. Regulatory Impact Analysis for the Final Mercury and Air Toxics Standards. EPA-452/R-11-011. December. Available on the Internet at <http://www3.epa.gov/ttn/ecas/regdata/RIAs/matsriafinal.pdf>.
[148] Woods & Poole Economics Inc. 2012. Population by Single Year of Age. CD-ROM. Woods & Poole Economics, Inc. Washington, D.C.
[149] Hollman, F.W., T.J. Mulder, and J.E. Kallan. 2000. Methodology and Assumptions for the Population Projections of the United States: 1999 to 2100. Population Division Working Paper No. 38, Population Projections Branch, Population Division, U.S. Census Bureau, Department of Commerce. January. Available on the Internet at <http://www.census.gov/population/www/documentation/twps0038/twps0038.html>.
[150] U.S. Bureau of Economic Analysis (U.S. BEA). 2004. BEA Economic Areas (EAs). U.S. Department of Commerce. Available on the Internet at <http://www.bea.gov/regional/docs/econlist.cfm>.
[151] U.S. Environmental Protection Agency (U.S. EPA). 2011. The Benefits and Costs of the Clean Air Act 1990 to 2020: EPA Report to Congress. Office of Air and Radiation, Office of Policy, Washington, DC. March. Available on the Internet at <http://www3.epa.gov/oar/sect812/feb11/fullreport.pdf>.
[152] U.S. Environmental Protection Agency (U.S. EPA). 2013. Integrated Science Assessment for Ozone and Related Photochemical Oxidants: Final. Research Triangle Park, NC: U.S. Environmental Protection Agency. (EPA document number EPA/600/R-10/076F).
[153] U.S. Environmental Protection Agency (U.S. EPA). 2009. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment—RTP Division. December. Available on the Internet at <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.
[154] U.S. Environmental Protection Agency (U.S. EPA). 2012. Provisional Assessment of Recent Studies on Health Effects of Particulate Matter Exposure. EPA/600/R-12/056A. National Center for Environmental Assessment—RTP Division. December.
[155] Abt Associates, Inc. 2012. BenMAP User’s Manual Appendices. Prepared for U.S. Environmental Protection Agency Office of Air Quality Planning and Standards. Research Triangle Park, NC. September. Available on the Internet at <http://www3.epa.gov/air/benmap/models/BenMAPAppendicesOct2012.pdf>.
[156] Krewski D, Jerrett M, Burnett RT, Ma R, Hughes E, Shi, Y, et al. 2009. Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. HEI Research Report, 140, Health Effects Institute, Boston, MA.
[157] Lepeule J, Laden F, Dockery D, Schwartz J. 2012. “Chronic Exposure to Fine Particles and Mortality: An Extended Follow-Up of the Harvard Six Cities Study from 1974 to 2009.” Environmental Health Perspectives 120 (7):965-70.
[158] Woodruff, T.J., J. Grillo, and K.C. Schoendorf. 1997. “The Relationship Between Selected of postneonatal infant mortality and particulate air pollution in the United States.” Environmental Health Perspectives 105(6): 608-612.
[159] Peters, A., D. W. Dockery, J. E. Muller and M. A. Mittleman. 2001. “Increased particulate air pollution and the triggering of myocardial infarction.” Circulation 103 (23): 2810-5.

[160] Pope, C. A., III, J. B. Muhlestein, et al. 2006. "Ischemic heart disease events triggered by short-term exposure to fine particulate air pollution." Circulation 114(23): 2443-8.
[161] Sullivan, J., L. Sheppard, et al. 2005. "Relation between short-term fine-particulate matter exposure and onset of myocardial infarction." Epidemiology 16(1): 41-8.
[162] Zanobetti A. and Schwartz, J. 2006. "Air pollution and emergency admissions in Boston, MA." Journal of Epidemiology and Community Health 60(10): 890-5.
[163] Kloog, I., B.A. Coull, A. Zanobetti, P. Koutrakis, J.D. Schwartz. 2012. "Acute and Chronic Effects of Particles on Hospital Admissions in New England." PLoS ONE. Vol 7 (4): 1-8.
[164] Moolgavkar, S.H. 2000. "Air Pollution and Hospital Admissions for Diseases of the Circulatory System in Three U.S. Metropolitan Areas." Journal of the Air and Waste Management Association 50:1199-1206.
[165] Babin, S. M., H. S. Burkom, et al. 2007. "Pediatric Patient Asthma-related Emergency Department Visits and Admissions in Washington, DC, from 2001–2004, and Associations with Air Quality, Socio-economic Status and Age Group." Environmental Health 6: 9.
[166] Sheppard, L. 2003. "Ambient Air Pollution and Nonelderly Asthma Hospital Admissions in Seattle, Washington, 1987-1994." In Revised Analyses of Time-Series Studies of Air Pollution and Health. Special Report. Boston, MA: Health Effects Institute.
[167] Peng, R. D., M. L. Bell, et al. 2009. "Emergency admissions for cardiovascular and respiratory diseases and the chemical composition of fine particle air pollution." Environmental Health Perspectives 117(6): 957-63.
[168] Peng, R. D., H. H. Chang, et al. 2008. "Coarse particulate matter air pollution and hospital admissions for cardiovascular and respiratory diseases among Medicare patients." Journal of the American Medical Association 299(18): 2172-9.
[169] Bell ML; Ebisu K; Peng RD; Walker J; Samet JM; Zeger SL; Dominic F. 2008. Seasonal and regional short-term effects of fine particles on hospital admissions in 202 U.S. counties, 1999-2005. Am J Epidemiol, 168: 1301-1310.
[170] Moolgavkar, S.H. 2000. "Air Pollution and Hospital Admissions for Diseases of the Circulatory System in Three U.S. Metropolitan Areas." Journal of the Air and Waste Management Association 50:1199-1206.
[171] Mar, T. F., J. Q. Koenig and J. Primomo. 2010. "Associations between asthma emergency visits and particulate matter sources, including diesel emissions from stationary generators in Tacoma, Washington." Inhalation Toxicology 22 (6): 445-8.
[172] Slaughter, James C et al. 2005. "Association between particulate matter and emergency room visits, hospital admissions and mortality in Spokane, Washington." Journal of Exposure Analysis and Environmental Epidemiology 15, 153–159.
[173] Glad, J.A., L.L. Brink, E.O. Talbott, P.C. Lee, X. Xu, M. Saul, and J. Rager. 2012. "The Relationship of Ambient ozone and PM2.5 Levels and Asthma Emergency Department Visits: Possible Influence of Gender and Ethnicity." Archives of Environmental & Occupational Health 62 (2): 103-108.
[174] Dockery, D.W., J. Cunningham, A.I. Damokosh, L.M. Neas, J.D. Spengler, P. Koutrakis, J.H. Ware, M. Raizenne, and F.E. Speizer. 1996. "Health Effects of Acid Aerosols On North American Children-Respiratory Symptoms." Environmental Health Perspectives 104(5):500-505.
[175] Ostro, B., M. Lipsett, J. Mann, H. Braxton-Owens, and M. White. 2001. "Air Pollution and Exacerbation of Asthma in African-American Children in Los Angeles." Epidemiology 12(2):200–208.
[176] Mar, T. F., T. V. Larson, et al. 2004. "An analysis of the association between respiratory symptoms in subjects with asthma and daily air pollution in Spokane, Washington." Inhalation Toxicology 16(13): 809-15.
[177] Ostro, B.D. 1987. "Air Pollution and Morbidity Revisited: A Specification Test." Journal of Environmental Economics Management 14:87-98.
[178] Ostro, B.D. and S. Rothschild. 1989. "Air Pollution and Acute Respiratory Morbidity: An Observational Study of Multiple Pollutants." Environmental Research 50:238-247.
[179] Pope, C.A., III, D.W. Dockery, J.D. Spengler, and M.E. Raizenne. 1991. "Respiratory Health and PM10 Pollution: A Daily Time Series Analysis." American Review of Respiratory Diseases 144:668-674.
[180] Schwartz, J., and L.M. Neas. 2000. "Fine Particles are More Strongly Associated than Coarse Particles with Acute Respiratory Health Effects in Schoolchildren." Epidemiology 11:6-10.
[181] Smith, R.L.; B. Xu and P. Switzer. 2009. Reassessing the relationship between ozone and short- term mortality in U.S. u Zanobetti, A; J. Schwartz. 2008. Mortality displacement in the association of ozone with mortality: an analysis of 48 cities in the United States. American Journal of Respiratory and Critical Care Medicine. 177:184-189.rban communities. Inhalation Toxicology. 21:37-61.
[182] Zanobetti, A; J. Schwartz. 2008. Mortality displacement in the association of ozone with mortality: an analysis of 48 cities in the United States. American Journal of Respiratory and Critical Care Medicine. 177:184-189.

[183] Katsouyanni, K.; J.M. Samet; H.R. Anderson; R. Atkinson; A.L. Tertre; S. Medina, et al. 2009. Air Pollution and Health: A European and North American Approach (APHENA). Health Effects Institute.
[184] Glad, J.A., L.L. Brink, E.O. Talbott, P.C. Lee, X. Xu, M. Saul, and J. Rager. 2012. "The Relationship of Ambient ozone and PM2.5 Levels and Asthma Emergency Department Visits: Possible Influence of Gender and Ethnicity." Archives of Environmental & Occupational Health 62 (2): 103-108.
[185] Ito, K.; G.D. Thurston and R.A. Silverman. 2007. Characterization of PM2.5, gaseous pollutants, and meteorological interactions in the context of time-series health effects models. Journal of Exposure Science and Environmental Epidemiology. 17(S2):S45-60.
[186] Mar, TF; Koenig, JQ. 2009. Relationship between visits to emergency departments for asthma and ozone exposure in greater Seattle, Washington. Ann Allergy Asthma Immunol 103: 474-479.http://dx.doi.org/10.1016/S1081-1206(10)60263-3.
[187] Peel, J.L., P.E. Tolbert, M. Klein et al. 2005. Ambient air pollution and respiratory emergency department visits. Epidemiology. Vol. 16 (2): 164-74.
[188] Sarnat, J. A., Sarnat, S. E., Flanders, W. D., Chang, H. H., Mulholland, J., Baxter, L., Ozkaynak, H. 2013. Spatiotemporally resolved air exchange rate as a modifier of acute air pollution-related morbidity in Atlanta. J Expo Sci Environ Epidemiol. doi: 10.1038/jes.2013.32.
[189] Wilson, A.M., C.P. Wake, T. Kelly et al. 2005. Air pollution and weather, and respiratory emergency room visits in two northern New England cities: an ecological time-series study. Environ Res. Vol. 97 (3): 312-21.
[190] Mortimer, KM; Neas, LM; Dockery, DW; Redline, S; Tager, IB. 2002. The effect of air pollution on innercity children with asthma. Eur Respir J 19: 699-705.
[191] Schildcrout, J. S., Sheppard, L., Lumley, T., Slaughter, J. C., Koenig, J. Q., & Shapiro, G. G. (2006). Ambient air pollution and asthma exacerbations in children: an eight-city analysis. Am J Epidemiol, 164(6), 505-517.
[192] Chen L, Jennison BL, Yang W, and Omaye ST. 2000. "Elementary school absenteeism and air pollution." Inhalation Toxicology 12(11):997-1016.
[193] Gilliland FD, Berhane K, Rappaport EB, Thomas DC, Avol E, Gauderman WJ, et al. 2001. "The effects of ambient air pollution on school absenteeism due to respiratory illnesses." Epidemiology 12(1):43-54.
[194] Ostro, B.D. and S. Rothschild. 1989. "Air Pollution and Acute Respiratory Morbidity: An Observational Study of Multiple Pollutants." Environmental Research 50:238-247.
[195] U.S. Science Advisory Board. (2004). *Advisory Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis –Benefits and Costs of the Clean Air Act, 1990—2020.* EPA-SAB-COUNCIL-ADV-04-004. EPA-HQ-OAR-2009-0472-4664.
[196] National Research Council (NRC). (2002). *Estimating the Public Health Benefits of Proposed Air Pollution Regulations.* Washington, DC: The National Academies Press.
[197] Abt Associates, Inc. October 2005. *Methodology for County-level Mortality Rate Projections.* Memorandum to Bryan Hubbell and Zachary Pekar, U.S. EPA.
[198] American Lung Association (ALA). 2002. Trends in Asthma Morbidity and Mortality. American Lung Association, Best Practices and Program Services, Epidemiology and Statistics Unit. Available at <http://www.lungusa.org/data/asthma/ASTHMAdt.pdf>.
[199] Adams PF, Hendershot GE, Marano MA. 1999. "Current Estimates from the National Health Interview Survey, 1996." Vital and Health Statistics 10(200):1-212.
[200] U.S. Census Bureau. 2000. Component Assumptions of the Resident Population by Age, Sex, Race, and Hispanic Origin. Available online at: http://www.census.gov/population/www/projections/natdet-D5.html
[201] Agency for Healthcare Research and Quality (AHRQ). 2007. HCUPnet, Healthcare Cost and Utilization Project. Rockville, MD. Available at <http://hcupnet.ahrq.gov>.
[202] American Lung Association (ALA). 2010. Trends in Asthma Morbidity and Mortality. American Lung Association Epidemiology and Statistics Unit Research and Program Services Division. February. Table 7. Based on NHIS data (CDC, 2008). Available at http://www.lungusa.org/finding-cures/our-research/trend-reports/asthma-trend-report.pdf.
[203] Centers for Disease Control and Prevention (CDC). 2008. National Center for Health Statistics. National Health Interview Survey, 1999-2008.
[204] Freeman (III), AM. 1993. The Measurement of Environmental and Resource Values: Theory and Methods. Washington, DC: Resources for the Future.
[205] Harrington, W., and P.R. Portney. 1987. Valuing the Benefits of Health and Safety Regulation. Journal of Urban Economics 22:101-112.
[206] Berger, M.C., G.C. Blomquist, D. Kenkel, and G.S. Tolley. 1987. Valuing Changes in Health Risks: A Comparison of Alternative Measures. The Southern Economic Journal 53:977-984.

[207] U.S. Environmental Protection Agency. (2012). Regulatory Impact Analysis for the Final Revisions to the National Ambient Air Quality Standards for Particulate Matter. Prepared by: Office of Air and Radiation, Office of Air Quality Planning and Standards. Retrieved April 27, 2016 at http://www3.epa.gov/ttn/ecas/ria.html. EPA-452/R-12-005

[208] U.S. Environmental Protection Agency. (2015). Regulatory Impact Analysis of the Final Revisions to the National Ambient Air Quality Standards for Ground-Level Ozone. Prepared by: Office of Air and Radiation, Office of Air Quality Planning and Standards. Retrieved April 27, 2016 at http://www3.epa.gov/ttn/ecas/ria.html. EPA-452/R-15-007.

[209] U.S. Environmental Protection Agency (U.S. EPA). 2010. Guidelines for Preparing Economic Analyses. EPA 240-R-10-001. National Center for Environmental Economics, Office of Policy Economics and Innovation. Washington, DC. December. Available at <http://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0568-50.pdf/$file/EE-0568- 50.pdf>.

[210] Cropper, M. L. and A. J. Krupnick. 1990. The Social Costs of Chronic Heart and Lung Disease. Resources for the Future. Washington, DC. Discussion Paper QE 89-16-REV.

[211] Russell, M.W., D.M. Huse, S. Drowns, E.C. Hamel, and S.C. Hartz. 1998. "Direct Medical Costs of Coronary Artery Disease in the United States." American Journal of Cardiology 81(9):1110-1115.

[212] Wittels, E.H., J.W. Hay, and A.M. Gotto, Jr. 1990. "Medical Costs of Coronary Artery Disease in the United States." American Journal of Cardiology 65(7):432-440.

[213] Agency for Healthcare Research and Quality (AHRQ). 2007. HCUPnet, Healthcare Cost and Utilization Project. Rockville, MD. Available at <http://hcupnet.ahrq.gov>.

[214] Smith, D.H., D.C. Malone, K.A. Lawson, L.J. Okamoto, C. Battista, and W.B. Saunders. 1997. "A National Estimate of the Economic Costs of Asthma." American Journal of Respiratory and Critical Care Medicine 156(3 Pt 1):787-793.

[215] Stanford, R., T. McLaughlin and L. J. Okamoto. 1999. "The cost of asthma in the emergency department and hospital." American Journal of Respiratory and Critical Care Medicine 160 (1): 211-5.

[216] Rowe, R.D., and L.G. Chestnut. 1986. "Oxidants and Asthmatics in Los Angeles: A Benefits Analysis—Executive Summary." Prepared by Energy and Resource Consultants, Inc. Report to the U.S. Environmental Protection Agency, Office of Policy Analysis. EPA- 230-09-86-018. Washington, DC.

[217] GeoLytics Inc. 2002. GeoLytics CensusCD® 2000 Short Form Blocks. CD-ROM Release 1.0. GeoLytics, Inc. East Brunswick, NJ. Available: http://www.geolytics.com/ [accessed 29 September 2004].

[218] Tolley, G.S. et al. 1986. Valuation of Reductions in Human Health Symptoms and Risks. University of Chicago. Final Report for the U.S. Environmental Protection Agency, Office of Policy Analysis. January. Available at <http://yosemite.epa.gov/ee/epa/eerm.nsf/a7a2ee5c6158cedd852563970080ee30/eaa2842b3d2bc2798525644d0053bf48!OpenDocument#_Section6>.

[219] U.S. Environmental Protection Agency (U.S. EPA). 2015. BenMAP-CE User's Manual Appendices. Office of Air Quality Planning and Standards. Research Triangle Park, NC. Available at <http://www2.epa.gov/benmap/manual-and-appendices-benmap-ce>.

[220] U.S. EPA, (2001), "Guidance for Demonstrating Attainment of Air Quality Goals for PM2.5 and Regional Haze," http://www3.epa.gov/ttn/scram/guidance_sip.htm, Modeling Guidance, DRAFT-PM

[221] National Research Council (NRC). 2002. Estimating the Public Health Benefits of Proposed Air Pollution Regulations. Washington, DC: The National Academies Press.

[222] National Research Council (NRC). 2008. Estimating Mortality Risk Reduction and Economic Benefits from Controlling Ozone Air Pollution. National Academies Press. Washington, DC.

Chapter 9. Safety Impacts

9.1 Summary of Supporting HD Vehicle Safety Research

As discussed in the Notice of Proposed Rulemaking, NHTSA and EPA considered the potential safety impact of technologies that improve Medium- and Heavy-Duty vehicle fuel efficiency and GHG emissions when determining potential regulatory alternatives. The safety assessment of the technologies in this rule was informed by two comprehensive NAS reports, an extensive analysis of safety effects of HD pickups and vans using estimates from the DOT report on the effect of mass reduction and vehicle size on safety, and focused agency-sponsored safety testing and research. The following section provides a concise summary of the literature and work considered by the agencies in development of this final rule.

9.1.1 National Academy of Sciences HD Phase 1 and Phase 2 Reports

As required by EISA, the National Research Council has been conducting continuing studies of the technologies and approaches for reducing The Fuel Consumption of Medium- and Heavy-Duty Vehicles. The first was a report issued in 2010, "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles'' ("NAS Report"). The second a report issued in 2014, "Reducing the Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two-First Report" ("NAS HD Phase 2 First Report"). While the reports primarily focused on reducing vehicle fuel consumption and emissions through technology application, and examined potential regulatory frameworks, both reports contain findings and recommendations related to safety. In developing this rule, the agencies carefully considered the reports' findings related to safety.

In particular, NAS indicated that idle reduction strategies can also accommodate for the safety of the driver in both hot and cold weather conditions. The agencies considered this potential approach for application of idle reduction technologies by allowing for override provisions, as defined in 40 CFR 1037.660(b), where operator safety is a primary consideration. Override is allowed if the external ambient temperature reaches a level below which or above which the cabin temperature cannot be maintained within reasonable heat or cold exposure threshold limit values for the health and safety of the operator (not merely comfort).

NAS also reported extensively on the emergence of natural gas (NG) as a viable fuel option for commercial vehicles, but alluded to the existence of uncertainties regarding its safety. The committee found that while the public crash databases do not contain information on vehicle fuel type, the information, at the time of the report, indicates that the crash-related safety risk for NG storage on vehicles does not appear to be appreciably different from diesel fuel risks. The committee also found that while there are two existing SAE-recommended practice standards for NG-powered HD vehicles, the industry will benefit from best practice directives to minimize crash risks for NG fuel tanks, such as on shielding to prevent punctures during crashes. As a final point, NAS stated that manufacturers and operators have a great incentive to prevent possible NG leakage from a vehicle fuel system because it would be a significant safety concern and reduce vehicle range. No recommendations were made for additional Federal safety regulations for these vehicles. In response, the agencies reviewed and discuss the existing NG vehicle standards and best practices cited by NAS in Section XI of the NPRM.

In the NAS Committee's Phase 1 report, the Committee indicated that aerodynamic fairings detaching from trucks on the road could be a potential safety issue. However, the Phase 2 interim report stated that "Anecdotal information gained during the observations of on-road trailers indicates a few skirts badly damaged or missing from one side. The skirt manufacturers report no safety concerns (such as side skirts falling off) and little maintenance needed."

The NAS report also identified the link between tire inflation and condition and vehicle stopping distance and handling, which impacts overall safety. The committee found that tire pressure monitoring systems and automatic tire inflation systems are being adopted by fleets at an increasing rate. However, the committee noted that there are no standards for performance, display, and system validation. The committee recommended that NHTSA issue a white paper on the minimum performance of tire pressure systems from a safety perspective.

The agencies considered the safety findings in both NAS reports in developing this rule and conducted additional research on safety to further examine information and findings of the reports.

9.1.2 DOT CAFE Model HD Pickup and Van Safety Analysis

This analysis considered the potential crash safety effects on the technologies manufacturers may apply to HD pickups and vans to meet each of the regulatory alternatives evaluated in the NPRM. NHTSA research has shown that vehicle mass reduction affects overall societal fatalities associated with crashes and, most relevant to this rule, that mass reduction in heavier light- and medium-duty vehicles has an overall beneficial effect on societal fatalities. Reducing the mass of a heavier vehicle involved in a multiple vehicle crash reduces the likelihood of fatalities among the occupants of the other vehicle(s). In addition to the effects of mass reduction, the analysis anticipates that these standards, by reducing the cost of driving HD pickups and vans, will lead to increased travel by these vehicles and, therefore, more crashes involving these vehicles. The Method A and B analyses, included in the NPRM, consider overall impacts from both of these factors, using a methodology similar to NHTSA's analyses for the MYs 2017 – 2025 CAFE and GHG emission standards.

The Method A analysis includes estimates of the extent to which HD pickups and vans produced during MYs 2014-2030 may be involved in fatal crashes, considering the mass, survival, and mileage accumulation of these vehicles, taking into account changes in mass and mileage accumulation under each regulatory alternative. These calculations make use of the same coefficients applied to light trucks in the MYs 2017-2025 CAFE rulemaking analysis. As discussed above, vehicle miles traveled may increase due to the fuel economy rebound effect, resulting from improvements in vehicle fuel efficiency and cost of fuel, as well as the assumed future growth in average vehicle use. Increases in total lifetime mileage increase exposure to vehicle crashes, including those that result in fatalities. Consequently, the modeling system computes total fatalities attributed to vehicle use for vehicles of a given model year based on safety class and weight threshold. These calculations also include a term that accounts for the fact that vehicles involved in future crashes will be certified to more stringent safety standards than those involved with past crashes upon which the base rates of involvement in fatal crashes were estimated. Since the use of mass reducing technology is present within the model, safety impacts may also be observed whenever a vehicle's base weight decreases. Thus, in addition to computing total fatalities related to vehicle use, the modeling system also estimates changes in fatalities due to reduction in a vehicle's curb weight.

The total fatalities attributed to vehicle use and vehicle weight change for vehicles of a given model year are then summed. Lastly, total fatalities occurring within the industry in a given model year are accumulated across all vehicles. In addition to using inputs to estimate the future involvement of modeled vehicles in crashes involving fatalities, the model also applies inputs defining other accident-related externalities estimated on a dollar per mile basis. For vehicles above 4,594 pounds—i.e., the majority of the HD pickup and van fleet—mass reduction is estimated to reduce the net incidence of highway fatalities by 0.34 percent per 100 pounds of removed curb weight. For the few HD pickups and vans below 4,594 pounds, mass reduction is estimated to increase the net incidence of highway fatalities by 0.52 percent per 100 pounds. Because there are many more HD pickups and vans above 4,594 pounds than below 4,594 pounds, the overall effect of mass reduction in the segment is estimated to reduce the incidence of highway fatalities. The estimated increase in vehicle miles traveled due to the fuel economy rebound effect is estimated to increase exposure to vehicle crashes and offset these reductions.

9.1.3 Volpe Research on MD/HD Fuel Efficiency Technologies

The 2010 NAS Report recommended that NHTSA perform a thorough safety analysis to identify and evaluate potential safety issues with fuel efficiency-improving technologies. The Department of Transportation Volpe Center's 2015 report titled "Review and Analysis of Potential Safety Impacts of and Regulatory Barriers to Fuel Efficiency Technologies and Alternative Fuels in Medium- and Heavy-Duty Vehicles"[1] summarizes research and analysis findings on potential safety issues associated with both the diverse alternative fuels (natural gas-CNG and LNG, propane, biodiesel, and power train electrification), and the specific FE technologies recently adopted by the MD/HDV fleets. These include Intelligent Transportation Systems (ITS) and telematics, speed limiters, idle reduction devices, tire technologies (single-wide tires, and tire pressure monitoring systems-TPMS and Automated Tire Inflation Systems-ATIS), aerodynamic components, vehicle light-weighting materials, and Long Combination Vehicles (LCVs).

Chapter 1 provides an overview of the study's rationale, background, and key objective, namely, to identify the technical and operational/behavioral safety benefits and disbenefits of MD/HDVs equipped with FE technologies and using emerging alternative fuels (AFs). Recent MD/HDV national fleet crash safety statistical averages are also provided for context, although no information exists in crash reports relating to specific vehicle FE technologies and fuels. (NHTSA/FARS and FMCSA/CSA databases do not include detailed information on vehicle fuel economy technologies, since the state crash report forms are not coded down to an individual fuel economy technology level).

Chapters 2 and 3 are organized by clusters of functionally-related FE technologies for vehicles and trailers (e.g., tire systems, ITS, light-weighting materials, and aerodynamic systems) and alternative fuels, which are described and their respective associated potential safety issues are discussed. Chapter 2 summarizes the findings from a comprehensive review of available technical and trade literature and Internet sources regarding the benefits, potential safety hazards, and the applicable safety regulations and standards for deployed FE technologies and alternative fuels. Chapter 2 safety-relevant fuel-specific findings include:

- Both CNG- and LNG-powered vehicles present potential hazards, and call for well-known engineering and process controls to assure safe operability and crashworthiness. However, based on the reported incident rates of NGVs and the experiences of adopting fleets, it appears that NGVs can be operated at least as safely as diesel MD/HDVs.

- There are no safety contraindications to the large scale fleet adoption of CNG or LNG fueled heavy duty trucks and buses, and there is ample experience with the safe operation of large public transit fleets. Voluntary industry standards and best practices suffice for safety assurance, though improved training of CMV operators and maintenance staff in natural gas safety of equipment and operating procedures is needed.

- Observing CNG and LNG fuel system and maintenance facility standards, coupled with sound design, manufacture, and inspection of natural gas storage tanks will further reduce the potential for leaks, tank ruptures, fires, and explosions.

- Biodiesel blends used as drop-in fuels have presented some operational safety concerns dependent on blending fraction, such as material compatibility, bio-fouling sludge accumulation, or cold-weather gelling. However, best practices for biodiesel storage, and improved gaskets and seals that are biodiesel resistant, combined with regular maintenance and leak inspection schedules for the fuel lines and components enable the safe use of biodiesel in newer MD/HDVs

- Propane (LPG, or autogas) presents well-known hazards including ignition (due to leaks or crash) that are preventable by using Overfill Prevention Devices (OPDs), which supplement the automatic stop-fill system on the fueling station side, and pressure release devices (PRDs). Established best practices and safety codes (e.g., NFPA) have proven that propane fueled MD/HDVs can be as operationally safe as the conventionally-fueled counterparts.

- As the market penetration of hybrid and electric drivetrain accelerates, and as the capacity and reliability of lithium ion batteries used in Rechargeable Energy Storage Systems (RESS) improve, associated potential safety hazards (e.g., electrocution from stranded energy, thermal runaway leading to battery fire) have become well understood, preventable, and manageable. Existing and emerging industry technical and safety voluntary standards, applicable NHTSA regulations and guidance, and the growing experience with the operation of hybrid and electric MD/HDVs will enable the safe operation and large-scale adoption of safer and more efficient power-train electrification technologies.

The safety findings from literature review pertaining to the specific FE technologies implemented to date in the MD/HDV fleet include:

- Telematics—integrating on-board sensors, video, and audio alerts for MD/HDV drivers—offer potential improvements in both driver safety performance and fuel efficiency. Both camera and non-camera based telematics setups are currently integrated with available crash avoidance systems (such as ESC, RSC, LDWS, etc.) and appear to be well accepted by MD/HDV fleet drivers.

- Both experience abroad and the cited US studies of trucks equipped with active speed limiters indicated a safety benefit, as measured by up to 50 percent reduced crash rates, in addition to fuel savings and other benefits, with good CMV driver acceptance. Any negative aspects were small and avoidable if all the speed limitation devices were set to the same speed, so there would be less need for overtaking at highway speeds.

- No literature reports of adverse safety impacts were found regarding implementation of on-board idle-reduction technologies in MD/HDVs (such as automatic start-stop, direct-fired heaters, and APUs).

- There was no clear consensus from the literature regarding the relative crash rates and highway safety impacts of LCVs, due to lack of sufficient data and controls and inconsistent study methodologies. Recent safety evaluations of LCVs and ongoing MAP-21 mandated studies will clarify and quantify this issue.

- Tire technologies for FE (including ATIS, TPMS, LRR and single-wide tires) literature raised potential safety concerns regarding lower stability or loss of control, e.g., when tire pressure is uneven or a single wide tire blows out on the highway. However, systems such as automated tire monitoring systems and stability enhancing electronic systems (ABS, ESC, and RSC) may compensate and mitigate any adverse safety impacts.

- Aerodynamic technologies that offer significant fuel savings have raised potential concerns about vehicle damage or injury in case of detached fairings or skirts, although there were no documented incidents of this type in the literature.

- Some light weighting materials may pose some fire safety and crashworthiness hazards, depending on their performance in structural or other vehicle subsystem applications (chassis, power-train, and crash box or safety cage). Some composites (fiberglass, plastics, CFRC, foams) may become brittle on impact or due to weathering from UV exposure or extreme cold. Industry has developed advanced, high performance lightweight material options tailored to their automotive applications, e.g., thermoplastics resistant to UV and weathering. No examples of such lightweight material failures on MD/HDVs were identified in the literature.

Chapter 3 provides complementary inputs on the potential safety issues associated with FE technologies and alternative fuels obtained from Subject Matter Experts (SMEs). The broad cross-section of SMEs consulted had experience with the operation of “green” truck and bus fleets, were Federal program managers, or were industry developers of FE systems for MD/HDVs. Safety concerns raised by the SMEs can be prevented or mitigated by complying with applicable regulations and safety standards and best practices, and are being addressed by evolving technologies, such as electronic collision prevention devices. Although SMEs raised some safety concerns, their experience indicates that system- or fuel-specific hazards can be prevented or mitigated by observing applicable industry standards, and by training managers, operators and maintenance staff in safety best practices. Specific safety concerns raised by SMEs based on their experience included:

- Alternative fuels did not raise major safety concerns, but generally required better education and training of staff and operators. There was a concern expressed regarding high pressure (4000 psi) CNG cylinders that could potentially explode in a crash scenario or if otherwise ruptured. However, aging CNG fuel tank safety can be assured by enforcing regulations such as FMVSS No. 304, and by periodic inspection and end-of-life disposal and replacement. A propane truck fleet manager stated that the fuel was as safe as or safer than gasoline, and reported no safety issues with the company’s propane, nor with hybrid gasoline-electric trucks. OEMs of drivetrain hybridization and electrification systems, including advanced Lithium Ion batteries for RESS, indicated that they undergo multiple safety tests and are designed with fail-safes for various misuse and abuse scenarios. Integration of hybrid components downstream by bodybuilders in retrofits, as opposed to new vehicles, was deemed a potential safety risk. Another potential safety concern raised was the uncertain battery lifetime due to variability of climate, duty-cycles, and aging. Without state-of-charge indicators, this could conceivably leave vehicles underpowered or stranded if the battery degrades and is not serviced or replaced in a timely manner.

- ITS and telematics raised no safety concerns; on the contrary, fleet managers stated that “efficient drivers are safer drivers.” Monitoring and recording of driver behavior, combined with coaching, appeared to reduce distracted and aggressive driving and provided significant FE and safety benefits.

- A wide-base single tire safety concern was the decrease in tire redundancy in case of a tire blowout at highway speeds. For LRRs, a concern was that they could negatively affect truck stopping distance and stability control.

- A speed-limiter safety concern was related to scenarios when such trucks pass other vehicles on the highway instead of staying in the right-hand lane behind other vehicles. By combining speed limiters with driver training programs, overall truck safety could actually improve, as shown by international practice.

- Aerodynamic systems’ safety performance to date was satisfactory, with no instances of on-road detaching. However, covering underside or other components with aerodynamic fairings can make them harder to inspect, such as worn lugs, CNG relief valve shrouds, wheel covers, and certain fairings. Drivers and inspectors need to be able to see through wheel covers and to be able to access lug nuts through them. These covers must also be durable to withstand frequent road abuse.

- For lightweighting materials, the safety concern raised was lower crashworthiness (de-bonding or brittle fracture on impact) and the potential for decreased survivability in vehicle fires depending on the specific material choice and its application.

The key finding from the literature review and SME interviews is that there appear to be no major safety hazards preventing the adoption of FE technologies, or the increased use of alternative fuels and vehicle electrification. In view of the scarcity of hard data currently available on actual highway crashes that can be directly or causally attributed to adoption of FE technologies and/or alternative fuels by MD/HDVs, and the limited experience with commercial truck and transit bus fleets operations equipped with these technologies, it was not possible to perform a quantitative, probabilistic risk assessment, or even a semi-quantitative preliminary hazard analysis (PHA).

Chapter 4 employs a deterministic scenario-based hazard analysis of potential crash or other safety concerns identified from the literature review or raised by subject matter experts (SMEs) interviewed (e.g., interfaces with charging or refueling infrastructure). For each specific hazard scenario discussed, the recommended prevention or mitigation options, including compliance with applicable NHTSA or FMCSA regulations, and voluntary industry standards and best practices are identified, along with FE technology or fuel-specific operator training. SMEs safety concerns identified in Sec 3.3 were complemented with actual incidents, and developed into the hazard scenarios analyzed in Chapter 4.

The scenario-based deterministic hazard analysis reflected not only the literature findings and SMEs' safety concerns, but also real truck or bus mishaps that have occurred in the past. Key hazard analysis scenarios included: CNG-fueled truck and bus vehicle fires or explosions due to tank rupture, when pressurized fuel tanks were degraded due to aging or when PRDs failed; LNG truck crashes leading to fires, or LNG refueling-related mishaps; the flammability or brittle fracture issues related to lightweighting materials in crashes; reduced safety performance for either LRR or wide-base tires; highway pile-ups when LCVs attempt to pass at highway speeds; aerodynamic components detaching while the vehicle traveled on a busy highway or urban roadway; and fires resulting in overheated lithium ion batteries in electric or hybrid buses. These hypothetical worst case scenarios appear to be preventable or able to be mitigated by observing safety regulations and voluntary standards, or with engineering and operational best practices.

Chapter 5 reviews and discusses the existing federal and state regulatory framework for safely operating MD/HDVs equipped with FE technologies or powered by alternative fuels. The review identifies potential regulatory barriers to their large-scale deployment in the national fleet that could delay achievement of desired fuel consumption and environmental benefits, while ensuring equal or better safety performance.

Chapter 6 summarizes the major findings and recommendations of this preliminary safety analysis of fuel efficiency technologies and alternative fuels adopted by MD/HDVs. The scenario-based hazard analysis, based on the literature review and experts' inputs, indicates that MD/HDVs equipped with advanced FE technologies and/or using alternative fuels have manageable potentially adverse safety impacts. The findings suggest that the potential safety hazards identified during operation, maintenance, and crash scenarios can be prevented or mitigated by complying with safety regulations and voluntary standards and industry best practices. The study also did not identify any major regulatory barriers to rapid adoption of FE technologies and alternative fuels by the MD/HDV fleet.

9.1.4 Oak Ridge National Laboratory (ORNL) Research on Low Rolling Resistance Truck Tires

DOT's Federal Motor Carrier Safety Administration and NHTSA sponsored a test program conducted by Oak Ridge National Laboratory to explore the effects of tire rolling resistance levels on Class 8 tractor-trailer stopping distance performance over a range of loading and surface conditions.[2] The objective was to determine whether there a relationship exists between tire rolling resistance and stopping distance for vehicles of this type. The overall results of this research suggest that tire rolling resistance is not a reliable indicator of Class 8 tractor-trailer stopping distance. The correlation coefficients (R^2 values) for linear regressions of wet and dry stopping distance versus overall vehicle rolling resistance values did not meet the minimum threshold for statistical significance for any of the test conditions. Correlation between CRR and stopping distance was found to be negligible for the dry tests for both loading conditions. While correlation was higher for the wet testing (showing a slight trend in which lower CRRs correspond to longer stopping distances), it still did not meet the minimum threshold for statistical significance. In terms of compliance with Federal safety standards, it was found that the stopping distance performance of the vehicle with the four tire sets studied in this research (with estimated tractor CRRs which varied by 33 percent), were well under the FMVSS No. 121 stopping distance requirements.

9.1.5 Additional Safety Considerations

The agencies' considered the-Organic Rankine Cycle waste heat recovery (WHR) as a fuel saving technology in the rulemaking timeframe. The basic approach of these systems is to use engine waste heat from multiple sources to evaporate a working fluid through a heat exchanger, which is then passed through a turbine or equivalent expander to create mechanical or electrical power. The working fluid is then condensed as it passes through a heat exchanger and returns to back to the fluid tank, and pulled back to the flow circuit through a pump to continue the cycle.

Despite the promising performance of pre-prototype WHR systems, manufacturers have not yet arrived at a consensus on which working fluid(s) to be used in WHR systems to balance concerns regarding performance, global warming potential (GWP), and safety. Working fluids have a high GWP (conventional refrigerant), are expensive (low GWP refrigerant), are hazardous (such as ammonia, etc.), are flammable (ethanol/methanol), or can freeze (water). One challenge is determining how to seal the working fluid properly under the vacuum condition and high temperatures to avoid safety issues for flammable/hazardous working fluids. Because of these challenges, choosing a working fluid will be an important factor for system safety, efficiency, and overall production viability.

The agencies believe manufacturers will require additional time and development effort to assure that a working fluid that is both appropriate, given the noted challenges, and has a low GWP for use in waste heat recovery systems. Based on this and other factors, the analysis used for both the proposed Preferred Alternative and for this final rule assumes that WHR will not achieve a significant market penetration for diesel tractor engines (i.e., greater than 5 percent) until 2027, which will provide time for these considerations to be addressed. The agencies assume no use of this technology in the HD pickups and vans and vocational vehicle segments.

9.2 Safety Related Comments to the NPRM

The agencies received safety related to the NPRM focused on the vehicle and operator safety benefits of central tire inflation systems, potential safety and traction impacts of low rolling resistance tires, and recommendations that NHTSA continue evaluations of potential safety impacts of fuel saving technologies.

AIR CTI, Inc., a supplier of central tire inflation systems, highlighted the safety benefits to both vehicle operation and the operators themselves through proper tire pressure management. More specifically, the proper tire inflation levels for the load being carried contributes to both proper handing for road conditions and reducing irregular road surface vibration from being transmission to vehicle component and, ultimately, the vehicle operator, where there may be potential health implications over prolonged exposure.

The agencies appreciate the additional points provided by AIR CTI in terms of not only the potential fuel efficiency benefits of central tire inflation systems but the potential equipment longevity benefits, vehicle dynamic impacts, and the potential to reduce driver fatigue and injury through proper tire inflation for the load being carried.

The American Trucking Associations (ATA) commented on the potential impact of Low Rolling Resistance Tires by indicating that, "The safety effects of LRRTs are not totally understood. While the "…agencies analysis indicate that this proposal should have no adverse impact on vehicle or engine safety," ATA remains leery of potential unintended consequences resulting from new generation tires that have yet to be developed. This especially holds true in terms of overall truck braking distances." The Owner-Operator Independent Drivers Association (OOIDA) similarly commented on LRRTs and their ability to meet the tractions needs in mountainous regions.

The agencies continue to stand behind the low rolling resistance tire research conducted to date, which includes the study mentioned in the previous section, along with any research supporting the development, and maintenance, of FMVSS No.121. The agencies agree, though, that continuing research will be important as new tire technologies enter the marketplace, and like the extensive rolling resistance testing conducting to support the Phase 1 regulation and, in part, this final rule, the agencies will continue to monitor developments in the tire supply marketplace through the EPA SmartWay program and other, potential, research. NHTSA notes that FMVSS No. 121 will continue to play a role in ensuring the safety of both current and future tire technologies.

The ATA also expressed support for the NHTSA study mentioned in the previous section, *Review and Analysis of Potential Safety Impacts of and Regulatory Barriers to Fuel*

Efficiency Technologies and Alternative Fuels in Medium- and Heavy-Duty Vehicles. More specifically, ATA requested that DOT/NHTSA and the DOT Volpe Center continue "to assess and evaluate potential safety impacts that may be attributed to the use of fuel efficiency devices." The agencies appreciate ATA's support and acknowledge of this comprehensive, peer-reviewed assessment and we look forward to continuing this work as the need arises.

9.3 The Agencies' Assessment of Potential Safety Impacts

NHTSA and EPA considered the potential safety impact of technologies that improve MDHD vehicle fuel efficiency and GHG emissions as part of the assessment of regulatory alternatives and selection of the final regulatory approach. The safety assessment of the technologies in this final rule was informed by two NAS reports, an analysis of safety effects of HD pickups and vans using estimates from the DOT report on the effect of mass reduction and vehicle size on safety, and agency-sponsored safety testing and research. The agencies considered safety from the perspective of both direct effects and indirect effects.

In terms of direct effects on vehicle safety, research from NAS and Volpe, and direct testing of technologies like the ORNL tire work, indicate that there are no major safety hazards associated with the adoption of technologies that improve MDHD vehicle fuel efficiency and GHG emissions or the increased use of alternative fuels and vehicle electrification. The findings suggest that the potential safety hazards identified during operation, maintenance, and crash scenarios can be prevented or mitigated by complying with safety regulations, voluntary standards, and industry best practices. Tire testing showed tire rolling resistance did not impact of Class 8 tractor-trailer stopping distance for the tires tested. For HD pickup and vans, mass reduction is anticipated to reduce the net incidence of highway fatalities, more specifically related to the majority of HD pickup and vans weigh more than 4,594 lbs. Taken together, these studies suggest that the fuel efficiency improving technologies assessed in the studies can be implemented with no degradation in overall safety.

However, analysis anticipates that the indirect effect of these standards, by reducing the operating costs, will lead to increased travel by tractor-trailers and HD pickups and vans and, therefore, more crashes involving these vehicles.

References

[1] Brecher, A., Epstein, A. K., & Breck, A. (2015, June). "Review and analysis of potential safety impacts of and regulatory barriers to fuel efficiency technologies and alternative fuels in medium- and heavy-duty vehicles." (Report No. DOT HS 812 159). Washington, DC: National Highway Traffic Safety Administration.
[2] Lascurain, M.B. (2015, June). "Effects of tire rolling resistance levels on Class 8 tractor trailer stopping distance performance." Washington, DC: National Highway Traffic Safety Administration.

Chapter 10: CAFE Model for HD Pickups and Vans

In the NPRM, the agencies conducted coordinated and complementary analyses using two analytical methods for the heavy-duty pickup and van segment, both of which used the same version of NHTSA's CAFE model to analyze technology. The agencies have also used two analytical methods for the joint final rule. However, unlike the NPRM, for the joint final rule, the agencies are using different versions of NHTSA's CAFE model to analyze technology. The Method B approach continues to use the same version of the model and inputs that was used for both methods in the NPRM. Method A uses an updated version of the CAFE model and some updated inputs.

In this chapter, both versions of the CAFE modeling system are described and used to analyze technology use and per-vehicle costs under each regulatory alternative, including the no action alternative (which reflects continuation of previously-promulgated standards). The Method A analysis uses the CAFE model which includes changes made subsequent to the NPRM, and the Method B analysis uses the CAFE model which includes only those changes made for the NPRM. However, this model is more comprehensive and also projects other impacts. NHTSA addresses these other impacts in the EIS and these are also presented here.[A]

NHTSA developed the CAFE model in 2002 to support the 2003 issuance of CAFE standards for MYs 2005-2007 light trucks. NHTSA has since significantly expanded and refined the model, and has applied the model to support every ensuing CAFE rulemaking for both light-duty and heavy-duty. For this analysis, the model was reconfigured to use the work based attribute metric of "work factor" established in the Phase 1 rule instead of the light duty "footprint" attribute metric.

Past analyses conducted using the CAFE model have been subjected to extensive and detailed review and comment, much of which has informed the model's expansion and refinement. NHTSA's use of the model was considered and supported in *Center for Biological Diversity* v. *National Highway Traffic Safety Admin.*, 538 F.3d 1172, 1194 (9th Cir. 2008). For further discussion see 76 FR 57198, and the model has been subjected to formal peer review and review by the General Accounting Office (GAO) and National Research Council (NRC). NHTSA makes public the model, source code, and—except insofar as doing so will compromise confidential business information (CBI) manufacturers have provided to NHTSA—all model inputs and outputs underlying published rulemaking analyses.

Although the CAFE model can also be used for more aggregated analysis (e.g., involving "representative vehicles," single-year snapshots, etc.), NHTSA designed the model with a view toward (a) detailed simulation of manufacturers' potential actions given a defined set of standards, followed by (b) calculation of resultant impacts and economic costs and benefits. The model is intended to describe actions manufacturers <u>could</u> take in light of defined standards and other input assumptions and estimates, not to predict actions manufacturers <u>will</u> take in light of

[A] EPA uses its MOVES model to project these other impacts as discussed in Chapters 5 through 8 of this RIA.

competing product and market interests (e.g. engine power, customer features, technology acceptance, etc.).

For the proposal, the agencies conducted coordinated and complementary analyses using two analytical methods for the heavy-duty pickup and van segment by employing both NHTSA's CAFE model and EPA's MOVES model. The agencies used EPA's MOVES model to estimate fuel consumption and emissions impacts for tractor-trailers (including the engine that powers the tractor), and vocational vehicles (including the engine that powers the vehicle). Additional calculations were performed to determine corresponding monetized program costs and benefits. For heavy-duty pickups and vans, the agencies performed complementary analyses, which we refer to as "Method A" and "Method B."

For the final rule, NHTSA's Method A uses a modified version of the CAFE model developed since the NPRM, as well as accompanying updates to CAFE model inputs, to project a pathway the industry could use to comply with each regulatory alternative and the estimated effects on fuel consumption, emissions, benefits and costs were industry to do so. Method A is presented below in Section 10.2 and differs from the Method A analysis provided in the NPRM. NHTSA considered the results of the Method A analysis for decision making for the final rule.

EPA's Method B analysis continues to use the CAFE model and inputs developed for the NPRM to identify technology pathways the industry could potentially use to comply with each regulatory alternative, along with resultant impacts on per vehicle costs should that compliance path be utilized, and the MOVES model was used to calculate corresponding changes in total fuel consumption and annual emissions. The results are presented in Section 10.3. Additional calculations were performed to determine corresponding monetized program costs and benefits. NHTSA's consideration of the Method A analysis and EPA's consideration of the Method B analysis led the agencies to the same conclusions regarding the selection of the Phase 2 standards. See Sections 10.2 and 10.3 for additional discussion of these two methods and the feasibility of the standards.

10.1 Overview of the CAFE Model

As a starting point, the model makes use of an input file defining the analysis fleet—that is, a set of specific vehicle models (e.g., Ford F250) and model configurations (e.g., Ford F250 with 6.2-liter V8 engine, 4WD, and 6-speed manual transmission) estimated or assumed to be produced by each manufacturer in each model year to be included in the analysis. The analysis fleet includes key engineering attributes (e.g., curb weight, payload and towing capacities, dimensions, presence of various fuel-saving technologies) of each vehicle model, engine, and transmissions, along with estimates or assumptions of future production volumes. It also specifies the extent to which specific vehicle models share engines, transmissions, and vehicle platforms, and describes each manufacturer's estimated or assumed product cadence (*i.e.*, timing for freshening and redesigning different vehicles and platforms). This input file also specifies a payback period used to estimate the potential that each manufacturer might apply technology to improve fuel economy beyond levels required by standards.

A second input file to the model contains a variety of contextual estimates and assumptions. Some of these inputs, such as future fuel prices and vehicle survival and mileage accumulation (versus vehicle age), are relevant to estimating manufacturers' potential application of fuel-saving technologies. Some others, such as fuel density and carbon content, vehicular and upstream emission factors, the social cost of carbon dioxide emissions, and the discount rate, are relevant to calculating physical and economic impacts of manufacturers' application of fuel-saving technologies.

A third input file contains estimates and assumptions regarding the future applicability, availability, efficacy, and cost of various fuel-saving technologies. Efficacy is expressed in terms of the percentage reduction in fuel consumption, cost is expressed in dollars, and both efficacy and cost are expressed on an incremental basis (i.e., estimates for more advanced technologies are specified as increments beyond less advanced technologies). The input file also includes "synergy factors" used to make adjustments accounting for the potential that some combinations of technologies may result fuel savings or costs different from those indicated by incremental values.

Finally, a fourth model input file specifies standards to be evaluated. Standards are defined on a year-by-year basis separately for each regulatory class (passenger cars, light trucks, and heavy-duty pickups and vans). Regulatory alternatives are specified as discrete scenarios, with one scenario defining the no-action alternative or "baseline," all other scenarios defining regulatory alternatives to be evaluated relative to that no-action alternative.

Given these inputs, the model estimates each manufacturer's potential year-by-year application of fuel-saving technologies to each engine, transmission, and vehicle. Subject to a range of engineering and planning-related constraints (e.g., secondary axle disconnect can't be applied to 2-wheel drive vehicles, many major technologies can only be applied practicably as part of a vehicle redesign, and applied technologies carry forward between model years), the model attempts to apply technology to each manufacturer's fleet in a manner that minimizes "effective costs" (accounting, in particular, for technology costs and avoided fuel outlays), continuing to add improvements as long as doing so will help toward compliance with specified standards or will produce fuel savings that "pay back" at least as quickly as specified in the input file mentioned above.

After estimating the extent to which each manufacturer might add fuel-saving technologies under each specified regulatory alternative, the model calculates a range of physical impacts, such as changes in highway travel (i.e., VMT), changes in fleetwide fuel consumption, changes in highway fatalities, and changes in vehicular and upstream greenhouse gas and criteria pollutant emissions. The model also applies a variety of input estimates and assumptions to calculate economic costs and benefits to vehicle owners and society, based on these physical impacts. These are considered Method A results.

Since the manufacturers of HD pickups and vans generally only have one basic pickup truck and van with different versions (*i.e.*, different wheelbases, cab sizes, two-wheel drive, four-wheel drive, etc.) there exists less flexibility than in the light-duty fleet to coordinate model improvements over several years. As such, the CAFE model allows changes to the HD pickups and vans to meet new standards according to estimated redesign cycles included as a model input. As noted above, the opportunities for large-scale changes (*e.g.*, new engines, transmission, vehicle body and mass) thus occur less frequently than in the light-duty fleet, typically at spans of eight or more years for this analysis. However, opportunities for gradual improvements not necessarily linked to large scale changes can occur between the redesign cycles (i.e., model refresh). Examples of such improvements are upgrades to an existing vehicle model's engine, transmission and aftertreatment systems.

10.1.1 How Did the Agencies Develop the Analysis Fleets

As discussed above, both agencies used a version of NHTSA's CAFE modeling system to estimate technology costs and application rates under each regulatory alternative considered in the NPRM. The modeling system relies on many inputs, including an analysis fleet. NHTSA uses the MY 2015 existing fleet as its analysis fleet in "Method A" and EPA continues to use the MY 2014 fleet as its analysis fleet. In order to estimate the impacts of potential standards, it is necessary to estimate the composition of the future vehicle fleet. Doing so enables estimation of the extent to which each manufacturer may need to add technology in response to a given series of attribute-based standards, accounting for the mix and fuel consumption of vehicles in each manufacturer's regulated fleet. The agencies created analysis fleets in order to track the volumes and types of fuel economy-improving and CO_2 -reducing technologies that are already present in the existing vehicle fleet. This aspect of the analysis fleets helps to keep the CAFE model from adding technologies to vehicles that already have these technologies, which will result in "double counting" of technologies' costs and benefits. An additional step involved projecting the fleets' sales into MYs 2019-2030. This represents the fleet volumes that the agencies believe will exist in MYs 2019-2030. The following presents an overview of the information and methods applied to develop the analyses fleets, and some basic characteristics of that fleet.

Most of the information about the vehicles that make up the 2014 analysis fleet (used in the NPRM and Method B of the FRM) and the 2015 analysis fleet (used in Method A of the FRM) was gathered from the 2014 and 2015 Pre-Model Year Reports submitted to EPA by the manufacturers under Phase 1 of Fuel Efficiency and GHG Emission Program for Medium- and Heavy-Duty Trucks, MYs 2014-2018. The major manufacturers of class 2b and class 3 trucks (Chrysler, Ford and GM) were asked to voluntarily submit updates to their Pre-Model Year Reports. The agencies used these updated data in constructing the analysis fleet for these manufacturers. The agencies agreed to treat this information as Confidential Business Information (CBI) until the publication of the proposed rule. This information can be made public at this time because by now all MY2014 and MY2015 vehicle models have been produced, which makes data about them essentially public information.

In addition to information about each vehicle, the agencies need additional information about the fuel economy-improving/CO_2-reducing technologies already on those vehicles in order to assess how much and which technologies to apply to determine a path toward future compliance. To correctly account for the cost and effectiveness of adding technologies, it is necessary to know the technology penetration in the existing vehicle fleet. Otherwise, "double-counting" of technology could occur. Thus, the agencies augmented this information with data from public and commercial sources[B] that include more complete technology descriptions, e.g. for specific engines and transmissions.

[B] e.g., manufacturers' web sites, Wards Automotive.

The resultant analysis fleets are provided in detail at NHTSA's web site, along with all other inputs to and outputs from both the NPRM and the current analysis. The agencies invited but did not receive comment on this analysis.

10.1.1.1 Vehicle Redesign Schedules and Platforms

10.1.1.2 Pickup Trucks

Product cadence in the Class 2b and 3 pickup market has historically ranged from 7-9 years between major redesigns. However, due to increasing competitive pressures and consumer demands the agency anticipates that manufacturers will generally shift to shorter design cycles resembling those of the light duty market. Pickup truck manufacturers in the Class 2b and 3 segments are shown to adopt redesign cycles of six years, allowing two redesigns prior to the end of the regulatory period in 2027.

10.1.1.1.1.1 Ford

In the 2b/3 pickup truck market, Ford produces the F250, F350 and F450, currently based on the P3 platform. These models adopted the Super Duty moniker in 1999, and began using architecture and product cadence distinct from the F150 light-duty pickup models. The first full redesign of these models occurred in 2008, with smaller redesigns in 2005 and 2011.

NHTSA estimates that the next major redesign of Ford's 2b/3 products will occur in or about 2017, trailing Ford's announced update of a redesigned F150 in its light-duty pickup portfolio, with a more rapid product cadence leading to a subsequent redesign in 2023 and refreshes in 2020 and 2029.

10.1.1.1.1.2 General Motors

General Motors HD pickup trucks, the Silverado and Sierra HD series, are based on the GMT910 platform and were introduced as a 2007 model. GM has announced a redesigned HD pickup for the 2015 model year. NHTSA estimates that, like Ford, GM will adopt an approximate six-year product cadence in the HD truck market, with redesigns in 2015 and 2021.

10.1.1.1.1.3 Fiat (Ram)

The current Ram HD models, on the D2/DJ platform, are anticipated for a major redesign in the 2018 model year, and the agencies estimate that the product will adopt a similar, shorter life cycle of six years, with a subsequent redesign in the 2024 model year.

10.1.1.3 Vans

The 2b/3 van market has changed markedly from five years ago. Ford, Nissan, Ram and Daimler have adopted vans of "Euro Van" appearance, and in many cases now use smaller turbocharged gasoline or diesel engines in the place of larger, naturally-aspirated V8s. The 2014 Model Year used in this analysis represents a period where most manufacturers, with the exception of General Motors, have recently introduced a completely redesigned product after many years. The van segment has historically been one of the slowest to be redesigned of any product segment, with some products going two decades or more between redesigns.

Due to new entrants in the field and increased competition, the agencies anticipate that most manufacturers will increase the pace of product redesigns in the van segment, but that they will continue to trail other segments. The cycle time used in this analysis is approximately ten years between major redesigns, allowing manufacturers' only one major redesign during the regulatory period.

10.1.1.1.1.4 General Motors

The GM Savana/Chevrolet Express, built on the GMT600 platform, has been produced since 1996 with a facelift in 2003. The van is currently due for a redesign, and while it is unknown when this will occur, the agencies anticipate a major redesign due to strong competitive pressure from other manufacturers will occur in or about 2017, with no further redesigns occurring until after 2025.

10.1.1.1.1.5 Ford

2014 marks the first year in more than three decades that Ford has used a completely new platform for its vans. The Transit replaces the Econoline except in Chassis Cab or cutaway configurations. The agencies anticipate that Ford will gradually shift production volume to the Transit, and will not redesign the Transit until 2025, with one intermediate product freshening.

10.1.1.1.1.6 Fiat (Ram)

The product cycle of the van from the Ram brand has less of a historical precedent. Fiat currently offers the Promaster (a variant of the Ducato van sold in other markets). Previously Chrysler sold Sprinter vans in an agreement with Daimler from 2003, and had previously manufactured its own full-sized van.

The Promaster has just been introduced to the US market, and the agencies anticipate that Fiat will offer a refreshed version in 2020 prior to a full redesign in 2025.

10.1.1.1.1.7 Nissan

The Nissan NV launched for the 2012 model using the F-alpha platform shared with the light-duty Nissan Titan pickup truck. Trade publications and internet sources suggest the next-generation Nissan Titan could debut in model year 2016, and the agencies anticipate that the NV van may adopt some of the features and components of the Titan for a mid-cycle freshening of the NV, with a full redesign in 2021.

10.1.1.1.1.8 Daimler

Daimler introduced its current Sprinter van for the 2007 model year on the NCV3 platform. U.S. models received an update across 2014 and 2015, with rear wheel drive models arriving one year ahead of AWD models. The agencies anticipate that Daimler will redesign the Sprinter for 2017 with a subsequent freshening in model year 2021.

10.1.1.4 Sales Volume Forecast

Since each manufacturer's required average fuel consumption and GHG levels are sales-weighted averages of the fuel economy/GHG targets across all model offerings, sales volumes play a critical role in estimating that burden. The CAFE model requires a forecast of sales volumes, at the vehicle model-variant level, in order to simulate the technology application necessary for a manufacturer to achieve compliance in each model year for which outcomes are simulated.

For this analysis, the agencies relied on the pre-model-year compliance submissions from manufacturers to provide sales volumes at the model level based on the level of disaggregation in which the models appear in the compliance data. However, the agencies only use these reported volumes without adjustment for the reference fleet model year (MY 2014 or MY 2015). For all future model years, we combine the manufacturer submissions with sales projections from the 2014 (for the NPRM and Method B of the FRM) or 2015 (for Method A of the FRM) Annual Energy Outlook Reference Case and IHS Automotive to determine model variant level sales volumes in future years.[C] The projected sales volumes by class that appear in the Annual Energy Outlook as a result of a collection of assumptions about economic conditions, demand for commercial miles traveled, and technology migration from light-duty pickup trucks in response to the concurrent light-duty CAFE/GHG standards. These are shown in Chapter 2 of the RIA.

The projection of total sales volumes for the Class 2b and 3 market segment was based on the total volumes in the 2014 AEO Reference Case in the NPRM and for Method B of this FRM. For the purposes of this analysis, the AEO2014 calendar year volumes have been used to represent the corresponding model-year volumes. While AEO2014 provides enough resolution in its projections to separate the volumes for the Class 2b and 3 segments, the agencies deferred to the vehicle manufacturers and chose to rely on the relative shares present in the pre-model-year compliance data. This methodology remains the same for the Method A FRM analysis, but we have replaced the 2014 AEO reference case with the 2015 AEO reference case. A description of key characteristics of the 2014 and 2015 analysis fleets follows.

10.1.1.4.1 Summary of the 2014 Analysis Fleet

The projection of total sales volumes for the Class 2b and 3 market segment was based on the total volumes in the 2014 AEO Reference Case. For the purposes of the Method B analysis, the AEO2014 calendar year volumes have been used to represent the corresponding model-year volumes. While AEO2014 provides enough resolution in its projections to separate the volumes for the Class 2b and 3 segments (see Figure 10-1), the agencies deferred to the vehicle manufacturers and chose to rely on the relative shares present in the pre-model-year compliance data.

[C] Tables from AEO's forecast are available at http://www3.eia.gov/oiaf/aeo/tablebrowser/. The agencies also made use of the IHS Automotive Light Vehicle Production Forecast (August 2014).

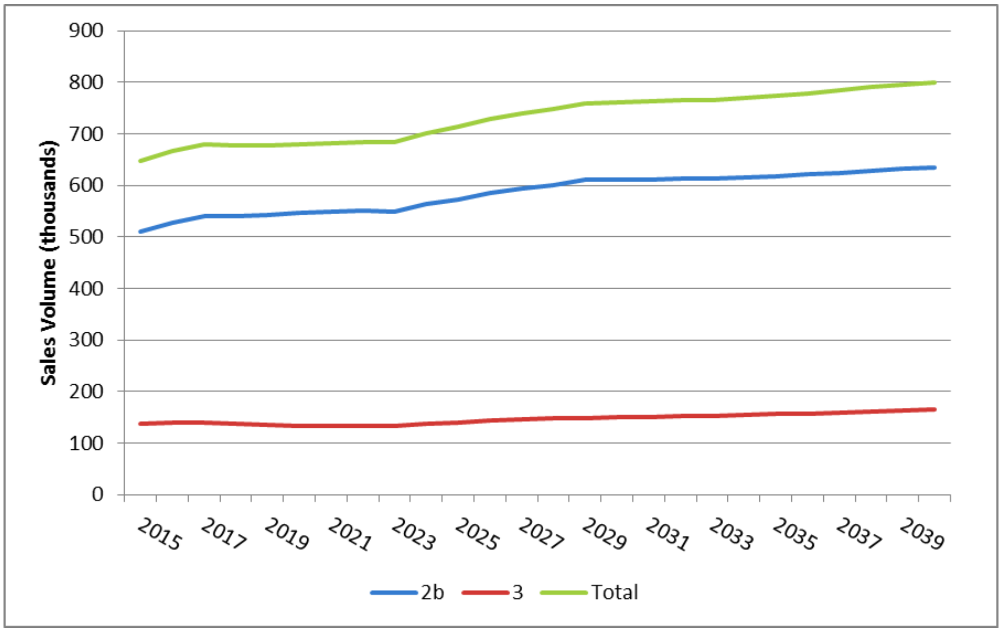

Figure 10-1 AEO2014 Sales Projections for 2b/3 Vehicles

The relative sales share by vehicle type (van or pickup truck, in this case) was derived from a sales forecast that the agencies purchased from IHS Automotive, and applied to the total volumes in the AEO2014 projection. Table 10-1 shows the implied shares of the total new 2b/3 vehicle market broken down by manufacturer and vehicle type.

Table 10-1 2014 IHS Automotive Market Share Forecast for 2b/3 Vehicles

		MODEL YEAR MARKET SHARE						
Manufacturer	**Style**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Daimler	Van	3%	3%	3%	3%	3%	3%	3%
Fiat	Van	2%	2%	2%	2%	2%	2%	3%
Ford	Van	16%	17%	17%	17%	18%	18%	18%
General Motors	Van	12%	12%	11%	12%	13%	13%	13%
Nissan	Van	2%	2%	2%	2%	2%	2%	2%
Daimler	Pickup	0%	0%	0%	0%	0%	0%	0%
Fiat	Pickup	14%	14%	14%	14%	11%	12%	12%
Ford	Pickup	28%	27%	30%	30%	30%	27%	26%
General Motors	Pickup	23%	23%	21%	21%	21%	22%	23%
Nissan	Pickup	0%	0%	0%	0%	0%	0%	0%

Within those broadly defined market shares, volumes at the manufacturer/model-variant level were constructed by applying the model-variant's share of manufacturer sales in the pre-model-year compliance data for the relevant vehicle style, and multiplied by the total volume estimated for that manufacturer and that style.

After building out a set of initial future sales volumes based on the sources described above, the agencies attempted to incorporate new information about changes in sales mix that will not be captured by either the existing sales forecasts or the simulated technology changes in vehicle platforms. In particular, Ford has announced intentions to phase out their existing Econoline vans, gradually shifting volumes to the new Transit platform for some model variants (notably chassis cabs and cutaways variants) and eliminating offerings outright for complete Econoline vans as early as model year 2015. In the case of complete Econoline vans, the volumes for those vehicles were allocated to MY2015 Transit vehicles based on assumptions about likely production splits for the powertrains of the new Transit platform. The volumes for complete Econoline vans were shifted at ratios of 50 percent, 35 percent, and 15 percent for 3.7 L, 3.5 L Eco-boost, and 3.2 L diesel, respectively. Within each powertrain, sales were allocated based on the percentage shares present in the pre-model-year compliance data. The chassis cab and cutaway variants of the Econoline were phased out linearly between MY2015 and MY2020, at which time the Econolines cease to exist in any form and all corresponding volume resides with the Transits.

The tables below summarize some of the characteristics of the MY2014 based analysis fleet for Class 2b and Class 3 trucks. Table 10-2 shows production by manufacturer and indicates that Ford is dominant with 52 percent of this market.

Table 10-2 Estimated MY2014 Production by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	25,327	4.0%
Fiat	138,902	21.8%
Ford	330,919	51.9%
General Motors	129,435	20.3%
Nissan	13,526	2.1%
Total	638,109	100.0%

Table 10-3 shows production by class with 80 percent of production in class 2b, those trucks with a GVW between 8,501 and 10,000 lbs.

Table 10-3 Estimated MY2014 Production by Class

GVW CLASS	PRODUCTION	PERCENT
2b (8,501-10,000 lbs.)	506,989	79.5%
3 (10,001-14,000 lbs.)	131,120	20.5%
Total	638,109	100.0%

Table 10-4 shows production by style or body type. Pickup trucks make up 52 percent of production and vans 42 percent of production.

Table 10-4 Estimated MY2014 Production by Vehicle Style

STYLE	PRODUCTION	PERCENT
Chassis Cab	19,724	3.1%
Cutaway	20,539	3.2%
Pickup	333,100	52.2%
Van	264,746	41.5%
Total	638,109	100.0%

Table 10-5 shows production by engine type. Diesel powered trucks make up a significant share (40 percent) of this market in comparison to light duty vehicles.

Table 10-5 Estimated MY2014 Production by Engine Type

ENGINE TYPE	PRODUCTION	PERCENT
Diesel	252,744	39.6%
Gasoline	105,604	16.5%
FFV	279,761	43.8%
Total	638,109	100.0%

Table 10-6 shows production by drive type with an almost equal division between two wheel drive (55 percent) and four wheel drive (45 percent).

Table 10-6 Estimated MY2014 Production by Drive

DRIVE	PRODUCTION	PERCENT
4WD	286,122	44.8%
FWD	23,309	3.7%
RWD	328,678	51.5%
Total	638,109	100.0%

The following tables show some of the characteristics of the baseline analysis fleet at the manufacturer level. Table 10-7 and Table 10-8show production by manufacturer for class 2b and class 3 trucks respectively. As noted above Ford is the dominant manufacturer with 52 percent of the market in both class 2b and class 3 trucks. While Fiat and General Motors have comparable shares of the class 2b market (20 percent and 22 percent respectively), Fiat (at 31 percent) has a significantly larger share of the class 3 market than General Motors (at 13 percent).

Table 10-7 Estimated MY2014 Production Class 2b by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	19,556	3.9%
Fiat	98,722	19.5%
Ford	262,687	51.8%
General Motors	112,498	22.2%
Nissan	13,526	2.7%
Total	506,989	100.0%

Table 10-8 Estimated MY2014 Production Class 3 by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	5,771	4.4%
Fiat	40,180	30.6%
Ford	68,232	52.0%
General Motors	16,937	12.9%
Nissan	-	0.0%
Total	131,120	100.0%

As noted above pickup trucks were the dominant body style in Class 2b and 3 trucks. Table 10-9 shows pickup truck production by manufacturer. Only three manufactures share this market with Ford the leader at 43 percent, followed by Fiat at 35 percent and General Motors at 22 percent.

Table 10-9 Estimated MY2014 Production Pickups by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	-	0.0%
Fiat	115,593	34.7%
Ford	142,580	42.8%
General Motors	74,927	22.5%
Nissan	-	0.0%
Total	333,100	100.0%

All five manufactures share the Class 2b and 3 van market. Table 10-10 shows van production by manufacturer. Ford is again dominant with 57 percent of the market followed by General Motors at 21 percent with the remainder divided among Fiat, Daimler and Nissan.

Table 10-10 Estimated MY2014 Production Vans by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	21,900	8.3%
Fiat	23,309	8.8%
Ford	151,503	57.2%
General Motors	54,508	20.6%
Nissan	13,526	5.1%
Total	264,746	100.0%

Table 10-11 and Table 10-12 give an indication of the significance of diesel powered trucks in the class 2b and 3 market. Table 10-11 shows the distribution of diesel trucks by manufacturer. Ford is the leader at 40 percent followed by Fiat at 34 percent. Table 10-12 shows diesel production as a percent of total production for each manufacturer. At either end of the spectrum are Nissan at 0 percent and Daimler at 100 percent. Of the producers with significant market share Fiat leads with 62 percent of its production in diesels, followed by General Motors at 32 percent and Ford at 30 percent.

Table 10-11 Estimated MY2014 Production Diesel Powered Trucks by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	25,327	10.0%
Fiat	86,124	34.1%
Ford	100,208	39.6%
General Motors	41,085	16.3%
Nissan	-	0.0%
Total	252,744	100.0%

Table 10-12 Estimated MY2014 Diesel Penetration by Manufacturer

MANUFACTURER	DIESEL PRODUCTION	TOTAL PRODUCTION	PERCENT DIESEL
Daimler	25,327	25,327	100.0%
Fiat	86,124	138,902	62.0%
Ford	100,208	330,919	30.3%
General Motors	41,085	129,435	31.7%
Nissan	-	13,526	0.0%
Total	252,744	638,109	39.6%

The resultant analysis fleet for Method A (and both Method A and B in the NPRM) is provided in detail at NHTSA's web site, along with all other inputs to and outputs from Method A (and NPRM) analysis.

10.1.1.4.2 Summary of the 2015 Analysis Fleet

For Method A, the projection of total sales volumes for the Class 2b and 3 market segment was based on the total volumes in the 2015 AEO Reference Case. For the purposes of the Method A analysis, the AEO2015 calendar year volumes have been used to represent the corresponding model-year volumes. While AEO2015 provides enough resolution in its projections to separate the volumes for the Class 2b and 3 segments (see Figure 10-2), NHTSA deferred to the vehicle manufacturers and chose to rely on the relative shares present in the pre-model-year compliance data.

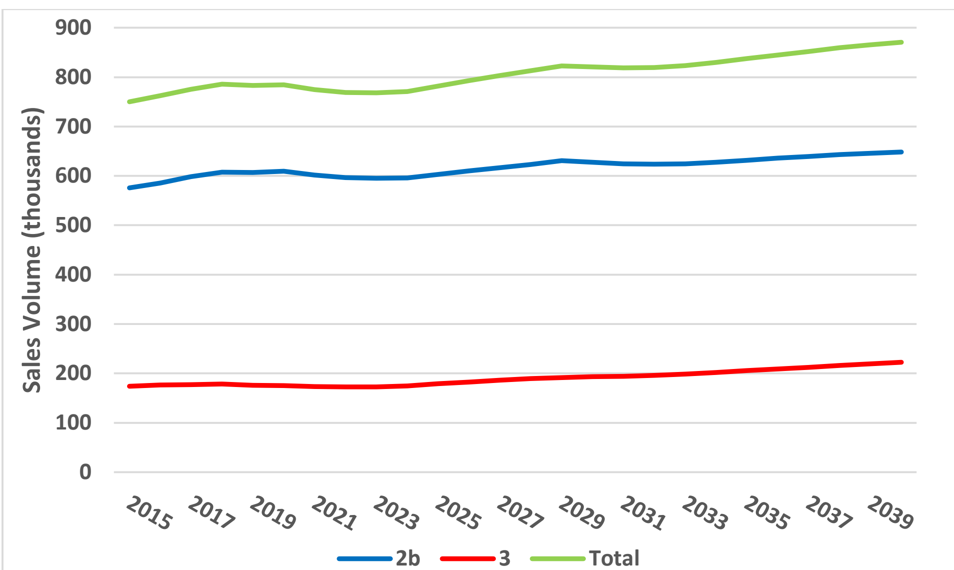

Figure 10-2 AEO2015 Sales Projections for 2b/3 Vehicles

As with the 2014 analysis fleet, the relative sales share by vehicle type (van or pickup truck, in this case) was derived from a sales forecast that the agencies purchased from IHS

Automotive, and applied to the total volumes in the AEO2015 projection. Table 10-13 shows the implied shares of the total new 2b/3 vehicle market broken down by manufacturer and vehicle type.

Table 10-13 2015 IHS Automotive Market Share Forecast for 2b/3 Vehicles

	MODEL YEAR MARKET SHARE						
Manufacturer	**Style**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Daimler	Van	2%	2%	2%	3%	3%	3%
Fiat	Van	3%	3%	3%	3%	3%	3%
Ford	Van	16%	16%	16%	17%	18%	19%
General Motors	Van	7%	7%	7%	7%	8%	8%
Nissan	Van	1%	1%	1%	1%	2%	2%
Daimler	Pickup	0%	0%	0%	0%	0%	0%
Fiat	Pickup	14%	14%	14%	14%	15%	14%
Ford	Pickup	29%	30%	31%	31%	28%	28%
General Motors	Pickup	28%	27%	26%	25%	24%	24%
Nissan	Pickup	0%	0%	0%	0%	0%	0%

Within those broadly defined market shares, volumes at the manufacturer/model-variant level were constructed by applying the model-variant's share of manufacturer sales in the pre-model-year compliance data for the relevant vehicle style, and multiplied by the total volume estimated for that manufacturer and that style.

The tables below summarize some of the characteristics of the MY2015 based analysis fleet for Class 2b and Class 3 trucks.

Table 10-14 shows production by manufacturer and indicates that Ford is dominant with 45 percent of this market.

Table 10-14 Estimated MY2015 Production by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	20,828	2.8%
Fiat	126,916	16.9%
Ford	334,859	44.6%
General Motors	254,852	34.0%
Nissan	12,728	1.7%
Total	750,183	100.0%

Table 10-15 shows production by class with 74 percent of production in class 2b, those trucks with a GVW between 8,501 and 10,000 lbs.

Table 10-15 Estimated MY2015 Production by Class

GVW CLASS	PRODUCTION	PERCENT
2b (8,501-10,000 lbs.)	555,415	74.0%
3 (10,001-14,000 lbs.)	194,768	26.0%
Total	750,183	100.0%

Table 10-16 shows production by engine type. Diesel powered trucks make up a significant share (46 percent) of this market in comparison to light duty vehicles.

Table 10-16 Estimated MY2015 Production by Engine Type

ENGINE TYPE	PRODUCTION	PERCENT
Diesel	342,376	45.6%
Gasoline	160,018	21.3%
FFV	242,510	32.3%
CNG	5,279	0.8%
Total	750,183	100.0%

Table 10-17 shows production by drive type with more four-wheel drive vehicles (62 percent) than two-wheel drive vehicles (38 percent) in the MY 2015 medium/heavy-duty fleet.

Table 10-17 Estimated MY2015 Production by Drive

DRIVE	PRODUCTION	PERCENT
4WD	467,761	62.4%
FWD	19,863	2.6%
RWD	262,559	35.0%
Total	750,183	100.0%

The following tables show some of the characteristics of the baseline analysis fleet at the manufacturer level. Table 10-18 Table 10-19show production by manufacturer for class 2b and class 3 trucks respectively. As noted above Ford is the dominant manufacturer with 41 percent of the market in the class 2b and 56 percent of the market in the class 3 trucks. While General Motors trails Ford in the class 3 market with 22 percent of the market, they have almost as much of the class 2b market (38 percent). Fiat has a similar share as General Motors in the class 3 market (19 percent), but makes up about half as much of the class 2b market (16 percent). Both Nissan and Daimler play a small part in the class 2b market, and of the two, only Daimler has a small share in the class 3 market.

Table 10-18 Estimated MY2015 Production Class 2b by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	14,110	2.5%
Fiat	89,707	16.2%
Ford	226,725	40.8%
General Motors	212,145	38.2%
Nissan	12,728	2.3%
Total	555,415	100.0%

Table 10-19 Estimated MY2015 Production Class 3 by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	6,718	3.5%
Fiat	37,209	19.1%
Ford	108,134	55.5%
General Motors	42,707	21.9%
Nissan	-	0.0%
Total	194,768	100.0%

As noted above pickup trucks were the dominant body style in Class 2b and 3 trucks. Table 10-20 shows pickup truck production by manufacturer. Only three manufactures share this market with Ford the leader at 43 percent, followed by General Motors at 37 percent and Fiat at 19 percent.

Table 10-20 Estimated MY2015 Production Pickups by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	-	0.0%
Fiat	107,053	19.3%
Ford	239,835	43.3%
General Motors	206,772	37.4%
Nissan	-	0.0%
Total	553,660	100.0%

All five manufactures share the Class 2b and 3 van market. Table 10-21 shows van production by manufacturer. Ford is again dominant with 48 percent of the market followed by General Motors at 25 percent with the remainder divided among Fiat (10 percent), Daimler (11 percent) and Nissan (7 percent).

Table 10-21 Estimated MY2014 Production Vans by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	20,828	10.6%
Fiat	19,863	10.1%
Ford	95,024	48.4%
General Motors	48,080	24.5%
Nissan	12,728	6.5%
Total	196,523	100.0%

Table 10-22 and Table 10-23 give an indication of the significance of diesel powered trucks in the class 2b and 3 market. Table 10-22 shows the distribution of diesel trucks by manufacturer. Ford is the leader at 43 percent followed by General Motors at 28 percent and Fiat at 23 percent. Daimler plays a minor role in the diesel market with 6 percent of the market.

Table 10-22 Estimated MY2014 Production Diesel Powered Heavy-Duty Vehicles by Manufacturer

MANUFACTURER	PRODUCTION	PERCENT
Daimler	20,828	6.1%
Fiat	79,478	23.2%
Ford	147,075	43.0%
General Motors	94,995	27.7%
Nissan	-	0.0%
Total	342,376	100.0%

Table 10-23 shows diesel production as a percent of total production for each manufacturer. At either end of the spectrum are Nissan at 0 percent and Daimler at 100 percent. Of the producers with significant market share Fiat leads with 63 percent of its production in diesels, followed by Ford at 44 percent and General Motors at 37 percent.

Table 10-23 Estimated MY2014 Diesel Penetration by Manufacturer

MANUFACTURER	DIESEL PRODUCTION	TOTAL PRODUCTION	PERCENT DIESEL
Daimler	20,828	20,828	100.0%
Fiat	79,478	126,916	62.6%
Ford	147,075	334,859	43.9%
General Motors	94,995	254,852	37.3%
Nissan	-	12,728	0.0%
Total	342,376	750,183	45.6%

The resultant 2015 analysis fleet used in Method B is provided in detail at NHTSA's web site, along with all other inputs to and outputs from the Method B analysis.

10.1.2 Other Analysis Inputs

In addition to the inputs summarized above, the analysis of potential standards for HD pickups and vans makes use of a range of other estimates and assumptions specified as inputs to the CAFE modeling system. Some significant inputs (e.g., estimates of future fuel prices) also applicable to other MDHD segments are discussed below in Section IX. Others more specific to the analysis of HD pickups and vans are as follows:

10.1.2.1 Vehicle Survival and Mileage Accumulation

The analysis estimates the travel, fuel consumption, and emissions over the useful lives of vehicles produced during model years 2014-2030. Doing so requires initial estimates of these vehicles' survival rates (i.e., shares expected to remain in service) and mileage accumulation rates (i.e., anticipated annual travel by vehicles remaining in service), both as a function of vehicle vintage (i.e., age). These estimates are based on an empirical analysis of changes in the fleet of registered vehicles over time from HIS/Polk data, in the case of survival rates. The NPRM and Method A of the FRM use data collected as part of the last Vehicle In Use Survey (the 2002 VIUS) for the mileage accumulation schedule. Method A of the FRM uses mileage accumulation schedules from 2014 Polk/IHS odometer reading data. The changes to the VMT schedules for Method A of the current analysis are further described below in the Method A FRM specific changes.

10.1.2.2 Rebound Effect

Expressed as an elasticity of mileage accumulation with respect to the fuel cost per mile of operation, the agencies have applied a rebound effect of 10 percent for today's analysis. Other rebound effects are considered in sensitivity analyses in Sections D and E.

10.1.2.3 On-Road "Gap"

The model was run with a 20 percent adjustment to reflect differences between on-road and laboratory performance.

10.1.2.4 Fleet Population Profile

Though not reported here, cumulative fuel consumption and CO_2 emissions are presented in the accompanying EIS, and these calculations utilize estimates of the numbers of vehicles produced in each model year remaining in service in calendar year 2014. The initial age distribution of the registered vehicle population in 2014 is based on vehicle registration data acquired by NHTSA from R.L. Polk Company. For Method A, these values were updated to reflect newer data acquired by NHTSA from Polk.

10.1.2.5 Past Fuel Consumption Levels

Though not reported here, cumulative fuel consumption and CO_2 emissions are presented in the accompanying EIS, and these calculations require estimates of the performance of vehicles produced prior to model year 2014. Consistent with AEO 2014, the model was run with the assumption that gasoline and diesel HD pickups and vans averaged 14.9 mpg and 18.6 mpg, respectively, with gasoline versions averaging about 48 percent of production. For Method A, these values were updated to reflect AEO2015, such that gasoline and diesel versions were projected to average 16.0 mpg and 20.0 mpg, respectively.

10.1.2.6 Long-Term Fuel Consumption Levels

Though not reported here, longer-term estimates of fuel consumption and emissions are presented in the accompanying EIS. These estimates include calculations involving vehicle produced after MY 2030 and, consistent with AEO 2014, the model was run with the assumption that fuel consumption and CO_2 emission levels will continue to decline at 0.05 percent annually (compounded) after MY 2030.

10.1.2.7 Payback Period

To estimate in what sequence and to what degree manufacturers might add fuel-saving technologies to their respective fleets, the CAFE model iteratively ranks remaining opportunities (i.e., applications of specific technologies to specific vehicles) in terms of effective cost, primary components of which are the technology cost and the avoided fuel outlays, attempting to minimize effective costs incurred.[D] Depending on inputs, the model also assumes manufacturers may improve fuel consumption beyond requirements insofar as doing so will involve applications of technology at negative effective cost—i.e., technology application for which buyers' up-front costs are quickly paid back through avoided fuel outlays. This calculation includes only fuel outlays occurring within a specified payback period. For both Method A and Method B, a payback period of 6 months was applied for the dynamic baseline case, or Alternative 1b. Thus, for example, a manufacturer already in compliance with standards is projected to apply a fuel consumption improvement projected to cost $250 (i.e., as a cost that could be charged to the buyer at normal profit to the manufacturer) and reduce fuel costs by $500 in the first year of vehicle operation. The agencies have conducted the same analysis applying a payback period of 0 months for the flat baseline case, or Alternative 1a. For Method A, Alternative 1b is the primary analysis, and Alternative 1a is one of a range of cases included in the sensitivity analysis.

10.1.2.8 Civil Penalties

EPCA and EISA require that a manufacturer pay civil penalties if it does not have enough credits to cover a shortfall with one or both of the light-duty CAFE standards in a model year. While these provisions do not apply to HD pickups and vans, at this time, the CAFE model will show civil penalties owed in cases where available technologies and credits are estimated to be insufficient for a manufacturer to achieve compliance with a standard. These model-reported estimates have been excluded from this analysis. For Method A, this aspect of the model has

[D] Volpe CAFE Model, available at http://www.nhtsa.gov/fuel-economy been modified to also exclude from the calculation of "effective cost" used to select among available options to add specific technologies to specific vehicles.

10.1.2.9 Coefficients for Fatality Calculations

Both the NPRM and the current analysis consider the potential effects on crash safety of the technologies manufacturers may apply to their vehicles to meet each of the regulatory alternatives. NHTSA research has shown that vehicle mass reduction affects overall societal fatalities associated with crashes[E] and, most relevant to this rule, mass reduction in heavier light- and medium-duty vehicles has an overall beneficial effect on societal fatalities. Reducing the mass of a heavier vehicle involved in a crash with another vehicle(s) makes it less likely there will be fatalities among the occupants of the other vehicles. In addition to the effects of mass reduction, the analysis anticipates that these standards, by reducing the cost of driving HD pickups and vans, will lead to increased travel by these vehicles and, therefore, more crashes involving these vehicles. The Method B analysis considers overall impacts considering both of these factors, using a methodology similar to NHTSA's analyses for the MYs 2017 – 2025 CAFE and GHG emission standards.

The Method B analysis includes estimates of the extent to which HD pickups and vans produced during MYs 2014-2030 may be involved in fatal crashes, considering the mass, survival, and mileage accumulation of these vehicles, taking into account changes in mass and mileage accumulation under each regulatory alternative. These calculations make use of the same coefficients applied to light trucks in the MYs 2017-2025 CAFE rulemaking analysis. Baseline rates of involvement in fatal crashes are 13.03 and 13.24 fatalities per billion miles for vehicles with initial curb weights above and below 4,594 lbs, respectively. Considering that the data underlying the corresponding statistical analysis included observations through calendar year 2010, these rates are reduced by 9.6 percent to account for subsequent impacts of recent Federal Motor Vehicle Safety Standards (FMVSS) and anticipated behavioral changes (e.g., continued increases in seat belt use). For vehicles above 4,594 lbs—i.e., the majority of the HD pickup and van fleet—mass reduction is estimated to reduce the net incidence of highway fatalities by 0.34 percent per 100 lbs. of removed curb weight. For the few HD pickups and vans below 4,594 lbs, mass reduction is estimated to increase the net incidence of highway fatalities by 0.52 percent per 100 lbs. Consistent with DOT guidance, the social cost of highway fatalities is estimated using a value of statistical life (VSL) of $9.36m in 2014, increasing thereafter at 1.18 percent annually.

The Method A analysis uses the same methodology as described above, but applies coefficients that have been updated to reflect more current data, updated statistical analysis by NHTSA staff, and updated DOT guidance regarding the VSL. Baseline rates of involvement in fatal crashes are 16.06 and 14.35 fatalities per billion miles for pickups and vans with initial curb weights above and below 4,947 lbs, respectively. Considering that the data underlying the corresponding statistical analysis included observations through calendar year 2012, these rates are reduced by 9.6 percent to account for subsequent impacts of recent Federal Motor Vehicle Safety Standards (FMVSS) and anticipated behavioral changes (e.g., continued increases in seat

[E] U.S. DOT/NHTSA, *Relationships Between Fatality Risk Mass and Footprint in MY 2000-2007 PC and LTVs*, ID: NHTSA-2010-0131-0336, Posted August 21, 2012.

belt use). For vehicles above 4,947 lbs—i.e., the majority of the HD pickup and van fleet—mass reduction is estimated to reduce the net incidence of highway fatalities by 0.72 percent per 100 lbs. of removed curb weight. For HD pickups and vans below 4,947 lbs (accounting for any applied mass reduction), mass reduction is estimated to reduce the net incidence of highway fatalities by 0.10 percent per 100 lbs. Consistent with DOT guidance, the social cost of highway fatalities is estimated using a value of statistical life (VSL) of $9.4m from 2015 forward.

10.1.2.10 Compliance Credit Provisions

Today's analysis accounts for the potential to over comply with standards and thereby earn compliance credits, applying these credits to ensuring compliance requirements. In doing so, the agencies treat any unused carried-forward credits as expiring after five model years, consistent with current and standards. For today's analysis, the agencies are not estimating the potential to "borrow"—i.e., to carry credits back to past model years.

10.1.2.11 Emission Factors

While CAFE model calculates vehicular CO_2 emissions directly on a per-gallon basis using fuel consumption and fuel properties (density and carbon content), the model calculates emissions of other pollutants (methane, nitrogen oxides, ozone precursors, carbon monoxide, sulfur dioxide, particulate matter, and air toxics) on a per-mile basis. In doing so, the Method A analysis used corresponding emission factors estimated using EPA's MOVES model.[F] To estimate emissions (including CO_2) from upstream processes involved in producing, distributing, and delivering fuel, NHTSA has applied emission factors—all specified on a gram per gallon basis—derived from Argonne National Laboratory's GREET model.[G]

10.1.2.12 Refueling Time Benefits

To estimate the value of time savings associated with vehicle refueling, the Method A analysis used estimates that an average refueling event involves refilling 60 percent of the tank's capacity over the course of 3.5 minutes, at an hourly cost of $27.22.

10.1.2.13 External Costs of Travel

Changes in vehicle travel will entail economic externalities. To estimate these costs, the Method A analysis used estimates that congestion-, accident-, and noise-related externalities will total 5.1 ¢/mi., 2.8 ¢/mi., and 0.1 ¢/mi., respectively.

10.1.2.14 Ownership and Operating Costs

Method A results predict that the total cost of vehicle ownership and operation will change not just due to changes in vehicle price and fuel outlays, but also due to some other costs likely to vary with vehicle price. To estimate these costs, NHTSA has applied factors of 5.5 percent (of

[F] EPA MOVES model available at http://www3.epa.gov/otaq/models/moves/index.htm (last accessed Feb 23, 2015).

[G] GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) Model, Argonne National Laboratory, https://greet.es.anl.gov/.

price) for taxes and fees, 15.3 percent for financing, 19.2 percent for insurance, 1.9 percent for relative value loss. The Method A analysis also estimates that average vehicle resale value will increase by 25 percent of any increase in new vehicle price.

10.1.3 What Technologies Did the Agencies Consider

The agencies considered over 35 vehicle technologies that manufacturers could use to improve the fuel consumption and reduce CO_2 emissions of their vehicles during MYs 2021-2027. The majority of the technologies described in this section are readily available, well known and proven in other vehicle sectors, and could be incorporated into vehicles once production decisions are made. Other technologies considered may not currently be in production, but are beyond the research phase and under development, and are expected to be in production in highway vehicles over the next few years. These are technologies that are capable of achieving significant improvements in fuel economy and reductions in CO_2 emissions, at reasonable costs. The agencies did not consider technologies in the research stage because there is insufficient time for such technologies to move from research to production during the model years covered by this final action.

The technologies considered in the agencies' analysis are briefly described below. They fall into five broad categories: engine technologies, transmission technologies, vehicle technologies, electrification/accessory technologies, and hybrid technologies.

In this class of trucks and vans, diesel engines are installed in about half of all vehicles. The buyer's decision to purchase a diesel versus gasoline engine depends on several factors including initial purchase price, fuel operating costs, durability, towing capability and payload capacity amongst other reasons. As discussed in above, the agencies generally prefer to set standards that do not distinguish between fuel types where technological or market-based reasons do not strongly argue otherwise. However, as with Phase 1, we continue to believe that fundamental differences between spark ignition and compression ignition engines warrant unique fuel standards, which is also important in ensuring that our program maintains product choices available to vehicle buyers. Therefore, we are maintaining separate standards for gasoline and diesel vehicles. In the context of our technology discussion for heavy-duty pickups and vans, we are treating gasoline and diesel engines separately so each has a set of baseline technologies. We discuss performance improvements in terms of changes to those baseline engines. Our cost and inventory estimates contained elsewhere reflect the current fleet baseline with an appropriate mix of gasoline and diesel engines. Note that we are not basing these standards on a targeted switch in the mix of diesel and gasoline vehicles. We believe our standards require similar levels of technology development and cost for both diesel and gasoline vehicles. Hence the program is not intended to force, nor discourage, changes in a manufacturer's fleet mix between gasoline and diesel vehicles.

The following contains a description of technologies the agencies considered as potentially available in the rule timeframe, and hence, having potential to be part of a compliance pathway for these vehicles. Additionally, the agencies did not receive any comments indicating that the technology effectiveness estimates used in the determination of potential reductions in

GHGs and fuel consumption are not representative of the expected ranges for expected duty cycles.

10.1.3.1 Engine Technologies

The agencies reviewed the engine technology estimates used in the 2017-2025 light-duty rule, the 2014-2018 heavy-duty rule, and the 2015 NHTSA Technology Study. In doing so the agencies reconsidered all available sources and updated the estimates as appropriate. The section below describes both diesel and gasoline engine technologies considered for this program.

10.1.3.1.1 Low Friction Lubricants

One of the most basic methods of reducing fuel consumption in both gasoline and diesel engines is the use of lower viscosity engine lubricants. More advanced multi-viscosity engine oils are available today with improved performance in a wider temperature band and with better lubricating properties. This can be accomplished by changes to the oil base stock (*e.g.*, switching engine lubricants from a Group I base oils to lower-friction, lower viscosity Group III synthetic) and through changes to lubricant additive packages (*e.g.*, friction modifiers and viscosity improvers). The use of 5W-30 motor oil is now widespread and auto manufacturers are introducing the use of even lower viscosity oils, such as 5W-20 and 0W-20, to improve cold-flow properties and reduce cold start friction. However, in some cases, changes to the crankshaft, rod and main bearings and changes to the mechanical tolerances of engine components may be required. In all cases, durability testing will be required to ensure that durability is not compromised. The shift to lower viscosity and lower friction lubricants will also improve the effectiveness of valvetrain technologies such as cylinder deactivation, which rely on a minimum oil temperature (viscosity) for operation.

10.1.3.1.2 Engine Friction Reduction

In addition to low friction lubricants, manufacturers can also reduce friction and improve fuel consumption by improving the design of both diesel and gasoline engine components and subsystems. Approximately 10 percent of the energy consumed by a vehicle is lost to friction, and just over half is due to frictional losses within the engine.[H] Examples include improvements in low-tension piston rings, piston skirt design, roller cam followers, improved crankshaft design and bearings, material coatings, material substitution, more optimal thermal management, and piston and cylinder surface treatments. Additionally, as computer-aided modeling software continues to improve, more opportunities for evolutionary friction reductions may become available. All reciprocating and rotating components in the engine are potential candidates for friction reduction, and minute improvements in several components can add up to a measurable fuel efficiency improvement.

[H] "Impact of Friction Reduction Technologies on Fuel Economy," Fenske, G. Presented at the March 2009 Chicago Chapter Meeting of the 'Society of Tribologists and Lubricated Engineers' Meeting, March 18th, 2009. Available at: http://www.chicagostle.org/program/2008-2009/Impact%20of%20Friction%20Reduction%20Technologies%20on%20Fuel%20Economy%20-%20with%20VGs%20removed.pdf (last accessed July 9, 2009).

10.1.3.1.3 Engine Parasitic Demand Reduction

In addition to physical engine friction reduction, manufacturers can reduce the mechanical load on the engine from parasitics, such as oil, fuel, and coolant pumps. The high-pressure fuel pumps of direct-injection gasoline and diesel engines have particularly high demand. Example improvements include variable speed or variable displacement water pumps, variable displacement oil pumps, more efficient high pressure fuel pumps, valvetrain upgrades and shutting off piston cooling when not needed.

10.1.3.1.4 Coupled Cam Phasing

Valvetrains with coupled (or coordinated) cam phasing can modify the timing of both the inlet valves and the exhaust valves an equal amount by phasing the camshaft of an overhead valve engine.[I] For overhead valve engines, which have only one camshaft to actuate both inlet and exhaust valves, couple cam phasing is the only variable valve timing (VVT) implementation option available and requires only one cam phaser.[J] We also considered variable valve lift (VVL), which alters the intake valve lift in order to reduce pumping losses and more efficiently ingest air.

10.1.3.1.5 Cylinder Deactivation

In conventional spark-ignited engines throttling the airflow controls engine torque output. At partial loads, efficiency can be improved by using cylinder deactivation instead of throttling. Cylinder deactivation can improve engine efficiency by disabling or deactivating (usually) half of the cylinders when the load is less than half of the engine's total torque capability – the valves are kept closed, and no fuel is injected – as a result, the trapped air within the deactivated cylinders is simply compressed and expanded as an air spring, with reduced friction and heat losses. The active cylinders combust at almost double the load required if all of the cylinders were operating. Pumping losses are significantly reduced as long as the engine is operated in this "part-cylinder" mode.

Cylinder deactivation control strategy relies on setting maximum manifold absolute pressures or predicted torque within a range in which it can deactivate the cylinders. Noise and vibration issues reduce the operating range to which cylinder deactivation is allowed, although manufacturers are exploring vehicle changes that enable increasing the amount of time that cylinder deactivation might be suitable. Some manufacturers may choose to adopt active engine mounts and/or active noise cancellations systems to address Noise Vibration and Harshness (NVH) concerns and to allow a greater operating range of activation.

[I] Although couple cam phasing appears only in the single overhead cam and overhead valve branches of the decision tree, it is noted that a single phaser with a secondary chain drive would allow couple cam phasing to be applied to direct overhead cam engines. Since this would potentially be adopted on a limited number of direct overhead cam engines NHTSA did not include it in that branch of the decision tree.

[J] It is also noted that coaxial camshaft developments would allow other variable valve timing options to be applied to overhead valve engines. However, since they would potentially be adopted on a limited number of overhead valve engines, NHTSA did not include them in the decision tree.

Cylinder deactivation has seen a recent resurgence thanks to better valvetrain designs and engine controls. General Motors and Chrysler Group have incorporated cylinder deactivation across a substantial portion of their V8-powered lineups, including some heavy duty applications.

10.1.3.1.6 Stoichiometric Gasoline Direct Injection

SGDI engines inject fuel at high pressure directly into the combustion chamber (rather than the intake port in port fuel injection). SGDI requires changes to the injector design, an additional high pressure fuel pump, new fuel rails to handle the higher fuel pressures and changes to the cylinder head and piston crown design. Direct injection of the fuel into the cylinder improves cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency without the onset of combustion knock. Recent injector design advances, improved electronic engine management systems and the introduction of multiple injection events per cylinder firing cycle promote better mixing of the air and fuel, enhance combustion rates, increase residual exhaust gas tolerance and improve cold start emissions. SGDI engines achieve higher power density and match well with other technologies, such as boosting and variable valvetrain designs.

Most manufacturers have introduced vehicles with SGDI engines in light duty sectors, including GM and Ford and have announced their plans to increase dramatically the number of SGDI engines in their portfolios. SGDI has not been introduction on heavy duty applications at this time however as these largely dedicated heavy duty engines approach their redesign window, they are expected to become SGDI engines.

10.1.3.1.7 Turbocharging and Downsizing

The specific power of a naturally aspirated engine is primarily limited by the rate at which the engine is able to draw air into the combustion chambers. Turbocharging and supercharging (grouped together here as boosting) are two methods to increase the intake manifold pressure and cylinder charge-air mass above naturally aspirated levels. Boosting increases the airflow into the engine, thus increasing the specific power level, and with it the ability to reduce engine displacement while maintaining performance. This effectively reduces the pumping losses at lighter loads in comparison to a larger, naturally aspirated engine.

Almost every major manufacturer currently markets a vehicle with some form of boosting. While boosting has been a common practice for increasing performance for several decades, turbocharging has considerable potential to improve fuel economy and reduce CO_2 emissions when the engine displacement is also reduced. Specific power levels for a boosted engine often exceed 100 hp/L, compared to average naturally aspirated engine power densities of roughly 70 hp/L. As a result, engines can be downsized roughly 30 percent or higher while maintaining similar peak output levels. In the last decade, improvements to turbocharger turbine and compressor design have improved their reliability and performance across the entire engine operating range. New variable geometry turbines and ball-bearing center cartridges allow faster turbocharger spool-up (virtually eliminating the once-common “turbo lag”) while maintaining high flow rates for increased boost at high engine speeds. Low speed torque output has been dramatically improved for modern turbocharged engines. However, even with turbocharger improvements, maximum engine torque at very low engine speed conditions, for example launch from standstill, is increased less than at mid and high engine speed conditions. The potential to downsize engines may be less on vehicles with low displacement to vehicle mass ratios for example a very small displacement engine in a vehicle with significant curb weight, in order to provide adequate acceleration from standstill, particularly up grades or at high altitudes.

The use of GDI in combination with turbocharging and charge air cooling reduces the fuel octane requirements for knock limited combustion enabling the use of higher compression ratios and boosting pressures. Recently published data with advanced spray-guided injection systems and more aggressive engine downsizing targeted towards reduced fuel consumption and CO_2 emissions reductions indicate that the potential for reducing CO_2 emissions for turbocharged, downsized GDI engines may be as much as 15 to 30 percent relative to port-fuel-injected engines.[14,15,16,17,18] Confidential manufacturer data suggests an incremental range of fuel consumption and CO_2 emission reduction of 4.8 to 7.5 percent for turbocharging and downsizing. Other publicly-available sources suggest a fuel consumption and CO_2 emission reduction of 8 to 13 percent compared to current-production naturally-aspirated engines without friction reduction or other fuel economy technologies: a joint technical paper by Bosch and Ricardo suggesting fuel economy gain of 8 to 10 percent for downsizing from a 5.7 liter port injection V8 to a 3.6 liter V6 with direct injection using a wall-guided direct injection system; a Renault report suggesting a 11.9 percent NEDC fuel consumption gain for downsizing from a 1.4 liter port injection in-line 4-cylinder engine to a 1.0 liter in-line 4-cylinder engine, also with wall-guided direct injection; and a Robert Bosch paper suggesting a 13 percent NEDC gain for downsizing to a turbocharged DI engine, again with wall-guided injection. These reported fuel economy benefits show a wide range depending on the SGDI technology employed.

Note that for this analysis we determined that this technology path is only applicable to heavy duty applications that have operating conditions more closely associated with light duty vehicles. This includes vans designed mainly for cargo volume or modest payloads and having similar GCWR to light duty applications. These vans cannot tow trailers heavier than similar light duty vehicles and are largely already sharing engines of significantly smaller displacement and cylinder count compared to heavy duty vehicles designed mainly for trailer towing.

ACEEE commented that 10 percent of pick-ups in the heavy duty sector are candidates for turbocharging and downsizing if they do not require higher payloads or towing capacity. Other commenters suggested that downsizing that has occurred in light duty could also occur in heavy duty. As discussed above, the agencies evaluated turbocharging and downsizing in vehicles like vans which are not typically designed for extensive trailer towing. When we looked at pick-ups, we determined that consumers needing a pick-up without higher payload and trailer towing requirements would migrate to the lower cost light-duty versions which are typically identical in cabin size and seating as the heavy-duty versions but have less work capability. Because of this, in the agencies assessment, the heavy-duty pickups retained the high trailer towing and payload requirements and the corresponding larger engines. AAPC comments supported this approach as the correct combination of engine to intended use and even provided in their comments data indicating that turbocharged and downsized engines are more fuel efficient at lighter loads however under working conditions expected of a heavy-duty pick-up they are actually less fuel efficient than the larger engines.

10.1.3.1.8 Cooled Exhaust-Gas Recirculation

Cooled exhaust gas recirculation or Boosted EGR is a combustion concept that involves utilizing EGR as a charge diluent for controlling combustion temperatures and cooling the EGR prior to its introduction to the combustion system. Higher exhaust gas residual levels at part load conditions reduce pumping losses for increased fuel economy. The additional charge dilution enabled by cooled EGR reduces the incidence of knocking combustion and obviates the need for fuel enrichment at high engine power. This allows for higher boost pressure and/or compression ratio and further reduction in engine displacement and both pumping and friction losses while maintaining performance. Engines of this type use GDI and both dual cam phasing and discrete variable valve lift. The EGR systems considered in this final rule, consistent with the rule, will use a dual-loop system with both high and low pressure EGR loops and dual EGR coolers. The engines will also use single-stage, variable geometry turbocharging with higher intake boost pressure available across a broader range of engine operation than conventional turbocharged SI engines. Such a system is estimated to be capable of an additional 3 to 5 percent effectiveness relative to a turbocharged, downsized GDI engine without cooled-EGR. The agencies have also considered a more advanced version of such a cooled EGR system that employs very high combustion pressures by using dual stage turbocharging.

10.1.3.1.9 Lean-burn Combustion

The agencies considered the concept that gasoline engines that are normally stoichiometric mainly for emission reasons can run lean over a range of operating conditions and utilize diesel like aftertreatment systems to control NO_X. For this analysis, we determined that the modal operation nature of this technology is currently only beneficial at light loads and will not be appropriate for a heavy duty application purchase specifically for its high work and load capacity.

10.1.3.2 Diesel Engine Technologies

Diesel engines have several characteristics that give them superior fuel efficiency compared to conventional gasoline, spark-ignited engines. Pumping losses are much lower due to lack of (or greatly reduced) throttling. The diesel combustion cycle operates at a higher compression ratio, with a very lean air/fuel mixture, and turbocharged light-duty diesels typically achieve much higher torque levels at lower engine speeds than equivalent-displacement naturally-aspirated gasoline engines. Additionally, diesel fuel has a higher energy content per gallon.[K] However, diesel fuel also has a higher carbon to hydrogen ratio, which increases the amount of CO_2 emitted per gallon of fuel used by approximately 15 percent over a gallon of gasoline.

Based on confidential business information and the 2010 NAS Report, two major areas of diesel engine design could be improved during the timeframe of this final rule. These areas include aftertreatment improvements and a broad range of engine improvements.

[K] Burning one gallon of diesel fuel produces about 15 percent more carbon dioxide than gasoline due to the higher density and carbon to hydrogen ratio.

10.1.3.2.1 Aftertreatment Improvements

The HD diesel pickup and van segment has largely adopted the SCR type of aftertreatment system to comply with criteria pollutant emission standards. As the experience base for SCR expands over the next few years, many improvements in this aftertreatment system such as construction of the catalyst, thermal management, and reductant optimization may result in a reduction in the amount of fuel used in the process. However, due to uncertainties with these improvements regarding the extent of current optimization and future criteria emissions obligations, the agencies are not considering aftertreatment improvements as a fuel-saving technology in the rulemaking analysis.

10.1.3.2.2 Engine Improvements

Diesel engines in the HD pickup and van segment are expected to have several improvements in their base design in the 2021-2027 timeframe. These improvements include items such as improved combustion management, optimal turbocharger design, and improved thermal management.

10.1.3.3 Transmission Technologies

The agencies have also reviewed the transmission technology estimates used in the 2017-2015 light-duty and 2014-2018 heavy-duty final rules. In doing so, NHTSA and EPA considered or reconsidered all available sources including the 2015 NHTSA Technology Study and updated the estimates as appropriate. The section below describes each of the transmission technologies considered for this rule.

10.1.3.3.1 Automatic 8-Speed Transmissions

Manufacturers can also choose to replace 6-speed automatic transmissions with 8-speed automatic transmissions. Additional ratios allow for further optimization of engine operation over a wider range of conditions, but this is subject to diminishing returns as the number of speeds increases. As additional gear sets are added, additional weight and friction are introduced requiring additional countermeasures to offset these losses. Some manufacturers are replacing 6-speed automatics already, and 7 to 10-speed automatics have entered production.

10.1.3.3.2 High Efficiency Transmission

For this rule, a high efficiency transmission refers to some or all of a suite of incremental transmission improvement technologies that should be available within the 2019 to 2027 timeframe. The majority of these improvements address mechanical friction within the transmission. These improvements include but are not limited to: shifting clutch technology improvements, improved kinematic design, dry sump lubrication systems, more efficient seals, bearings and clutches (reducing drag), component superfinishing and improved transmission lubricants.

10.1.3.3.3 Secondary Axle Disconnect

The ability to disconnect some of the rotating components in the front axle on 4wd vehicles when the secondary axle is not needed for traction. This will reduce friction and increase fuel economy.

10.1.3.4 Electrification/Accessory Technologies

10.1.3.4.1 Electrical Power Steering or Electrohydraulic Power Steering

Electric power steering (EPS) or Electrohydraulic power steering (EHPS) provides a potential reduction in CO_2 emissions and fuel consumption over hydraulic power steering because of reduced overall accessory loads. This eliminates the parasitic losses associated with belt-driven power steering pumps which consistently draw load from the engine to pump hydraulic fluid through the steering actuation systems even when the wheels are not being turned. EPS is an enabler for all vehicle hybridization technologies since it provides power steering when the engine is off. EPS may be implemented on most vehicles with a standard 12V system. Some heavier vehicles may require a higher voltage system which may add cost and complexity.

10.1.3.4.2 Improved Accessories

The accessories on an engine, including the alternator, coolant and oil pumps are traditionally mechanically-driven. A reduction in CO_2 emissions and fuel consumption can be realized by driving them electrically, and only when needed ("on-demand").

Electric water pumps and electric fans can provide better control of engine cooling. For example, coolant flow from an electric water pump can be reduced and the radiator fan can be shut off during engine warm-up or cold ambient temperature conditions which will reduce warm-up time, reduce warm-up fuel enrichment, and reduce parasitic losses.

Indirect benefit may be obtained by reducing the flow from the water pump electrically during the engine warm-up period, allowing the engine to heat more rapidly and thereby reducing the fuel enrichment needed during cold operation and warm-up of the engine. Faster oil warm-up may also result from better management of the coolant warm-up period. Further benefit may be obtained when electrification is combined with an improved, higher efficiency engine alternator used to supply power to the electrified accessories.

Intelligent cooling can more easily be applied to vehicles that do not typically carry heavy payloads, so larger vehicles with towing capacity present a challenge, as these vehicles have high cooling fan loads.[L] However, towing vehicles tend to have large cooling system capacity and flow scaled to required heat rejection levels when under full load situations such as towing at GCWR in extreme ambient conditions. During almost all other situations, this design characteristic may result in unnecessary energy usage for coolant pumping and heat rejection to the radiator.

[L] In the CAFE model, improved accessories refers solely to improved engine cooling.

The agencies considered whether to include electric oil pump technology for the rulemaking. Because it is necessary to operate the oil pump any time the engine is running, electric oil pump technology has insignificant effect on efficiency. Therefore, the agencies decided to not include electric oil pump technology.

10.1.3.4.3 Mild Hybrid

Mild hybrid systems offer idle-stop functionality and a limited level of regenerative braking and power assist. These systems replace the conventional alternator with a belt or crank driven starter/alternator and may add high voltage electrical accessories (which may include electric power steering and an auxiliary automatic transmission pump). The limited electrical requirements of these systems allow the use of lead-acid batteries or supercapacitors for energy storage, or the use of a small lithium-ion battery pack.

10.1.3.4.4 Strong Hybrid

A hybrid vehicle is a vehicle that combines two significant sources of propulsion energy, where one uses a consumable fuel (like gasoline), and one is rechargeable (during operation, or by another energy source). Hybrid technology is well established in the U.S. light-duty market and more manufacturers are adding hybrid models to their lineups. Hybrids reduce fuel consumption through three major mechanisms:

- The internal combustion engine can be optimized (through downsizing, modifying the operating cycle, or other control techniques) to operate at or near its most efficient point more of the time. Power loss from engine downsizing can be mitigated by employing power assist from the secondary power source.

- A significant amount of the energy normally lost as heat while braking can be captured and stored in the energy storage system for later use.

- The engine is turned off when it is not needed, such as when the vehicle is coasting or when stopped.

Hybrid vehicles utilize some combination of the three above mechanisms to reduce fuel consumption and CO_2 emissions. The effectiveness of fuel consumption and CO_2 reduction depends on the utilization of the above mechanisms and how aggressively they are pursued. One area where this variation is particularly prevalent is in the choice of engine size and its effect on balancing fuel economy and performance. Some manufacturers choose not to downsize the engine when applying hybrid technologies. In these cases, overall performance (acceleration) is typically improved beyond the conventional engine. However, fuel efficiency improves less than if the engine was downsized to maintain the same performance as the conventional version. The non-downsizing approach is used for vehicles like trucks where towing and/or hauling are an integral part of their performance requirements. In these cases, if the engine is downsized, the battery can be quickly drained during a long hill climb with a heavy load, leaving only a downsized engine to carry the entire load. Because towing capability is currently a heavily-marketed truck attribute, manufacturers are hesitant to offer a truck with downsized engine which can lead to a significantly diminished towing performance when the battery state of charge level is low, and therefore engines are traditionally not downsized for these vehicles.

Strong Hybrid technology utilizes an axial electric motor connected to the transmission input shaft and connected to the engine crankshaft through a clutch. The axial motor is a motor/generator that can provide sufficient torque for launch assist, all electric operation, and the ability to recover significant levels of braking energy.

10.1.3.4.5 Air Conditioning Systems

These technologies include improved hoses, connectors and seats for leakage control. They also include improved compressors, expansion valves, heat exchangers and the control of these components for the purposes of improving tailpipe CO_2 emissions as a result of A/C use[M].

10.1.3.5 Vehicle Technologies

10.1.3.5.1 Mass Reduction

Mass reduction is a technology that can be used in a manufacturer's strategy to meet the Heavy Duty Greenhouse Gas Phase 2 standards. Vehicle mass reduction (also referred to as "down-weighting" or 'light-weighting"), decreases fuel consumption and GHG emissions by reducing the energy demand needed to overcome inertia forces, and rolling resistance. Automotive companies have worked with mass reduction technologies for many years and a lot of these technologies have been used in production vehicles. The weight savings achieved by adopting mass reduction technologies offset weight gains due to increased vehicle size, larger powertrains, and increased feature content (sound insulation, entertainment systems, improved climate control, panoramic roof, etc.). Sometimes mass reduction has been used to increase vehicle towing and payload capabilities.

Manufacturers employ a systematic approach to mass reduction, where the net mass reduction is the addition of a direct component or system mass reduction, also referred to as primary mass reduction, plus the additional mass reduction taken from indirect ancillary systems and components, also referred to as secondary mass reduction or mass compounding. There are more secondary mass reductions achievable for light-duty vehicles compared to heavy-duty vehicles, which are limited due to the higher towing and payload requirements for these vehicles.

Mass reduction can be achieved through a number of approaches, even while maintaining other vehicle functionalities. As summarized by NAS in its 2011 light duty vehicle report,[N] there are two key strategies for primary mass reduction: 1) changing the design to use less material; 2) substituting lighter materials for heavier materials.

[M] See RIA Chapter 2.3 for more detailed technology descriptions.

[N] Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy; National Research Council, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles," 2011. Available at http://www.nap.edu/catalog.php?record_id=12924 (last accessed Jun 27, 2012).

The first key strategy of using less material compared to the baseline component can be achieved by optimizing the design and structure of vehicle components, systems and vehicle structure. Vehicle manufacturers have long used these continually-improving CAE tools to optimize vehicle designs. For example, the Future Steel Vehicle (FSV) project[O] sponsored by WorldAutoSteel used three levels of optimization: topology optimization, low fidelity 3G (Geometry Grade and Gauge) optimization, and subsystem optimization, to achieve 30 percent mass reduction in the body structure of a vehicle with a mild steel unibody structure. Using less material can also be achieved through improving the manufacturing process, such as by using improved joining technologies and parts consolidation. This method is often used in combination with applying new materials.

The second key strategy to reduce mass of an assembly or component involves the substitution of lower density and/or higher strength materials. Material substitution includes replacing materials, such as mild steel, with higher-strength and advanced steels, aluminum, magnesium, and composite materials. In practice, material substitution tends to be quite specific to the manufacturer and situation. Some materials work better than others for particular vehicle components, and a manufacturer may invest more heavily in adjusting to a particular type of advanced material, thus complicating its ability to consider others. The agencies recognize that like any type of mass reduction, material substitution has to be conducted not only with consideration to maintaining equivalent component strength, but also to maintaining all the other attributes of that component, system or vehicle, such as crashworthiness, durability, and noise, vibration and harshness (NVH).

If vehicle mass is reduced sufficiently through application of the two primary strategies of using less material and material substitution described above, secondary mass reduction options may become available. Secondary mass reduction is enabled when the load requirements of a component are reduced as a result of primary mass reduction. If the primary mass reduction reaches a sufficient level, a manufacturer may use a smaller, lighter, and potentially more efficient powertrain while maintaining vehicle acceleration performance. If a powertrain is downsized, a portion of the mass reduction may be attributed to the reduced torque requirement which results from the lower vehicle mass. The lower torque requirement enables a reduction in engine displacement, changes to transmission torque converter and gear ratios, and changes to final drive gear ratio. The reduced powertrain torque enables the downsizing and/or mass reduction of powertrain components and accompanying reduced rotating mass (e.g., for transmission, driveshafts/halfshafts, wheels, and tires) without sacrificing powertrain durability. Likewise, the combined mass reductions of the engine, drivetrain, and body in turn reduce stresses on the suspension components, steering components, wheels, tires, and brakes, which can allow further reductions in the mass of these subsystems. Reducing the unsprung masses such as the brakes, control arms, wheels, and tires further reduce stresses in the suspension mounting points, which will allow for further optimization and potential mass reduction. However, pickup trucks have towing and hauling requirements which must be taken

[O] SAE World Congress, "Focus B-pillar 'tailor rolled' to 8 different thicknesses," Feb. 24, 2010. Available at http://www.sae.org/mags/AEI/7695 (last accessed Jun. 10, 2012).

into account when determining the amount of secondary mass reduction that is possible and so it is less than that of passenger cars.

In 2015, EPA completed a multi-year study with FEV North America, Inc. on the lightweighting of a light-duty pickup truck, a 2011 GMC Silverado, titled "Mass Reduction and Cost Analysis –Light-Duty Pickup Trucks Model Years 2020-2025."[P] Results contain a cost curve for various mass reduction percentages with the main solution being evaluated for a 20.8 percent (510 kg/1122 lb.) mass reduction resulting in an increased direct incremental manufacturing cost of $2228. In addition, the report outlines the compounding effect that occurs in a vehicle with performance requirements including hauling and towing. Secondary mass evaluation was performed on a component level based on an overall 20 percent vehicle mass reduction. Results revealed 84 kg of the 510 kg, or 20 percent of the overall mass reduction, were from secondary mass reduction. Information on this study is summarized in SAE paper 2015-01-0559. NHTSA has also sponsored an on-going pickup truck lightweighting project. This project uses a more recent baseline vehicle, a MY 2014 GMC Silverado, and the project will be finished in 2016. Both projects will be utilized for the light-duty GHG and CAFE Midterm Evaluation mass reduction baseline characterization and may be used to update assumptions of mass reduction for HD pickups and vans for the final Phase 2 rulemaking.

In order to determine if technologies identified on light duty trucks are applicable to heavy-duty pickups, EPA contracted with FEV North America, Inc. to perform a scaling study in order to evaluate whether the technologies identified for the light-duty truck would be applicable for a heavy-duty pickup truck. In this study a 2013MY Silverado 2500, a 2007 Mercedes Sprinter and a 2010 Renault Master[Q] were analyzed. A 2013MY Silverado 2500 was purchased and torn down. The mass reduction results were 18.9 percent mass reduction at a cost of $2372 and focused on aluminum intensive with AHSS frame. The Mercedes Sprinter and Renault Master analyses were performed based on information from the A2Mac1 database. The results were 18.15 percent mass reduction at a cost add of $2,293 for the Mercedes Sprinter and 18.55 percent mass reduction at a cost add of $2293 for the Master.

In September 2015, Ford announced that its MY 2017 F-Series Super duty pickup (F250) would be manufactured with an aluminum body and overall the truck will be 350 lbs. lighter (5 percent-6 percent) than the current gen truck with steel.[R,S] This is less overall mass reduction than the resultant lightweighting effort on the MY 2015 F-150, which achieved up to 750 lb decrease in curb weight (12 percent-13 percent) per vehicle.[T] Strategies were employed by Ford in the F250 to "improve the productivity of the Super Duty." In addition, Ford added several safety systems (and consequent mass) including cameras, lane departure warning, brake assist,

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[P] "Mass Reduction and Cost Analysis – Light-Duty Pickup Trucks Model Years 2020-2025," FEV, North America, Inc., April 2015, Document no. EPA-420-R-15-006.

[Q] "Mass Reduction and Cost Analysis Heavy Duty Pickup Truck and Light Commercial Vans," 2016, EPA-420-D-16-003.

[R] http://www.techtimes.com/articles/87961/20150925/ford-s-2017-f-250-super-duty-with-an-aluminum-body-is-the-toughest-smartest-and-most-capable-super-duty-ever.htm, September 25, 2015.

[S] https://www.ford.com/trucks/superduty/2017/.

[T] "2008/9 Blueprint for Sustainability," Ford Motor Company. Available at: http:// www.ford.com/go/sustainability (last accessed February 8, 2010).

etc. More details on the F250 will be known once it is released; however, a review of the F150 vehicle aluminum intensive design shows that it has an aluminum cab structure, body panels, and suspension components, as well as a high strength steel frame and a smaller, lighter and more efficient engine. The Executive Summary to Ducker Worldwide's 2014 report[U] states that the MY 2015 F-150 contains 1080 lbs. of aluminum with at least half being aluminum sheet and extrusions for body and closures. Ford's engine range for its light duty truck fleet includes a 2.7L EcoBoost V-6. The integrated loop, between Ford and the aluminum sheet suppliers, of aluminum manufacturing scrap and new aluminum sheet is integral to making aluminum a feasible lightweighting technology option for Ford. It is also possible that the strategy of aluminum body panels will be applied to the heavy duty F-350 version when it is redesigned.[V]

The RIA for this rulemaking shows that 10 percent or less mass reduction is part of the projected strategy for compliance for HD pickups and vans. The cost and effectiveness assumptions for mass reduction technology are described in the RIA.

10.1.3.5.2 Low Rolling Resistance Tires

Tire rolling resistance is the frictional loss associated mainly with the energy dissipated in the deformation of the tires under load and thus influences fuel efficiency and CO_2 emissions. Other tire design characteristics (*e.g.*, materials, construction, and tread design) influence durability, traction (both wet and dry grip), vehicle handling, and ride comfort in addition to rolling resistance. A typical LRR tire's attributes will include: increased tire inflation pressure, material changes, and tire construction with less hysteresis, geometry changes (*e.g.*, reduced aspect ratios), and reduction in sidewall and tread deflection. These changes will generally be accompanied with additional changes to suspension tuning and/or suspension design.

10.1.3.5.3 Aerodynamic Drag Reduction

Many factors affect a vehicle's aerodynamic drag and the resulting power required to move it through the air. While these factors change with air density and the square and cube of vehicle speed, respectively, the overall drag effect is determined by the product of its frontal area and drag coefficient, Cd. Reductions in these quantities can therefore reduce fuel consumption and CO_2 emissions. Although frontal areas tend to be relatively similar within a vehicle class (mostly due to market-competitive size requirements), significant variations in drag coefficient can be observed. Significant changes to a vehicle's aerodynamic performance may need to be implemented during a redesign (*e.g.*, changes in vehicle shape). However, shorter-term aerodynamic reductions, with a somewhat lower effectiveness, may be achieved through the use of revised exterior components (typically at a model refresh in mid-cycle) and add-on devices that currently being applied. The latter list will include revised front and rear fascias, modified

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[U] "2015 North American Light Vehicle Aluminum Content Study – Executive Summary," June 2014, http://www.drivealuminum.org/research-resources/PDF/Research/2014/2014-ducker-report (last accessed February 26, 2015).
[V] http://www.foxnews.com/leisure/2014/09/30/ford-confirms-increased-aluminum-use-on-next-gen-super-duty-pickups/.

front air dams and rear valances, addition of rear deck lips and underbody panels, and lower aerodynamic drag exterior mirrors.

10.1.4 How Did the Agencies Determine the Costs and Effectiveness of Each of These Technologies

Building on the technical analysis underlying the 2017-2025 MY light-duty vehicle rule, the 2014-2018 MY heavy-duty vehicle rule, and the 2015 NHTSA Technology Study, the agencies took a fresh look at technology cost and effectiveness values for purposes of this rule. For costs, the agencies reconsidered both the direct (or "piece") costs and indirect costs of individual components of technologies. For the direct costs, the agencies followed a bill of materials (BOM) approach employed by the agencies in the light-duty rule as well as referencing costs from the 2014-2018 MY heavy-duty vehicle rule and a new cost survey performed by Tetra Tech in 2014.

For two technologies, stoichiometric gasoline direct injection (SGDI) and turbocharging with engine downsizing, the agencies relied to the extent possible on the available tear-down data and scaling methodologies used in EPA's ongoing study with FEV, Incorporated. This study consists of complete system tear-down to evaluate technologies down to the nuts and bolts to arrive at very detailed estimates of the costs associated with manufacturing them.[W]

For the other technologies, considering all sources of information and using the BOM approach, the agencies worked together intensively to determine component costs for each of the technologies and build up the costs accordingly. Where estimates differ between sources, we have used engineering judgment to arrive at what we believe to be the best cost estimate available today, and explained the basis for that exercise of judgment.

Once costs were determined, they were adjusted to ensure that they were all expressed in 2012 dollars (see Section IX.B.1.e of this Preamble), and indirect costs were accounted for using a methodology consistent with the new ICM approach developed by EPA and used in the Phase 1 rule, and the 2012-2016 and 2017-2025 light-duty rules. NHTSA and EPA also reconsidered how costs should be adjusted by modifying or scaling content assumptions to account for differences across the range of vehicle sizes and functional requirements, and adjusted the associated material cost impacts to account for the revised content. We present the individual technology costs used in this analysis in Chapter 2.12 of the Draft RIA.

Regarding estimates for technology effectiveness, the agencies used the estimates from the 2014 Southwest Research Institute study as a baseline, which was designed specifically to inform this rulemaking. In addition, the agencies used 2017-2025 light-duty rule as a reference, and adjusted these estimates as appropriate, taking into account the unique requirement of the heavy-duty test cycles to test at curb weight plus half payload versus the light-duty requirement of curb plus 300 lb. The adjustments were made on an individual technology basis by assessing the specific impact of the added load on each technology when compared to the use of the

[W] U.S. Environmental Protection Agency, "Draft Report – Light-Duty Technology Cost Analysis Pilot Study," Contract No. EP-C-07-069, Work Assignment 1-3, September 3, 2009.

technology on a light-duty vehicle. The agencies also considered other sources such as the 2010 NAS Report, recent compliance data, and confidential manufacturer estimates of technology effectiveness. The agencies reviewed effectiveness information from the multiple sources for each technology and ensured that such effectiveness estimates were based on technology hardware consistent with the BOM components used to estimate costs. Together, the agencies compared the multiple estimates and assessed their validity, taking care to ensure that common BOM definitions and other vehicle attributes such as performance and drivability were taken into account.

The agencies note that the effectiveness values estimated for the technologies may represent average values applied to the baseline fleet described earlier, and do not reflect the potentially limitless spectrum of possible values that could result from adding the technology to different vehicles. For example, while the agencies have estimated an effectiveness of 0.5 percent for low friction lubricants, each vehicle could have a unique effectiveness estimate depending on the baseline vehicle's oil viscosity rating. Similarly, the reduction in rolling resistance (and thus the improvement in fuel efficiency and the reduction in CO_2 emissions) due to the application of LRR tires depends not only on the unique characteristics of the tires originally on the vehicle, but on the unique characteristics of the tires being applied, characteristics which must be balanced between fuel efficiency, safety, and performance. Aerodynamic drag reduction is much the same—it can improve fuel efficiency and reduce CO_2 emissions, but it is also highly dependent on vehicle-specific functional objectives. For purposes of this final rule, the agencies believe that employing average values for technology effectiveness estimates is an appropriate way of recognizing the potential variation in the specific benefits that individual manufacturers (and individual vehicles) might obtain from adding a fuel-saving technology.

The assessment of the technology effectiveness and costs was determined from a combination of sources. First an assessment was performed by SwRI under contract with the agencies to determine the effectiveness and costs on several technologies that were generally not considered in the Phase 1 GHG rule time frame. Some of the technologies were common with the light-duty assessment but the effectiveness and costs of individual technologies were appropriately adjusted to match the expected effectiveness and costs when implemented in a heavy-duty application. Finally, the agencies performed extensive outreach to suppliers of engine, transmission and vehicle technologies applicable to heavy-duty applications to get industry input on cost and effectiveness of potential GHG and fuel consumption reducing technologies. The agencies did not receive comments disputing the expected technology effectiveness values or costs developed with input from industry.

To achieve the levels of the Phase 2 standards for gasoline and diesel powered heavy-duty vehicles, a combination of the technologies previously discussed will be required respective to unique gasoline and diesel technologies and their challenges. Although some of the technologies may already be implemented in a portion of heavy-duty vehicles, none of the technologies discussed are considered ubiquitous in the heavy-duty fleet. Also, as will be expected, the available test data show that some vehicle models will not need the full complement of available technologies to achieve these standards. Furthermore, many technologies can be further improved (e.g., aerodynamic improvements) from today's best levels, and so allow for compliance without needing to apply a technology that a manufacturer might deem less desirable.

Technology costs for HD pickups and vans are shown in Table 10-24. These costs reflect direct and indirect costs to the vehicle manufacturer for the 2021 model year. See Chapter 2.11 of the RIA for a more complete description of the basis of these costs.

Table 10-24 Technology Costs for HD Pickups/Vans Inclusive of Indirect Cost Markups for MY2021 (2012$)

TECHNOLOGY	GASOLINE	DIESEL
Engine changes to accommodate low friction lubes	$6	$6
Engine friction reduction – level 1	$116	$116
Engine friction reduction – level 2	$254	$254
Dual cam phasing	$183	$183
Cylinder deactivation	$196	N/A
Stoichiometric gasoline direct injection	$451	N/A
Turbo improvements	N/A	$16
Cooled EGR	$373	$373
Turbocharging & downsizing[a]	$671	N/A
"Right-sized" diesel from larger diesel	N/A	$0
8s automatic transmission (increment to 6s automatic transmission)	$457	$457
Improved accessories – level 1	$82	$82
Improved accessories – level 2	$132	$132
Low rolling resistance tires – level 1	$10	$10
Passive aerodynamic improvements (aero 1)	$51	$51
Passive plus Active aerodynamic improvements (aero2)	$230	$230
Electric (or electro/hydraulic) power steering	$151	$151
Mass reduction (10% on a 6500 lb vehicle)	$318	$318
Driveline friction reduction	$139	$139
Stop-start (no regenerative braking)	$539	$539
Mild HEV	$2730	$2730
Strong HEV, without inclusion of any engine changes	$6779	$6779

Note:
[a] Cost to downsize from a V8 OHC to a V6 OHC engine with twin turbos.

As explained above, the CAFE model works by adding technologies in an incremental fashion to each particular vehicle in a manufacturer's fleet until that fleet complies with the imposed standards. It does this by following a predefined set of decision trees whereby the particular vehicle is placed on the appropriate decision tree and it follows the predefined progression of technology available on that tree. At each step along the tree, a decision is made regarding the cost of a given technology relative to what already exists on the vehicle along with the fuel consumption improvement it provides relative to the fuel consumption at the current location on the tree, prior to deciding whether to take that next step on the tree or remain in the current location. Because the model works in this way, the input files must be structured to provide costs and effectiveness values for each technology relative to whatever technologies have been added in earlier steps along the tree. Table 10-25presents the cost and effectiveness values used in the CAFE model input files.

Table 10-25 CAFE Model Input Values for Cost & Effectiveness for Given Technologies[a]

TECHNOLOGY	FC SAVINGS	INCREMENTAL COST (2012$)[A,B,C]		
		2021	2025	2027
Improved Lubricants and Engine Friction Reduction	1.60%	24	24	23
Coupled Cam Phasing (SOHC)	3.82%	48	43	39
Dual Variable Valve Lift (SOHC)	2.47%	42	37	34
Cylinder Deactivation (SOHC)	3.70%	34	30	27
Intake Cam Phasing (DOHC)	0.00%	48	43	39
Dual Cam Phasing (DOHC)	3.82%	46	40	37
Dual Variable Valve Lift (DOHC)	2.47%	42	37	34
Cylinder Deactivation (DOHC)	3.70%	34	30	27
Stoichiometric Gasoline Direct Injection (OHC)	0.50%	71	61	56
Cylinder Deactivation (OHV)	3.90%	216	188	172
Variable Valve Actuation (OHV)	6.10%	54	47	43
Stoichiometric Gasoline Direct Injection (OHV)	0.50%	71	61	56
Engine Turbocharging and Downsizing				
Small Gasoline Engines	8.00%	518	441	407
Medium Gasoline Engines	8.00%	-12	-62	-44
Large Gasoline Engines	8.00%	623	522	456
Cooled Exhaust Gas Recirculation	3.04%	382	332	303
Cylinder Deactivation on Turbo/downsized Eng.	1.70%	33	29	26
Lean-Burn Gasoline Direct Injection	4.30%	1,758	1,485	1,282
Improved Diesel Engine Turbocharging	2.51%	22	19	18
Engine Friction & Parasitic Reduction				
Small Diesel Engines	3.50%	269	253	213
Medium Diesel Engines	3.50%	345	325	273
Large Diesel Engines	3.50%	421	397	334
Downsizing of Diesel Engines (V6 to I-4)	11.10%	0	0	0
8-Speed Automatic Transmission[d]	5.00%	482	419	382
Electric Power Steering	1.00%	160	144	130

Improved Accessories (Level 1)	0.93%	93	83	75
Improved Accessories (Level 2)	0.93%	57	54	46
Stop-Start System	1.10%	612	517	446
Integrated Starter-Generator	3.20%	1,040	969	760
Strong Hybrid Electric Vehicle	17.20%	3,038	2,393	2,133
Mass Reduction (5%)	1.50%	0.28	0.24	0.21
Mass Reduction (additional 5%)	1.50%	0.87	0.75	0.66
Reduced Rolling Resistance Tires	1.10%	10	9	9
Low-Drag Brakes	0.40%	106	102	102
Driveline Friction Reduction	0.50%	153	137	124
Aerodynamic Improvements (10%)	0.70%	58	52	47
Aerodynamic Improvements (add'l 10%)	0.70%	193	182	153

Notes:
[a] Values for other model years available in CAFE model input files available at NHTSA web site.
[b] For mass reduction, cost reported on mass basis (per pound of curb weight reduction).
[c] The model output has been adjusted to 2013$
[d] 8 speed automatic transmission costs include costs for high efficiency gearbox and aggressive shift logic whereas those costs were kept separate in prior analyses.

In addition to the base technology cost and effectiveness inputs described above, the CAFE model accommodates inputs to adjust accumulated effectiveness under circumstances when combining multiple technologies could result in underestimation or overestimation of total incremental effectiveness relative to an "unevolved" baseline vehicle. These so-called synergy factors may be positive, where the combination of the technologies results in greater improvement than the additive improvement of each technology, or negative, where the combination of the technologies is lower than the additive improvement of each technology. The synergy factors used in the NPRM and Method B of the FRM are described in Table 10-26. Method A of the FRM uses synergies derived from a simulation project NHTSA undertook with Autnomie Argonne National Lab. A description of these changes is given Section D(8).

Table 10-26 Technology Pair Effectiveness Synergy Factors for HD Pickups and Vans

TECHNOLOGY PAIR	ADJUSTMENT		TECHNOLOGY PAIR	ADJUSTMENT
8SPD/CCPS	-4.60%		IATC/CCPS	-1.30%
8SPD/DEACO	-4.60%		IATC/DEACO	-1.30%
8SPD/ICP	-4.60%		IATC/ICP	-1.30%
8SPD/TRBDS1	4.60%		IATC/TRBDS1	1.30%
AERO2/SHEV1	1.40%		MR1/CCPS	0.40%
CCPS/IACC1	-0.40%		MR1/DCP	0.40%
CCPS/IACC2	-0.60%		MR1/VVA	0.40%
DCP/IACC1	-0.40%		MR2/ROLL1	-0.10%
DCP/IACC2	-0.60%		MR2/SHEV1	-0.40%
DEACD/IATC	-0.10%		NAUTO/CCPS	-1.70%
DEACO/IACC2	-0.80%		NAUTO/DEACO	-1.70%
DEACO/MHEV	-0.70%		NAUTO/ICP	-1.70%
DEACS/IATC	-0.10%		NAUTO/SAX	-0.40%
DTURB/IATC	1.00%		NAUTO/TRBDS1	1.70%
DTURB/MHEV	-0.60%		ROLL1/AERO1	0.10%
DTURB/SHEV1	-1.00%		ROLL1/SHEV1	1.10%
DVVLD/8SPD	-0.60%		ROLL2/AERO2	0.20%
DVVLD/IACC2	-0.80%		SHFTOPT/MHEV	-0.30%
DVVLD/IATC	-0.60%		TRBDS1/MHEV	0.80%
DVVLD/MHEV	-0.70%		TRBDS1/SHEV1	-3.30%
DVVLS/8SPD	-0.60%		TRBDS1/VVA	-8.00%
DVVLS/IACC2	-0.80%		TRBDS2/EPS	-0.30%
DVVLS/IATC	-0.50%		TRBDS2/IACC2	-0.30%
DVVLS/MHEV	-0.70%		TRBDS2/NAUTO	-0.50%
			VVA/IACC1	-0.40%
			VVA/IACC2	-0.60%
			VVA/IATC	-0.60%

The CAFE model also accommodates inputs to adjust accumulated incremental costs under circumstances when the application sequence could result in underestimation or overestimation of total incremental costs relative to an “unevolved” baseline vehicle. For today’s analysis, the agencies have applied one such adjustment, increasing the cost of medium-sized gasoline engines by $513 in cases where turbocharging and engine downsizing is applied with variable valve actuation.

The analysis performed using Method A also applied cost inputs to address some costs encompassed neither by the agencies’ estimates of the direct cost to apply these technologies, nor by the agencies’ methods for “marking up” these costs to arrive at increases in the new vehicle purchase costs. To account for the additional costs that could be incurred if a technology is applied and then quickly replaced, the CAFE model accommodates inputs specifying a "stranded capital cost" specific to each technology. For this analysis, the model was run with inputs to apply about $78 of additional cost (per engine) if gasoline engine turbocharging and downsizing (separately for each "level" considered) is applied and then immediately replaced, declining steadily to zero by the tenth model year following initial application of the technology. The model also accommodates inputs specifying any additional changes owners might incur in maintenance and post-warranty repair costs. For this analysis, the model was run with inputs indicating that vehicles equipped with less rolling-resistant tires could incur additional tire replacement costs equivalent to $21-$23 (depending on model year) in additional costs to purchase the new vehicle. The agencies did not, however, include inputs specifying any potential changes repair costs that might accompany application of any of the above technologies. A sensitivity analysis using Method A, discussed below, includes a case in which repair costs are estimated using factors consistent with those underlying the indirect cost multipliers used to markup direct costs for the agencies' central analysis.

10.1.5 Regulatory Alternatives Considered by the Agencies

As discussed above, the model considers regulatory alternatives. The results of regulatory alternatives are considered relative to a "no action" alternative where existing standards persist, but no further regulatory action is taken (in this case the MY2018 standards from Phase I are the last regulatory action taken). The agencies also considered four regulatory alternatives. The preferred alternative with a standard that increases 2.5 percent in stringency annually for MY's 2021-2027, and three others with annual increases in stringency of: 2.0 percent, 3.5 percent, and 4.0 percent for MY's 2021-2025. For each of the "action alternatives" (i.e., those involving stringency increases beyond the no-action alternative), the annual stringency increases are applied as follows: An annual stringency increase of *r* is applied by multiplying the model year 2020 target functions (identical to those applicable to model year 2018) by 1 – *r* to define the model year 2021 target functions, multiplying the model year 2021 target functions by 1 – *r* to define the model year 2022 target functions, continuing through 2025 for all alternatives except for the preferred Alternative 3 which extends through 2027. In summary, the agencies have considered the following five regulatory alternatives in the CAFE model.

Table 10-27 Considered Regulatory Alternatives

REGULATORY ALTERNATIVE	ANNUAL STRINGENCY INCREASE		
	2019-2020	2021-2025	2026-2027
1: No Action	None	None	None
2: 2.0%/y	None	2.0%	None
3: 2.5%/y	None	2.5%	2.5%
4: 3.5%/y	None	3.5%	None
5: 4.0%/y	None	4.0%	None

10.1.6 NPRM Modifications of the Model

The NPRM analysis (and the current analysis) reflect several changes made to the model since 2012, when NHTSA used the model to estimate the effects, costs, and benefits of final CAFE standards for light-duty vehicles produced during MYs 2017-2021, and augural standards for MYs 2022-2025. Some of these changes specifically enable analysis of potential fuel consumption standards (and, hence, CO_2 emissions standards harmonized with fuel consumption standards) for heavy-duty pickups and vans; other changes implement more general improvements to the model. Key changes include the following:

- Changes to accommodate standards for heavy-duty pickups and vans, including attribute-based standards involving targets that vary with "work factor."
- Explicit calculation of test weight, taking into account test weight "bins" and differences in the definition of test weight for light-duty vehicles (curb weight plus 300 pound) and heavy-duty pickups and vans (average of GVWR and curb weight).
- Procedures to estimate increases in payload when curb weight is reduced, increases in towing capacity if GVWR is reduced, and calculation procedures to correspondingly update calculated work factors.
- Expansion of model inputs, procedures, and outputs to accommodate technologies not included in prior analyses.
- Changes to the algorithm used to apply technologies, enabling more explicit accounting for shared vehicle platforms and adoption and "inheritance" of major engine changes.

These changes are reflected in updated model documentation available at NHTSA's web site, the documentation also providing more information about the model's purpose, scope, structure, design, inputs, operation, and outputs. The agencies invited but did not receive comments on the CAFE model used for the NPRM analysis and used in this final rule for the Method B analysis.

10.1.6.1 Product Cadence

Past comments on the CAFE model have stressed the importance of product cadence—i.e., the development and periodic redesign and freshening of vehicles—in terms of involving technical, financial, and other practical constraints on applying new technologies, and NHTSA has steadily made changes to the model with a view toward accounting for these considerations. For example, early versions of the model added explicit "carrying forward" of applied technologies between model years, subsequent versions applied assumptions that most technologies would be applied when vehicles are freshened or redesigned, and more recent versions applied assumptions that manufacturers would sometimes apply technology earlier than "necessary" in order to facilitate compliance with standards in ensuing model years. Thus, for example, if a manufacturer is expected to redesign many of its products in model years 2018 and 2023, and the standard's stringency increases significantly in model year 2021, the CAFE model will estimate the potential that the manufacturer will add more technology than necessary for compliance in MY 2018, in order to carry those product changes forward through the next redesign and contribute to compliance with the MY 2021 standard.

The model also accommodates estimates of overall limits (expressed as "phase-in caps" in model inputs) on the rates at which manufacturers' may practicably add technology to their respective fleets. So, for example, even if a manufacturer is expected to redesign half of its production in MY 2016, if the manufacturer is not already producing any strong hybrid electric vehicles (SHEVs), a phase-in cap can be specified in order to assume that manufacturer will stop applying SHEVs in MY 2016 once it has done so to at least 3 percent of its production in that model year.

After the light-duty rulemaking analysis accompanying the 2012 final rule regarding post-2016 CAFE standards and related GHG emissions standards, NHTSA staff began work on CAFE model changes expected to better reflect additional considerations involved with product planning and cadence. These changes, summarized below, interact with preexisting model characteristics discussed above.

10.1.6.2 Platforms and Technology

The term "platform" is used loosely in industry, but generally refers to a common structure shared by a group of vehicle variants. The degree of commonality varies, with some platform variants exhibiting traditional "badge engineering" where two products are differentiated by little more than insignias, while other platforms be used to produce a broad suite of vehicles that bear little outer resemblance to one another.

Given the degree of commonality between variants of a single platform, manufacturers do not have complete freedom to apply technology to a vehicle: while some technologies (e.g. low rolling resistance tires) are very nearly "bolt-on" technologies, others involve substantial changes to the structure and design of the vehicle, and therefore necessarily are constant between vehicles that share a common platform. NHTSA staff has, therefore, modified the CAFE model such that all mass reduction and aero technologies are forced to be constant between variants of a platform. The agencies requested but did not receive comment on the suitability of this viewpoint, and which technologies can deviate from one platform variant to another.

Within the analysis fleet, each vehicle is associated with a specific platform. As the CAFE model applies technology, it first defines a platform "leader" as the vehicle variant of a platform with the highest technology utilization vehicle of mass reduction and aerodynamic technologies. As the vehicle applies technologies, it effectively harmonizes to the highest common denominator of the platform. If there is a tie, the CAFE model begins applying aerodynamic and mass reduction technology to the vehicle with the lowest average sales across all available model years. If there remains a tie, the model begins by choosing the vehicle with the highest average MSRP across all available model years. The model follows this formulation due to previous market trends suggesting that many technologies begin deployment at the high-end, low-volume end of the market as manufacturers build their confidence and capability in a technology, and later expand the technology across more mainstream product lines.

In the HD pickup and van market, there is a relatively small amount of diversity in platforms produced by manufacturers: typically 1-2 truck platforms and 1-2 van platforms. However, accounting for platforms will take on greater significance in future analyses involving the light-duty fleet. The agency requested but did not receive comments on the general use of platforms within CAFE rulemaking.

10.1.6.3 Engine and Transmission Inheritance

In practice, manufacturers are limited in the number of engines and transmissions that they produce. Typically a manufacturer produces a number of engines—perhaps six or eight engines for a large manufacturer—and tunes them for slight variants in output for a variety of car and truck applications. Manufacturers limit complexity in their engine portfolio for much the same reason as they limit complexity in vehicle variants: they face engineering manpower limitations, and supplier, production and service costs that scale with the number of parts produced.

In previous usage of the CAFE model, engines and transmissions in individual models were allowed relative freedom in technology application, potentially leading to solutions that would, if followed, involve unaccounted-for costs associated with increased complexity in the product portfolio. The lack of a constraint in this area allowed the model to apply different levels of technology to the engine in each vehicle at the time of redesign or refresh, independent of what was done to other vehicles using a previously identical engine.

In the current version of the CAFE model, engines and transmissions that are shared between vehicles must apply the same levels of technology in all technologies dictated by engine or transmission inheritance. This forced adoption is referred to as "engine inheritance" in the model documentation.

As with platform-shared technologies, the model first chooses an "engine leader" among vehicles sharing the same engine. The leader is selected first by the vehicle with the lowest average sales across all available model years. If there is a tie, the vehicle with the highest average MSRP across model years is chosen. The model applies the same logic with respect to the application of transmission changes. As with platforms, this is driven by the concept that vehicle manufacturers typically deploy new technologies in small numbers prior to deploying widely across their product lines.

10.1.6.4 Interactions between Regulatory Classes

Like earlier versions, the current CAFE model provides for integrated analysis spanning different regulatory classes, accounting both for standards that apply separately to different classes and for interactions between regulatory classes. Light vehicle CAFE standards are specified separately for passenger cars and light trucks. However, there is considerable sharing between these two regulatory classes. Some specific engines and transmissions are used in both passenger cars and light trucks, and some vehicle platforms span these regulatory classes. For example, some sport-utility vehicles are offered in 2WD versions classified as passenger cars and 4WD versions classified as light trucks. Integrated analysis of manufacturers' passenger car and light truck fleets provides the ability to account for such sharing and reduce the likelihood of finding solutions that could involve impractical levels of complexity in manufacturers' product lines. In addition, integrated analysis provides the ability to simulate the potential that manufactures could earn CAFE credits by over complying with one standard and use those credits toward compliance with the other standard (i.e., to simulate credit transfers between regulatory classes).

HD pickups and vans are regulated separately from light-duty vehicles. While manufacturers cannot transfer credits between light-duty and MDHD classes, there is some sharing of engineering and technology between light-duty vehicles and HD pickups and vans. For example, some passenger vans with GVWR over 8,500 lbs. are classified as medium-duty passenger vehicles (MDPVs) and thus included in manufacturers' light-duty truck fleets, while cargo vans sharing the same nameplate are classified as HD vans.

10.1.6.5 Phase-In Caps

The CAFE model retains the ability to use phase-in caps (specified in model inputs) as proxies for a variety of practical restrictions on technology application. Unlike vehicle-specific restrictions related to redesign, refreshes or platforms/engines, phase-in caps constrain technology application at the vehicle manufacturer level. They are intended to reflect a manufacturer's overall resource capacity available for implementing new technologies (such as engineering and development personnel and financial resources), thereby ensuring that resource capacity is accounted for in the modeling process.

In previous CAFE rulemakings, redesign/refresh schedules and phase-in caps were the primary mechanisms to reflect an OEM's limited pool of available resources during the rulemaking time frame and the years leading up to the rulemaking time frame, especially in years where many models may be scheduled for refresh or redesign. The newly-introduced representation platform-, engine-, and transmission-related considerations discussed above augment the model's preexisting representation of redesign cycles and accommodation of phase-in caps. Considering these new constraints, inputs for today's analysis de-emphasize reliance on phase-in caps.

In the NPRM and Method B of the FRM application of the CAFE model, phase-in caps are used only for the most advanced technologies included in the analysis, i.e., SHEVs and lean-burn GDI engines, considering that these technologies are most likely to involve implementation costs and risks not otherwise accounted for in corresponding input estimates of technology cost. For these two technologies, the agencies have applied caps that begin at 3 percent (i.e., 3 percent of the manufacturer's production) in MY 2017, increase at 3 percent annually during the ensuing nine years (reaching 30 percent in the MY 2026), and subsequently increasing at 5 percent annually for four years (reaching 50 percent in MY 2030). Note that the agencies did not feel that lean-burn engines were feasible in the timeframe of this rulemaking, so decided to reject any model runs where they were selected. Due to the cost ineffectiveness of this technology, it was never chosen. The agencies did not receive comments specifically on this approach for phase-in caps. The agencies received comments regarding the general feasibility of SHEVs in this market segment, with some commenters commenting that SHEVs are not feasible for HD pickups and vans. These comments are discussed in below. While the agencies have retained the above approach for SHEV phase-in caps, the agencies have conducted a sensitivity analysis setting the

SHEV caps at zero, showing that the Phase 2 standards are feasible and appropriate without the use of SHEVs. This sensitivity analysis is described in Section 10.3.1 below.

For Method A of the NPRM the phase-in caps have been set to 100 percent, so that the model no longer relies on phase-in caps to limit the early-year application of advanced technologies. This changes is further described in the Method B of the FRM specific section below.

10.1.6.6 Impact of Vehicle Technology Application Requirements

Compared to prior analyses of light-duty standards, these model changes, along with characteristics of the HD pickup and van fleet result in some changes in the broad characteristics of the model's application of technology to manufacturers' fleets. First, since the number of HD pickup and van platforms in a portfolio is typically small, compliance with standards may appear especially "lumpy" (compared to previous applications of the CAFE model to the more highly segmented light-duty fleet), with significant over compliance when widespread redesigns precede stringency increases, and/or significant application of carried-forward (aka "banked") credits.

Second, since the use of phase-in caps has been de-emphasized and manufacturer technology deployment remains tied strongly to estimated product redesign and freshening schedules, technology penetration rates may jump more quickly as manufacturers apply technology to high-volume products in their portfolio.

By design, restrictions that enforce commonality of mass reduction and aerodynamic technologies on variants of a platform, and those that enforce engine inheritance, will result in fewer vehicle-technology combinations in a manufacturer's future modeled fleet. These restrictions are expected to more accurately capture the true costs associated with producing and maintaining a product portfolio.

10.1.6.7 Accounting for Test Weight, Payload, and Towing Capacity

As mentioned above, NHTSA has also revised the CAFE model to explicitly account for the regulatory "binning" of test weights used to certify light-duty fuel economy and HD pickup and van fuel consumption for purposes of evaluating fleet-level compliance with fuel economy and fuel consumption standards. For HD pickups and vans, test weight (TW) is based on adjusted loaded vehicle weight (ALVW), which is defined as the average of gross vehicle weight rating (GVWR) and curb weight (CW). TW values are then rounded, resulting in TW "bins":

ALVW ≤ 4,000 lb.: TW rounded to nearest 125 lb.

4000 lb. < ALVW ≤ 5,500 lb.: TW rounded to nearest 250 lb.

ALVW > 5,500 lb.: TW rounded to nearest 500 lb.

This "binning" of TW is relevant to calculation of fuel consumption reductions accompanying mass reduction. Model inputs for mass reduction (as an applied technology) are expressed in terms of a percentage reduction of curb weight and an accompanying estimate of the percentage reduction in fuel consumption, setting aside rounding of test weight. Therefore, to account for rounding of test weight, NHTSA has modified these calculations as follows:

$$\Delta FC_{rounded\_TW} = \Delta TW \times \frac{\Delta FC_{unrounded\_TW}}{\Delta CW}$$

Where:

ΔCW = % change in curb weight (from model input),

$\Delta FC_{unrounded\_TW}$ = % change in fuel consumption (from model input), without TW rounding,

ΔTW = % change in test weight (calculated), and

$\Delta FC_{rounded\_TW}$ = % change in fuel consumption (calculated), with TW rounding.

As a result, some applications of vehicle mass reduction will produce no compliance benefit at all, in cases where the changes in ALVW are too small to change test weight when rounding is taken into account. On the other hand, some other applications of vehicle mass reduction will produce significantly more compliance benefit than when rounding is not taken into account, in cases where even small changes in ALVW are sufficient to cause vehicles' test weights to increase by, e.g., 500 lbs. when rounding is accounted for. Model outputs now include initial and final TW, GVWR, and GCWR (and, as before, CW) for each vehicle model in each model year. The agencies invited but did not receive comment on how TW is modeled.

In addition, considering that the regulatory alternatives in the agencies' analysis all involve attribute-based standards in which underlying fuel consumption targets vary with "work factor" (defined by the agencies as the sum of three quarters of payload, one quarter of towing capacity, and 500 lb. for vehicles with 4WD), NHTSA has modified the CAFE model to apply inputs defining shares of curb weight reduction to be "returned" to payload and shares of GVWR reduction to be returned to towing capacity. The standards' dependence on work factor provides some incentive to increase payload and towing capacity, both of which are buyer-facing measures of vehicle utility. In the agencies' judgment, this provides reason to assume that if vehicle mass is reduced, manufacturers are likely to "return" some of the change to payload and/or towing capacity. For this analysis, the agencies have applied the following assumptions:

- GVWR will be reduced by half the amount by which curb weight is reduced. In other words, 50 percent of the curb weight reduction will be returned to payload
- GCWR will not be reduced. In other words, 100 percent of any GVWR reduction will be returned to towing capacity
- GVWR/CW and GCWR/GVWR will not increase beyond levels observed among the majority of similar vehicles (or, for outlier vehicles, initial values)

Table 10-28 Ratios for Modifying GVW and GCW as a Function of Mass Reduction

	MAXIMUM RATIOS ASSUMED ENABLED BY MASS REDUCTION	
Group	**GVWR/CW**	**GCWR/GVWR**
Unibody	1.75	1.50
Gasoline pickups > 13k GVWR	2.00	1.50
Other gasoline pickups	1.75	2.25
Diesel SRW pickups	1.75	2.50
All other	1.75	2.25

The first of two of these inputs are specified along with standards for each regulatory alternative, and the GVWR/CW and GCWR/GVWR "caps" are specified separately for each vehicle model in the analysis fleet.

In addition, NHTSA has changed the model to prevent HD pickup and van GVWR from falling below 8,500 lbs. when mass reduction is applied (because doing so will cause vehicles to be reclassified as light-duty vehicles), and to treat any additional mass for hybrid electric vehicles as reducing payload by the same amount (e.g., if adding a strong HEV package to a vehicle involves a 350 pound penalty, GVWR is assumed to remain unchanged, such that payload is also reduced by 350 lbs).

The agencies invited but did not receive comment on estimating how changes in vehicle mass may impact fuel consumption, GVWR, and GCWR.

10.1.7 Subsequent Changes to the CAFE Model (for Method A)

Since issuing the NPRM, NHTSA has made further changes to the CAFE model, in order to estimate the potential impacts of simultaneous standards for both light-duty vehicles and HD pickups and vans. Among the updates most relevant to analysis supporting the final standards for HD pickups and vans, the current model: includes refinements to enable accounting for platforms, engines, and transmissions sharing between light-duty and HD pickups and vans; reflects refinements to how models for the first application of new technology are identified among shared platforms, engines, and transmissions; allows payback period, discount rate, survival rates, and mileage accumulation schedules to be specified separately for each vehicle class; makes use of large scale simulation modeling to more accurately account for synergies among technologies to estimate the fuel consumption impact of different combinations of technologies; provides the ability to selectively exclude fine payment from the "effective cost" calculation used to simulation manufacturers' decisions regarding the application of fuel-saving technologies; and expands the use of forward planning to estimate decisions to use credits that would otherwise expire. Changes to the CAFE model are discussed at greater length below and in the CAFE model documentation.

Also since issuing the NPRM, NHTSA has revised many model inputs to reflect information that has become available since the proposal. Among the updates most relevant to analysis supporting the final rule, these inputs reflect: an updated vehicle-level market forecast based on data regarding the 2015 model year fleet and a new commercially-available manufacturer- and segment-level market forecast, and spanning light-duty vehicles and HD pickups and vans; newer fuel prices and total vehicle production volumes from the Energy Information Administration's Annual Energy Outlook 2015; a database, based on a large-scale full vehicle simulation study, of estimates of the effect of thousands of different combinations of technologies on fuel consumption; and updated mileage accumulation schedules based on a database of more than 70 million odometer readings.

NHTSA implemented these changes to the CAFE model and accompanying inputs to support both today's final rule promulgating new fuel consumption standards for HD pickups and vans and the Draft Technical Assessment Report regarding agency's consideration of CAFE standards for light duty vehicles for model years 2022-2025. This provided a basis to analyze the fleets simultaneously, accounting for interactions between the fleets; the draft RIA (p. 10-18) accompanying the NPRM identified this as a planned improvement for the final rule, and some stakeholders' comments (e.g., CARB,[X] UCS,[Y] and CBD[Z]) indicated that such interactions should be accounted for. Implementing the changes at the same time for both actions also provided means to release mutually consistent analyses intended for publication nearly concurrently, and for review by many of the same stakeholders (e.g., by manufacturers producing both light-duty vehicle and HD pickups and vans).

The remainder of this section summarizes changes to the CAFE model and inputs made subsequent to the NPRM analysis, summarizes results of the updated analysis, and discusses.

10.1.7.1 Interactions between Regulatory Classes

Like earlier versions, the current CAFE model provides for integrated analysis spanning different regulatory classes, accounting both for standards that apply separately to different classes and for interactions between regulatory classes. Light vehicle CAFE standards are specified separately for passenger cars and light trucks. However, there is considerable sharing between these two regulatory classes. Some specific engines and transmissions are used in both passenger cars and light trucks, and some vehicle platforms span these regulatory classes. For example, some sport-utility vehicles are offered in 2WD versions classified as passenger cars and 4WD versions classified as light trucks. Integrated analysis of manufacturers' passenger car and light truck fleets provides the ability to account for such sharing and reduce the likelihood of finding solutions that could involve impractical levels of complexity in manufacturers' product lines. In addition, integrated analysis provides the ability to simulate the potential that manufactures could earn CAFE credits by over complying with one standard and use those credits toward compliance with the other standard (i.e., to simulate credit transfers between regulatory classes).

HD pickups and vans are regulated separately from light-duty vehicles. While manufacturers cannot transfer credits between light-duty and MDHD classes, there is some sharing of engineering and technology between light-duty vehicles and HD pickups and vans. For example, some passenger vans with GVWR over 8,500 pounds are classified as medium-

[X] CARB, Docket No. NHTSA-2014-0132-0125, at 17-18; 52-53.
[Y] UCS, Docket No. EPA-HQ-OAR-2014-0827-1329, at pages 23-24
[Z] CBD, Docket No. NHTSA-2014-0132-0101 at pages 8-9.

duty passenger vehicles (MDPVs) and thus included in manufacturers' light-duty truck fleets, while cargo vans sharing the same nameplate are classified as HD vans.

Today's analysis uses an overall analysis fleet spanning both the light-duty and HD pickup and van fleets. As discussed below, doing so shows some technology "spilling over" to HD pickups and vans due, for example, to the application of technology in response to current light-duty standards. For most manufacturers, these interactions appear relatively small. For Nissan, however, they appear considerable, because Nissan's heavy-duty vans use engines also used in Nissan's light-duty SUVs.

In the NPRM proposing new standards for heavy-duty pickups and vans, NHTSA and EPA comment on the expansion of the analysis fleet such that the impacts of new HD pickup and van standards can be estimated within the context of an integrated analysis of light-duty vehicles and HD pickups and vans, accounting for interactions between the fleets. As mentioned above, some environmental organizations specifically cited commonalities and overlap between light- and heavy-duty products.

10.1.7.2 Phase-In Caps

The model also accommodates estimates of overall limits (expressed as "phase-in caps" in model inputs) on the rates at which manufacturers' may practicably add technology to their respective fleets. So, for example, even if a manufacturer is expected to redesign half of its production in MY 2016, if the manufacturer is not already producing any strong hybrid electric vehicles (SHEVs), a phase-in cap can be specified in order to assume that manufacturer will stop applying SHEVs in MY 2016 once it has done so to at least 3 percent of its production in that model year. Today's analysis sets all of these caps at 100 percent, relying on other model constraints (in particular, the assumption that many technologies are most practicably applied as part of a vehicle freshening or redesign) to estimate practicable technology application pathways.

The CAFE model retains the ability to use phase-in caps (specified in model inputs) as proxies for a variety of practical restrictions on technology application. Unlike vehicle-specific restrictions related to redesign, refreshes or platforms/engines, phase-in caps constrain technology application at the vehicle manufacturer level. Introduced in the 2006 version of the CAFE model, they were intended to reflect a manufacturer's overall resource capacity available for implementing new technologies (such as engineering and development personnel and financial resources), thereby ensuring that resource capacity is accounted for in the modeling process.

In previous fuel efficiency rulemakings, redesign/refresh schedules and phase-in caps were the primary mechanisms to reflect an OEM's limited pool of available resources during the rulemaking time frame and the years leading up to the rulemaking time frame, especially in years where many models may be scheduled for refresh or redesign. The newly-introduced representation platform-, engine-, and transmission-related considerations discussed above augment the model's preexisting representation of redesign cycles, and as discussed above, inputs for today's analysis de-emphasize reliance on phase-in caps.

10.1.7.3 Impact of Vehicle Technology Application Requirements

Compared to prior analyses of light-duty standards, these model changes result in some changes in the broad characteristics of the model's application of technology to manufacturers' fleets. Since the use of phase-in caps has been de-emphasized and manufacturer technology deployment remains tied strongly to estimated product redesign and freshening schedules, technology penetration rates may jump more quickly as manufacturers apply technology to high-volume products in their portfolio.

By design, restrictions that enforce commonality of mass reduction and aerodynamic technologies on variants of a platform, and those that enforce engine inheritance, will result in fewer vehicle-technology combinations in a manufacturer's future modeled fleet. As explained in the NPRM proposing new standards for HD pickups and vans, these restrictions are expected to more accurately capture the true costs associated with producing and maintaining a product portfolio.

10.1.7.4 Accounting for Credits

The changes discussed above relate specifically to the model's approach to simulating manufacturers' potential addition of fuel-saving technology in response to fuel efficiency standards and fuel prices within an explicit product planning context. The model's approach to simulating compliance decisions also accounts for the potential to earn and use fuel consumption credits, as provided by EPCA/EISA. Like past versions, the current CAFE model can be used to simulate credit carry-forward (a.k.a. banking) between model years and transfers between the passenger car and light truck fleets, but not credit carry-back (a.k.a. borrowing) between model years or trading between manufacturers. Unlike past versions, the current CAFE model provides a basis to specify (in model inputs) fuel consumption credits available from model years earlier than those being simulated explicitly. For example, with today's analysis representing model years 2015-2032 explicitly, credits specified as being available from model year 2014 are made available for use through model year 2019 (given the current 5-year limit on carry-forward of credits).

As discussed in the CAFE model documentation, the model's default logic attempts to maximize credit carry-forward—that is to "hold on" to credits for as long as possible. Although the model uses credits before expiry if needed to cover shortfalls when insufficient opportunity to add technology is available to achieve compliance with a standard, the model will otherwise carry forward credits until they are about to expire, at which point it will use them before adding technology. As further discussed in the CAFE model documentation, model inputs can be used to adjust this logic to shift the use of credits ahead by one or more model years.

The example presented below illustrates how some of aspects of the current model logic around credits impacts estimation of technology application by a manufacturer within the context of a specified set of standards, focusing here on the model's estimate of Ford's potential technology application under the preferred alternative. Overall results for Ford and other manufacturers are summarized in Section E.

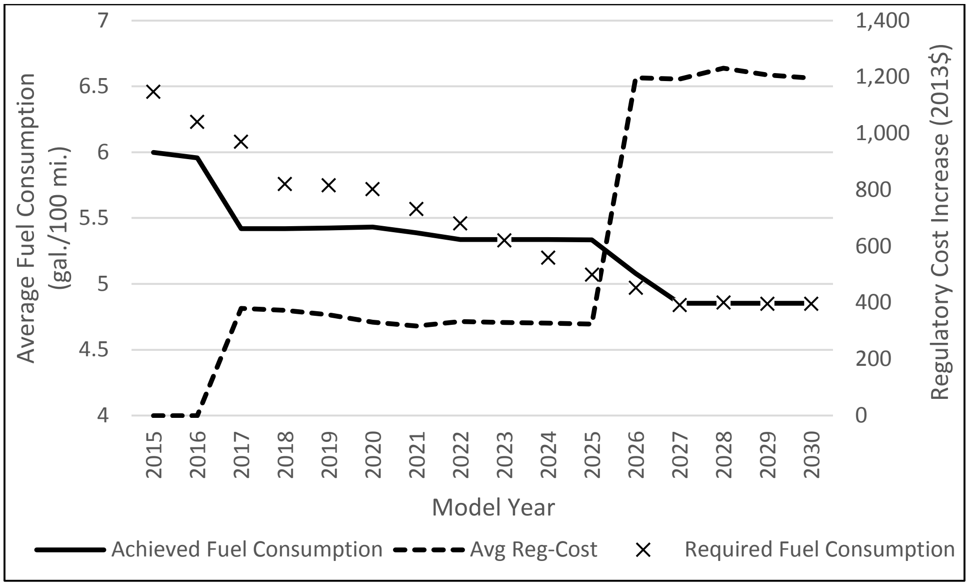

Figure 10-3 Example of a Possible Compliance Strategy for Ford

Several aspects of the estimated achieved and required fuel consumption levels shown above are notable. First, the characteristics of Ford's fleet as represented in today's analysis fleet are such that the heavy duty pickup and van fleet falls short of average fuel efficiency standard in MY's 2023 through 2027. However, they exceed their standard for MY's 2016 through 2022. The current analysis uses logic that reflect the potential that Ford could use the 5-year carry forward provision to use fuel efficiency credits earned in MY's 2018 through MY 2022, to cover the shortfalls for MY's 2023 to 2027. The model assumes Ford will use as many of the MY 2018 expiring credits as necessary to cover the shortfall in MY 2023. For MY 2024 they will use all available MY 2019 credits before applying any additional MY 2020 credits necessary to cover the shortfall (in this particular case there are enough MY 2019 credits to cover the shortfall in MY 2024). This pattern continues for all model years where there is a shortfall—the model applies the oldest remaining credits first. Even so, today's analysis indicates Ford could be required to pay civil penalties for noncompliance without the addition of modest fuel savings in MY 2027. The change to the model which accounts for credits earned prior to MY 2015 is not illustrated in this example. However, Ford comes in with fuel consumption credits from MY's prior to MY 2015; if they had come in with an initial shortfall, they could have used these banked credits to cover, at least a portion, of that shortfall.

As discussed above, these results provide an estimate, based on analysis inputs, of one way General Motors could add fuel-saving technologies to its products under the preferred alternative considered here, and are not a prediction of what General Motors would do under this alternative. In addition, it should be recognized that specific results vary among manufacturers and among regulatory alternatives (and under different analytical inputs). Still, the example should serve to illustrate how the ability to model credit banking can impact results.

10.1.7.5 Integrating Vehicle Simulation Results into the Synergy Values

The CAFE model does not itself evaluate which technologies will be available, nor does it evaluate how effective or reliable they will be. The technological availability and effectiveness rather, are predefined inputs to the model based on the agencies' judgements and not outputs from the model, which is simply a tool for calculating the effects of combining input assumptions.

In previous versions of the CAFE Model, technology effectiveness values entered into the model as a single number for each technology (for each of several classes), intended to represent the incremental improvement in fuel consumption achieved by applying that technology to a vehicle in a particular class. At a basic level, this implied that successive application of new vehicle technologies resulted in an improvement in fuel consumption (as a percentage) that was the product of the individual incremental effectiveness of each technology applied. Since this construction fails to capture interactive effects – cases where a given technology either improves or degrades the impact of subsequently applied technologies – the CAFE Model applied "synergy factors." The synergy factors were defined for a relatively small number of technology pairs, and were intended to represent the result of physical interactions among pairs of technologies – attempting to account for situations where $2 \times 2 \neq 4$.

For a more specific example, for a vehicle with an initial fuel consumption of FC_0, if two technologies are applied, one with an incremental effectiveness of 5 percent, and a second with an incremental effectiveness of 10 percent, the effectiveness after the application of both technologies without consideration of synergies could be expressed as follows:

$$FC_0*(1-.05)*(1-.1)$$

Which is equivalent to:

$$FC_0*(1-.145)$$

This suggests that the combined effectiveness of the two technologies is 14.5 percent. The synergy factors aim to correct for cases where fuel consumption improvements are not perfectly multiplicative, and the combined fuel consumption in the example above is either greater than or less than 14.5 percent.

For this analysis, the CAFE Model has been modified to accommodate the results of the large-scale vehicle simulation study conducted by Argonne National Laboratory (described in more detail in the light-duty TAR). While Autonomie, Argonne's vehicle simulation model, produces absolute fuel consumption values for each simulation record, the results have been modified in a way that preserves much of the existing structure of the CAFE Model's compliance logic, but still faithfully reproduces the totality of the simulation outcomes present in the database. Fundamentally, the implementation represents a translation of the absolute values in the simulation database into incremental improvements and a substantially expanded set of synergy factors.

Since the simulation efforts only included light-duty vehicles, the effectiveness values for heavy duty were not integrated into the heavy-duty fleet; for future rule-makings NHTSA hopes to extend the vehicle simulation efforts to include simulations that would be relevant for heavy-duty pickups and vans. While the effectiveness values for individual technologies remain the same, the synergies between two or more technologies incorporate information from Autonomie Argonne's light-duty pickup simulations. While these synergy values are not a perfect approximation of the interaction of technology applications particular to heavy-duty vehicles, it is consistent with what we did in the NPRM (where we also used synergy values from light-duty pickups).

Updating the synergy values to use Argonne's simulation efforts does two things: 1) it allows that these synergies may occur between more than two technologies, and 2) because the synergies are multiplicative, rather than additive, it allows for the consideration that the order of other technology applications matter in determining the incremental percentage improvement correction of the synergy value. Instead of having one additive incremental percentage synergy value for a pair of technologies, regardless of the order of technology application between these pair of technologies, the synergy values are dependent on the initial state and ending point of a vehicle within the database.

As stated, in the past, synergy values in the Volpe model were represented as pairs. However, the new values are 7-tuples and there is one for every point in the database. The synergy factors are based (entirely) on values in the Argonne database, producing one for each unique technology combination for each technology class, and are calculated as

$$S_k = \frac{FC_k}{FC_0 \cdot \prod(1 - x_i)}$$

where S_k is the synergy factor for technology combination *k*, FC_0 is the fuel consumption of the reference vehicle (in the database), x_i is the fuel consumption improvement of each technology *i* represented in technology combination *k* (where some technologies are present in combination *k*, and some are precedent technologies that were applied, incrementally, before reaching the current state on one of the paths).

In order to incorporate the results of the Argonne database, while still preserving the basic structure of the CAFE model's technology module, it was necessary to translate the points in the database into locations on the technology tree.[AA] By recognizing that most of the paths on the technology tree are unrelated, or separable, it is possible to decompose the technology tree into a small number of paths and branches by technology type. To achieve this level of linearity, we define technology groups – only one of which is new. They are: engine cam configuration (CONFIG), engine technologies (ENG), transmission technologies (TRANS), electrification (ELEC), mass reduction levels (MR), aerodynamic improvements (AERO), and rolling resistance (ROLL). The combination of technology levels along each of these paths define a unique technology combination that corresponds to a single point in the database for each technology class. These technology state definitions are more important for defining synergies

[AA] Complete details in the technology tree used to develop the synergies for the heavy-duty rule are available in the light-duty Draft TAR.

than for determining incremental effectiveness, but the paths are incorporated into both. Again, because we did not simulate results applicable to the heavy-duty fleet, we did not use the database to define the incremental technology effectiveness, but only to adjust for the unique interaction of different combinations of technology.

As an example, a technology state vector describing a vehicle with a SOHC engine, variable valve timing (only), a 6-speed automatic transmission, a belt-integrated starter generator, mass reduction (level 1), aerodynamic improvements (level 2), and rolling resistance (level 1) would be specified as SOHC;VVT;AT6;BISG;MR1;AERO2;ROLL1. Once a vehicle is assigned a technology state (one of the tens of thousands of unique 7-tuples, defined as CONFIG;ENG;TRANS;ELEC;MR;AERO;ROLL), adding a new technology to the vehicle simply represents progress from one technology state to another. The vehicle's fuel consumption is:

$$FC_i = FC_0 \cdot (1 - FCI_i) \cdot S_k / S_0$$

where FC_i is the fuel consumption resulting from the application of technology *i*, FC_0 is the vehicle's fuel consumption before technology *i* is applied, FCI_i is the incremental fuel consumption (percentage) improvement associated with technology *i*, S_k is the synergy factor associated with the combination, *k*, of technologies the vehicle technology *i* is applied, and S_0 the synergy factor associated with the technology state that produced fuel consumption FC_0. The synergy factor is defined in a way that captures the incremental improvement of moving between points in the database, where each point is defined uniquely as a 7-tuple describing its cam configuration, highest engine technology, transmission, electrification type, mass reduction level, and level of aerodynamic or rolling resistance improvement. For the current heavy-duty adoption, it is only these synergy values that were used in the current analysis. While, like with the individual fuel consumption improvements, there is likely not a simple mapping from light-duty pickups to heavy-duty pickups (size and power matter), the previous synergy values were also an adoption from light-duty pickups. The integration of the simulation data allows for a more complete set of synergies that account for the order of technology application and the interaction of more than two individual technologies.

10.1.7.6 Updating Mileage Accumulation Schedules

In order to develop new mileage accumulation schedules for vehicles regulated under NHTSA's fuel efficiency and CAFE programs (classes 1-3), NHTSA purchased a data set of vehicle odometer readings from IHS/Polk (Polk). Polk collects odometer readings from registered vehicles when they encounter maintenance facilities, state inspection programs, or interactions with dealerships and OEMs. The (average) odometer readings in the data set NHTSA purchased are based on over 74 million unique odometer readings across 16 model years (2000-2015) and vehicle classes present in the data purchase (all registered vehicles less than 14,000 lbs. GVW).

The Polk data provide a measure of the cumulative lifetime vehicle miles traveled (VMT) for vehicles, at the time of measurement, aggregated by the following parameters: make, model, model year, fuel type, drive type, door count, and ownership type (commercial or personal). Within each of these subcategories they provide the average odometer reading, the number of odometer readings in the sample from which Polk calculated the averages, and the total number of that subcategory of vehicles in operation. From these NHTSA was able to develop new estimates of vehicle miles traveled by age as inputs for the CAFE Model.

10.1.7.6.1 Updated Schedules

The new medium-duty van/pickup schedule in Figure 10-4predicts higher annual VMT for vehicles between ages one through five years, and lower annual VMT for all other vehicle ages, than the old schedule. Over the first 30-year span, the new schedule predicts that medium-duty vans/pickups drive 24,249 (9 percent) fewer miles than the old schedule. We predict the maximum average annual VMT for medium-duty vehicles (23,307 miles) at age two. These changes to the schedule will have important implications on certain benefits of the standards. More monetary fuel savings will occur during the first five years of a vehicle's life under the new schedule, but a decrease in fuel savings will occur overall while using these schedules. For payback periods shorter than 5 years, the new schedule will show shorter payback periods than the old schedule. Section 10 of the RIA offers similar figures for light-duty vehicles types. It also offers further explanation about the shape of the new annual VMT schedule.

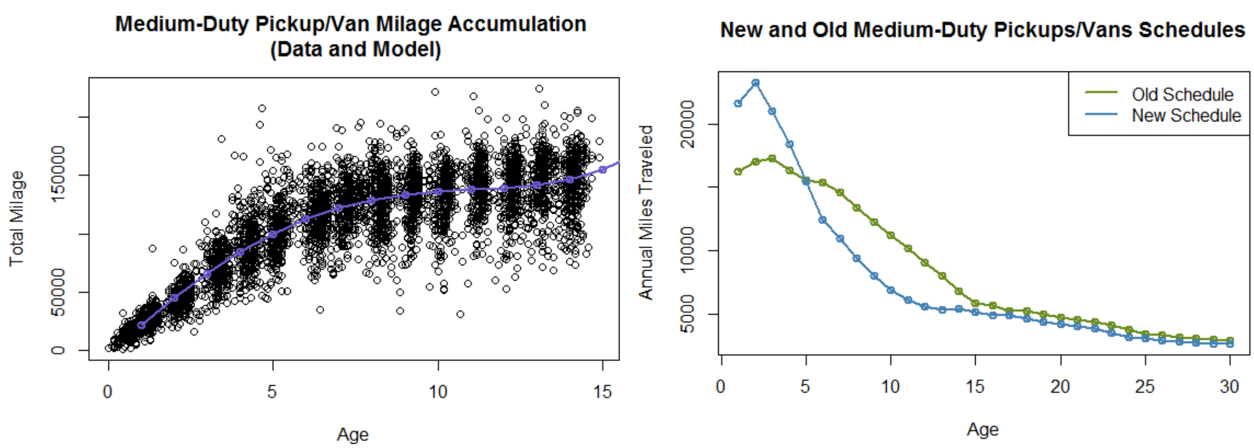

Figure 10-4 A Comparison of the New and Old Heavy-Duty Van/Pickup Schedules

Figure 10-5 shows that while the maximum share of commercially-owned vehicles occurs at age one, the registration population-weighted average odometer reading for personally and commercially owned vehicles are almost identical for this age. However, the share of commercially-owned vehicles is higher for age two vehicles than all older ages, and there is a larger spread between the average odometer readings of the two ownership types for this age of vehicle (while the spread between the average odometer readings for age three is even larger, the share of commercially-owned vehicles is smaller, and likely counteracts this effect in the registration population-weighted models). This increase in discrepancy between the average odometer reading of the ownership types can explain the peak annual VMT at age two.

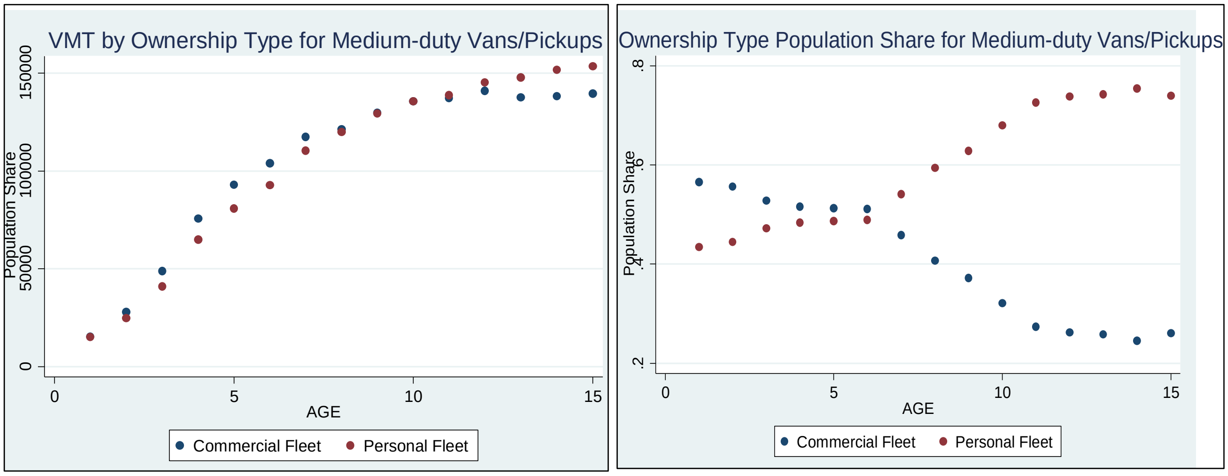

Figure 10-5 Total VMT and Population Share by Ownership Type for MD Vans/Pickups

Table 10-29 offers a summary of the comparison of lifetime VMT (by class) under the new schedule, compared with lifetime VMT under the old schedule. In addition to the total lifetime VMT expected under each schedule for vehicles that survive to their full useful life, Table 10-29also shows the survival-weighted lifetime VMT for both schedules. This represents the average lifetime VMT for all vehicles, not only those that survive to their full useful life. The percentage difference between the two schedules is not as stark for the survival-weighted schedules: the percentage decrease of survival-weighted lifetime VMT under the new schedules range from 6.5 percent (for medium-duty trucks and vans) to 21.2 percent (for passenger vans).

Table 10-29 Summary Comparison of Lifetime VMT of the New and Old Schedules

				SURVIVAL-WEIGHTED		
	Lifetime VMT			Lifetime VMT		
	New	Old	% difference	New	Old	% difference
Car	204,233	301,115	32.2%	142,119	179,399	20.8%
Van	237,623	362,482	34.4%	155,115	196,725	21.2%
SUV	237,623	338,646	29.8%	155,115	193,115	19.7%
Pickup	265,849	360,982	26.4%	157,991	188,634	16.2%
2b/3	246,413	270,662	9.0%	176,807	189,020	6.5%

10.1.7.6.2 Data Description

While the Polk data set contains model-level average odometer readings, the CAFE model assigns lifetime VMT schedules at a lower resolution based on vehicle body style. For the purposes of VMT accounting, the CAFE model classifies every vehicle in the analysis fleet as being one of the following: passenger car, SUV, pickup truck, passenger van, or medium-duty pickup/van. In order to use the Polk data to develop VMT schedules for each of the (VMT) classes in the CAFE model, we constructed a mapping between the classification of each model in the Polk data and the classes in the CAFE model. The only difference between the mapping for the VMT schedules and the rest of the CAFE model is that we merged the SUV and van body styles into one class (for reasons described in our discussion of the SUV/van schedule above). This mapping allowed us to predict the lifetime miles traveled, by the age of a vehicle, for the categories in the CAFE model.

In estimating the VMT models, we weighted each data point (make/model classification) by the share of each make/model in the total population of the corresponding CAFE class. This weighting ensures that the predicted odometer readings, by class and model year, represent each of vehicle classification among observed vehicles (i.e., the vehicles for which Polk has odometer readings), based on each vehicles' representation in the registered vehicle population of its class. Implicit in this weighting scheme, is the assumption that the samples used to calculate each average odometer reading by make, model, and model year are representative of the total population of vehicles of that type. Several indicators suggest that this is a reasonable assumption.

First, the majority of each vehicle make/model is well-represented in the sample. Histograms and empirical cumulative distribution functions (CDF's) of the ratio of the number of odometer readings to the total population of those makes/models by each class (Figure 10-6 below), show that for more than 85 percent of make/model combinations, the average odometer readings are collected for 20 percent or more of the total population. Most make/model observations have sufficient sample sizes, relative to their representation in the vehicle population, to produce meaningful average odometer totals at that level[BB].

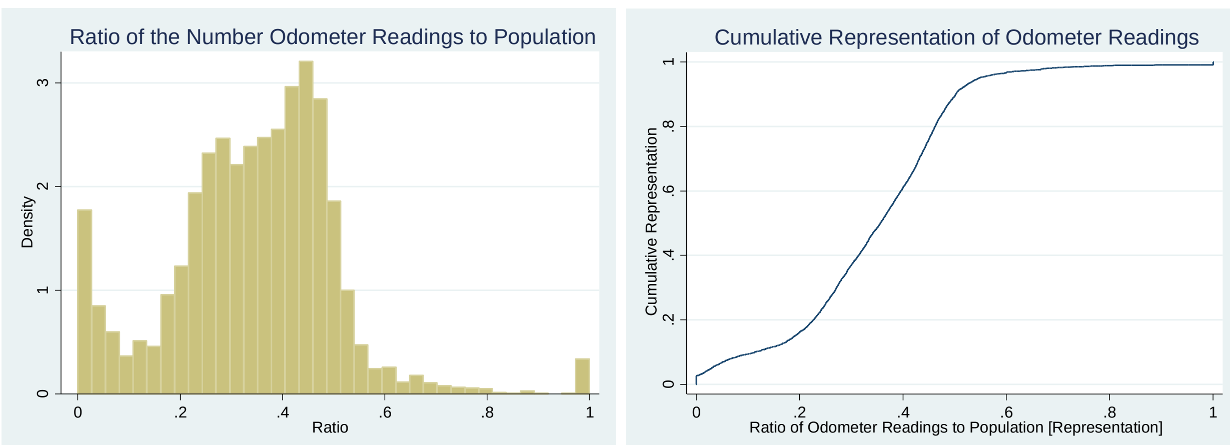

Figure 10-6 Distribution of the Ratio of the Sample Size to the Population Size (By Make/Model/MY)

We also considered whether the representativeness of the odometer sample varies by vehicle age, since VMT schedules in the CAFE model are specific to each age. To investigate, we calculated the percentage of vehicle types (by make, model, and model year) that did not

[BB] We developed similar figures, stratified by each vehicle class, but these were no more revealing than the figures for all vehicles.

have odometer readings. Figure 10-7 shows that all model years, apart from 2015, have odometer readings for 96 percent or more of the total types of vehicles observed in the fleet.

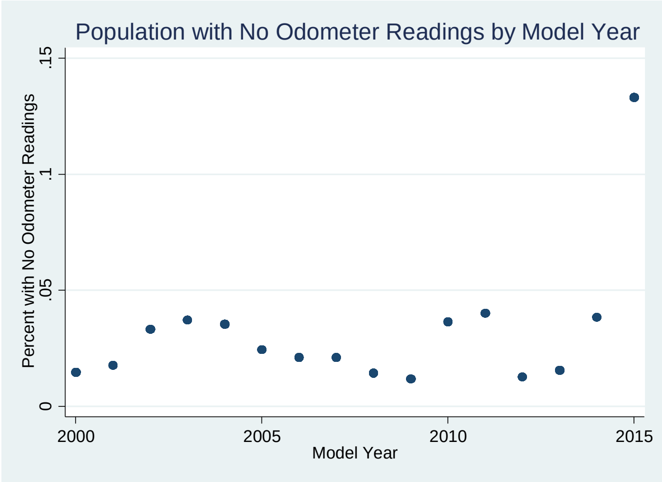

Figure 10-7 Percentage of the Total Vehicle Population with No Odometer Readings across Model Year

While the preceding discussion supports the *coverage* of the odometer sample across makes/models by each model year, it is possible that, for some of those models, an insufficient number of odometer readings is recorded to create an average that is likely to be representative of all of those models in operation for a given year. Figure 10-8 below shows the percentage of all vehicle types for which the number of odometer readings is less than 5 percent of the total population (for that model). Again, for all model years other than 2015, about 95 percent or more of vehicles types are represented by at least 5 percent of their population. For this reason, we included observations from all model years, other than 2015, in the estimation of the new VMT schedules.

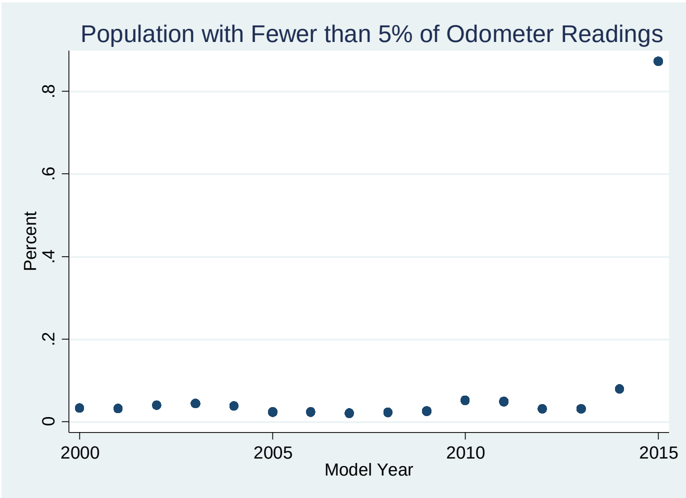

Figure 10-8 Percentage of Vehicles with Fewer Than 5% of Population in Odometer Readings (By Class)

It is possible that the odometer sample is biased. If certain vehicles are over-represented in the sample of odometer readings relative to the registered vehicle population, a simple average, or even one weighted by the number of odometer observations will be biased. However, while weighting by the share of each vehicle in the population will account for this bias, it would not correct for a sample that entirely omits a large number of makes/models within a model year. We tested for this by computing the proportion of the count of odometer readings for each individual vehicle type—within a class and model year—to the total count of readings for that class and model year. We also compared the population of each make/model—within each class and model year—to the population of the corresponding class and model year. The difference of these two ratios shows the difference of the representation of a vehicle type—in its respective class and model year—in the sample versus the population. All vehicle types are represented in the sample within 10 percent of their representation in the population, and the variance between the two representations is normally distributed. This suggests that, on average, the likelihood that a vehicle is in the sample is comparable to its proportion in the relevant population, and that there is little under or over sampling of certain vehicle makes/models.[CC]

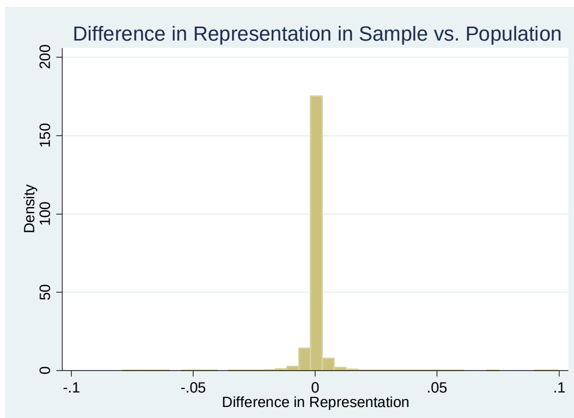

Figure 10-9 Difference in the Share of Each Vehicle in the Population versus the Sample (By Class)

10.1.7.6.3 Estimation

Since model years are sold in in the fall of the previous calendar year, throughout the same calendar year, and even into the following calendar year—not all registered vehicles of a make/model/model year will have been registered for at least a year (or more) until age 3. The result is that some MY2014 vehicles may have been driven for longer than one year, and some less, at the time the odometer was observed. In order to consider this in our definition of age, we assign the age of a vehicle to be the difference between the average reading date of a make/model and the average first registration date of that make/model. The result is that the continuous age variable reflects the amount of time that a car has been registered at the time of odometer reading, and presumably the time span that the car has accumulated the miles.

[CC] We produced similar figures, stratified by class, but these were no more revealing; the only difference being that cars are represented in the sample within 5 percent of their representation in the population (with a distribution range of .05 on either side).

After creating the "Age" variable, we fit the make/model lifetime VMT data points to a weighted quartic polynomial regression of the age of the vehicle. The predicted values of the quartic regressions are used to calculate the marginal annual VMT by age for each class by calculating differences in estimated lifetime mileage accumulation by age. However, the Polk data acquired by NHTSA only contains observations for vehicles newer than 16 years of age. In order to estimate the schedule for vehicles older than the age 15 vehicles in the Polk data, we combined information about that portion of the schedule from the VMT schedules used in both the 2017-2021 Final Light Duty Rule and 2019-2025 Medium-Duty NPRM. The light-duty schedules were derived from the survey data contained in the 2009 National Household Travel Survey (NHTS) and the 2001 Vehicle in Use Survey (VIUS), for medium-duty trucks.

Based on the vehicle ages for which we have data (from the Polk purchase), the newly estimated annual schedules differ from the previous version in important ways. Perhaps most significantly, the annual mileage associated with ages beyond age 8 begin to, and continue to, trend much lower. The approach taken here attempts to preserve the results obtained through estimation on the Polk observations, while leveraging the existing (NHTS-based) schedules to support estimation of the higher ages (age 16 and beyond). Since the two schedules are so far apart, simply splicing them together would have created not only a discontinuity, but also precluded the possibility of a monotonically decreasing scale with age (which is consistent with previous schedules, the data acquired from Polk, and common sense).

From the old schedules, we expect that the annual VMT is decreasing for all ages. Towards the end of our sample, the predictions for annual VMT increase. In order to force the expected monotonicity, we perform a triangular smoothing algorithm until the schedule is monotonic. This performs a weighted average which weights the observations close to the observation more than those farther from it. The result is a monotonic function, which predicts similar lifetime VMT for the sample span as the original function. Since we do not have data beyond 15 years of age, we are not able to correctly capture that part of the annual VMT curve using only the new dataset. For this reason, we use trends in the old data to extrapolate the new schedule for ages beyond the sample range.

In order to use the VMT information from the newer data source for ages outside of the sample, we use the final in-sample age (15 years) as a seed and then apply the proportional trend from the old schedules to extrapolate the new schedules out to age 30. To do this, we calculated the annual percentage difference in VMT of the old schedule for ages 15-30. The same annual percentage difference in VMT is applied to the new schedule to extend beyond the final in-sample value. This assumes that the overall proportional trend in the outer years is correctly modeled in the old VMT schedule, and imposes this same trend for the outer years of the new schedule. The extrapolated schedules are the final input for the VMT schedules in the CAFE model.

10.1.7.6.4 Comparison to Previous Schedules

The new VMT data suggests that the VMT schedule used in the last Light-Duty CAFE Final Rule likely does not represent current annual VMT rates. Across all classes, the previous VMT schedules overestimate the average annual VMT. The previous schedules are based on data that is outdated and self-reported, while the observations from Polk are between 5 and 7 years newer than those in the NHTS and represent valid odometer readings (rather than self-reported information).

Additionally, while the NHTS may be a representative sample of *households*, it is less likely to be a representative sample of *vehicles*. However, by properly accounting for vehicle population weights in the new averages and models, we corrected for this issue in the derivation of the new schedules.

Insofar as these changes better represent actual VMT, they lead to better estimates of actual impacts, such as avoided fuel consumption and GHG emissions, safety impacts, and monetized benefits.

10.1.7.6.5 Future Direction

In consultation with other agencies closely involved with VMT estimation (e.g., FHWA), NHTSA will continue to seek means to further refine estimated mileage accumulation schedules. For example, one option under consideration would be to obtain odometer reading data from successive calendar years, thus providing a more robust basis to consider, for example, the influence of changing fuel prices or economic conditions on the accumulation of miles by vehicles of a given age.

10.1.7.7 Updated Analysis Fleet

For the current analysis we updated the reference fleet from MY 2014, to the latest available MY 2015. The projection of total sales volumes for the Class 2b and 3 market segment was based on the total volumes in the 2015 AEO Reference Case. For the purposes of this analysis, the AEO2015 calendar year volumes have been used to represent the corresponding model-year volumes. While AEO2015 provides enough resolution in its projections to separate the volumes for the Class 2b and 3 segments, the agencies deferred to the vehicle manufacturers and chose to rely on the relative shares present in the pre-model-year compliance data.

10.1.7.8 Changes to Costs

10.1.7.8.1 Use of Retail Price Equivalent (RPE) Multiplier to Calculate Indirect Costs

To produce a unit of output, vehicle manufacturers incur direct and indirect costs. Direct costs include cost of materials and labor costs. Indirect costs are all the costs associated with producing the unit of output that are not direct costs – for example, they may be related to production (such as research and development [R&D]), corporate operations (such as salaries, pensions, and health care costs for corporate staff), or selling (such as transportation, dealer support, and marketing). Indirect costs are generally recovered by allocating a share of the costs to each unit of good sold. Although it is possible to account for direct costs allocated to each unit of good sold, it is more challenging to account for indirect costs allocated to a unit of goods sold. To make a cost analysis process more feasible, markup factors, which relate total indirect costs to total direct costs, have been developed. These factors are often referred to as retail price equivalent (RPE) multipliers.

Cost analysts and regulatory agencies (including both NHTSA and EPA) have frequently used these multipliers to predict the resultant impact on costs associated with manufacturers' responses to regulatory requirements. The best approach, if it were possible, to determining the impact of changes in direct manufacturing costs on a manufacturer's indirect costs would be to actually estimate the cost impact on each indirect cost element. However, doing this within the constraints of an agency's time or budget is not always feasible, and the technical, financial, and accounting information to carry out such an analysis may simply be unavailable.

The one empirically derived metric that addresses the markup of direct costs to consumer costs is the RPE multiplier, which is measured from manufacturer 10-K accounting statements filed with the Securities and Exchange Commission. Over roughly a three decade period, the measured RPE has been remarkably stable, averaging 1.5, with minor annual variation. The National Research Council notes that, "Based on available data, a reasonable RPE multiplier would be 1.5." The historical trend in the RPE is illustrated in Figure 10-10.

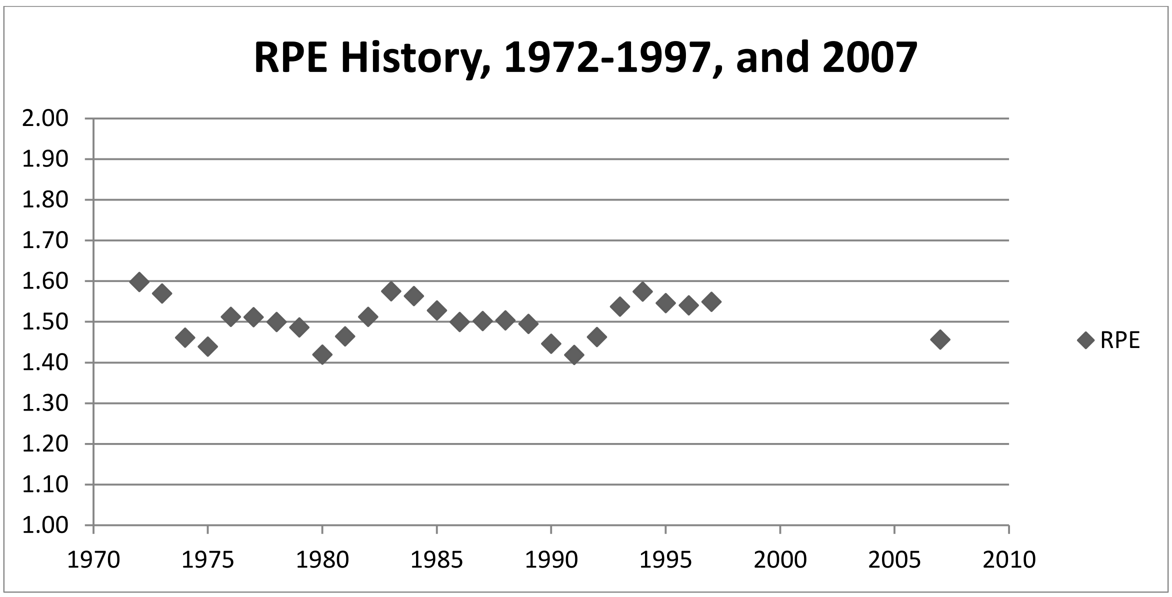

Figure 10-10 RPE History, 1972-1997, and 2007

RPE multipliers provide, at an aggregate level, the relationship between revenue and direct manufacturing costs. They are measured by dividing total revenue by direct costs. However, because this provides only a single aggregate measure, using RPE multipliers results in the application of a common incremental markup to all technologies. It assures that the aggregate cost impact across all technologies is consistent with empirical data, but does not allow for indirect cost discrimination among different technologies. Thus, a concern in using the RPE multiplier in cost analysis for new technologies added in response to regulatory requirements is that the indirect costs of vehicle modifications are not likely to be the same for all different technologies. For example, less complex technologies could require fewer R&D efforts or less warranty coverage than more complex technologies. In addition, some simple technological adjustments may, for example, have no effect on the number of corporate personnel and the indirect costs attributable to those personnel. The use of RPEs, with their assumption that all technologies have the same proportion of indirect costs, is likely to overestimate the costs of less complex technologies and underestimate the costs of more complex technologies. However, for regulations such as the CAFE and GHG emission standards under consideration, which drive changes to nearly every vehicle system, overall average indirect costs should align with the RPE value. Applying RPE to the cost for each technology assures that alignment.

Modified multipliers have been developed by EPA, working with a contractor, for use in rulemakings.[1] These multipliers are referred to as indirect cost multipliers (or ICMs). ICMs assign unique incremental changes to each indirect cost contributor at several different technology levels.

ICM = (direct cost + adjusted indirect cost)/(direct cost)

Developing the ICMs from the RPE multipliers requires developing adjustment factors based on the complexity of the technology and the time frame under consideration: the less complex a technology, the lower its ICM, and the longer the time frame for applying the technology, the lower the ICM. This methodology was used in the cost estimation for the recent light-duty MYs 2012-2016 and MYs 2017-2025 rulemaking and for the heavy-duty MYs 2014-2018 rulemaking. The ICMs for the light-duty context were developed in a peer-reviewed report from RTI International and were subsequently discussed in a peer-reviewed journal article.[2] Importantly, since publication of that peer-reviewed journal article, the agencies have revised the methodology to include a return on capital (i.e., profits) based on the assumption implicit in ICMs (and RPEs) that capital costs are proportional to direct costs, and businesses need to be able to earn returns on their investments.

Since their original development in February 2009, the agencies have made some changes to both the ICMs factors and to the method of applying those factors relative to the factors developed by RTI and presented in their reports. We have described and explained those changes in several rulemakings over the years, most notably the 2017-2025 FR for light vehicles and the more recent Heavy-duty GHG Phase 2 NPRM.[3] In the 2015 NAS study, the committee stated a conceptual agreement with the ICM method since ICM takes into account design challenges and the activities required to implement each technology. However, although endorsing ICMs as a concept, the NAS Committee stated that "…the empirical basis for such multipliers is still lacking, and, since their application depends on expert judgment, it is not possible to determine whether the Agencies' ICMs are accurate or not." NAS also states that "…the specific values for the ICMs are critical since they may affect the overall estimates of costs and benefits for the overall standards and the cost effectiveness of the individual technologies." The committee did encourage continued research into ICMs given the lack of empirical data for them to evaluate the ICMs used by the agencies in past analyses. EPA, for its part, continues to study the issue surrounding ICMs but has not pursued further efforts given resource constraints and demands in areas such as technology benchmarking and cost teardowns.

On balance, NHTSA believes that the empirically derived RPE is a more reliable basis for estimating indirect costs. To ensure overall indirect costs in the analysis align with the RPE value, NHTSA has developed its primary analysis based on applying the RPE value of 1.5 to each technology. NHTSA also has conducted a sensitivity analysis examining the impact of applying the ICM approach in the sensitivity analysis portion later in this Section. This marks a change from the NPRM where we use the ICM multiplier to calculate indirect costs as the central analysis and the RPE multiplier as a sensitivity case.

10.1.7.8.2 Updates to Mass Reduction Based on 2014 Silverado Study

As proposed in the NPRM we have updated the HD pickup and van mass reduction cost curves with a MY 2014 GMC Silverado EDAG study. The updated mass reduction study suggests that mass reduction will be more costly for heavy-duty vans and pickups than was suggested in the NPRM. This can explain the reduction in mass reduction in the current analysis compared to the NPRM.

NHTSA awarded a contract to EDAG to conduct a vehicle weight reduction feasibility and cost study of a 2014MY full size pick-up truck. The light weighted version of the full size pick-up truck (LWT) used manufacturing processes that will likely be available during the model years 2025-2030 and be capable of high volume production. The goal was to determine the maximum feasible weight reduction while maintaining the same vehicle functionalities, such as towing, hauling, performance, noise, vibration, harshness, safety, and crash rating, as the baseline vehicle, as well as the functionality and capability of designs to meet the needs of sharing components across same or cross vehicle platform. Consideration was also given to the sharing of engines and other components with vehicles built on other platforms to achieve manufacturing economies of scale, and in recognition of resource constraints which limit the ability to optimize every component for every vehicle.

A comprehensive teardown/benchmarking of the baseline vehicle was conducted for the engineering analysis. The analysis included geometric optimization of load bearing vehicle structures, advanced material utilization along with a manufacturing technology assessment that would be available in the 2017 to 2025 time frame. The baseline vehicle's overall mass, center of gravity and all key dimensions were determined. Before the vehicle teardown, laboratory torsional stiffness tests, bending stiffness tests and normal modes of vibration tests were performed on baseline vehicles so that these results could be compared with the CAE model of the light weighted design. After conducting a full tear down and benchmarking of the baseline vehicle, a detailed CAE model of the baseline vehicle was created and correlated with the available crash test results. The project team then used computer modeling and optimization techniques to design the light-weighted pickup truck and optimized the vehicle structure considering redesign of structural geometry, material grade and material gauge to achieve the maximum amount of mass reduction while achieving comparable vehicle performance as the baseline vehicle. Only technologies and materials projected to be available for large scale production and available within two to three design generations (e.g. model years 2020, 2025 and 2030) were chosen for the LWT design. Three design concepts were evaluated: 1) a multi-material approach; 2) an aluminum intensive approach; and 3) a Carbon Fiber Reinforced Plastics approach. The multi-material approach was identified as the most cost effective. The recommended materials (advanced high strength steels, aluminum, magnesium and plastics), manufacturing processes, (stamping, hot stamping, die casting, extrusions, and roll forming) and assembly methods (spot welding, laser welding, riveting and adhesive bonding) are currently used, although some to a lesser degree than others. These technologies can be fully developed within the normal product design cycle using the current design and development methods.

The design of the LWT was verified, through CAE modeling, that it meets all relevant crash tests performance. The LS-DYNA finite element software used by the EDAG team is an industry standard for crash simulation and modeling. The researchers modeled the crashworthiness of the LWT design using the NCAP Frontal, Lateral Moving Deformable Barrier, and Lateral Pole tests, along with the IIHS Roof, Lateral Moving Deformable Barrier, and Frontal Offset (40 percent and 25 percent) tests. All of the modeled tests were comparable to the actual crash tests performed on the 2014 Silverado in the NHTSA database. Furthermore, the FMVSS No. 301 rear impact test was modeled and it showed no damage to the fuel system.

The baseline 2014 MY Chevrolet Silverado's platform shares components across several platforms. Some of the chassis components and other structural components were designed to accommodate platform derivatives, similar to the components in the baseline vehicle which are shared across platforms such as GMT 920 (GM Tahoe, Cadillac Escalade, GMC Yukon), GMT 930 platform (Chevy Suburban, Cadillac Escalade ESV, GMC Yukon XL), and GMT 940 platform (Chevy Avalanche and Cadillac Escalade EXT) and GMT 900 platform (GMC Sierra). As per the National Academy of Science's guidelines, the study assumes engines would be downsized or redesigned for mass reduction levels at or greater than 10 percent. As a consequence of mass reduction, several of the components used designs that were developed for other vehicles in the weight category of light-weighted designed vehicles were used to maximize economies of scale and resource limitations. Examples include brake systems, fuel tanks, fuel lines, exhaust systems, wheels, and other components.

Cost is a key consideration when vehicle manufacturers decide which fuel-saving technology to apply to a vehicle. Incremental cost analysis for all of the new technologies applied to reduce mass of the light-duty full-size pickup truck designed were calculated. The cost estimates include variable costs as well as non-variable costs, such as the manufacturer’s investment cost for tooling. The cost estimates include all the costs directly related to manufacturing the components. For example, for a stamped sheet metal part, the cost models estimate the costs for each of the operations involved in the manufacturing process, starting from blanking the steel from coil through the final stamping operation to fabricate the component. The final estimated total manufacturing cost and assembly cost are a sum total of all the respective cost elements including the costs for material, tooling, equipment, direct labor, energy, building and maintenance.

The information from the LWT design study was used to develop a cost curve representing cost effective full vehicle solutions for a wide range of mass reduction levels. At lower levels of mass reduction, non-structural components and aluminum closures provide weight reduction which can be incorporated independently without the redesign of other components and are stand-alone solutions for the LWV. The holistic vehicle design using a combination of AHSS and aluminum provides good levels of mass reduction at reasonably acceptable cost. The LWV solution achieves 17.6 percent mass reduction from the baseline curb mass. Further two more analytical mass reduction solutions (all aluminum and all carbon fiber reinforced plastics) were developed to show additional mass reduction that could be potentially achieved beyond the LWV mass reduction solution point. The aluminum analytical solution predominantly uses aluminum including chassis frame and other components. The carbon fiber reinforced plastics analytical solution predominantly uses CFRP in many of the components. The CFRP analytical solution shows higher level of mass reduction but at very high costs. Note here that both all-Aluminum and all CFRP mass reduction solutions are analytical solutions only and no computational models were developed to examine all the performance metrics.

An analysis was also conducted to examine the cost sensitivity of major vehicle systems to material cost and production volume variations.

Table 10-30 lists the components included in the various levels of mass reduction for the LWV solution. The components are incorporated in a progression based on cost effectiveness.

Table 10-30 Components Included for Different Levels of Mass Reduction

Vehicle Component/System	Cumulative Mass Saving (kg)	Cumulative MR%	Cumulative Cost	Cumulative Cost $/kg
Interior Electrical Wiring	1.38	0.06%	($28.07)	-20.34
Headliner	1.56	0.06%	($29.00)	-18.59
Trim – Plastic	2.59	0.11%	($34.30)	-13.24
Trim - misc.	4.32	0.18%	($43.19)	-10.00
Floor Covering	4.81	0.20%	($45.69)	-9.50
Headlamps	6.35	0.26%	($45.69)	-7.20
HVAC System	8.06	0.33%	($45.69)	-5.67
Tail Lamps	8.46	0.35%	($45.69)	-5.40
Chassis Frame	54.82	2.25%	$2.57	0.05
Front Bumper	59.93	2.46%	$7.89	0.13
Rear Bumper	62.96	2.59%	$11.04	0.18
Towing Hitch	65.93	2.71%	$14.13	0.21
Rear Doors	77	3.17%	$28.09	0.36
Wheels	102.25	4.20%	$68.89	0.67
Front Doors	116.66	4.80%	$92.53	0.79
Fenders	128.32	5.28%	$134.87	1.05
Front/Rear Seat & Console	157.56	6.48%	$272.57	1.73
Steering Column Assy	160.78	6.61%	$287.90	1.79
Pickup Box	204.74	8.42%	$498.35	2.43
Tailgate	213.14	8.76%	$538.55	2.53
Instrument Panel	218.66	8.99%	$565.06	2.58
Instrument Panel Plastic Parts	221.57	9.11%	$580.49	2.62
Cab	304.97	12.54%	$1,047.35	3.43
Radiator Support	310.87	12.78%	$1,095.34	3.52
Powertrain	425.82	17.51%	1246.68	2.93

A fitted curve was developed based on the above listed mass reduction points to derive cost per kilogram at distinct mass reduction points. The current curve shows costs per kilogram approximately six times as expensive for 5 percent mass reduction (MR1) than in the NPRM, and approximately twice as expensive per kilogram for 7.5 percent mass reduction (MR2), which explains the reduction in mass reduction in the current analysis relative to the NPRM.

10.2 What Impacts Did NHTSA's "Method A" Analysis Show for Regulatory Alternatives?

EPCA and EISA require NHTSA to "implement a commercial medium- and heavy-duty on-highway vehicle and work truck fuel efficiency improvement program designed to achieve the maximum feasible improvement" and to establish corresponding fuel consumption standards "that are appropriate, cost-effective, and technologically feasible."[DD] For both the NPRM and the current analysis of potential standards for HD pickups and vans, NHTSA applied NHTSA's CAFE Compliance and Effects Modeling System (sometimes referred to as "the CAFE model" or "the Volpe model") to aid in determination of the maximally feasible standards. The subsequent analysis, referred to as "Method A," includes several updates to the model and to accompanying inputs, as discussed above in Chapter 10.1. The "Method A" results are used as the primary basis for NHTSA's final determination of the suitability of the Phase 2 standards. Further discussion of the determination are provided after the discussion of the "Method A" modeling results above.

10.2.1 Baseline Costs across Manufacturers

As in the NPRM, the main analysis of Method A considers costs, benefits and other effects of regulatory alternatives relative to the dynamic baseline—or a baseline which assumes that manufacturers will apply all technologies with associated cost that pays back from retail-priced fuel savings within 6 months of purchase. The assumption is that consumers are willing to pay additional technology costs that return in fuel savings within 6-months of purchase, and that as a result, manufacturers will adopt these technologies regardless of fuel efficiency standards. We considered alternative runs with voluntary overcompliance of technologies with a payback period of 0-months (manufacturers will not voluntarily overcomply if there is a cost associated with a technology), 12-months, 18-months, and 24-months in the sensitivity analysis.

Before considering the effects of increases in the standards, it is important to discuss the baseline costs. These costs are assumed to be incurred even if no additional regulatory action is taken to increase standards beyond the existing MY 2018 standards. Table 10-31shows the baseline average and total technology costs for each manufacturer in the heavy duty market, and for the heavy duty industry as a whole for the MY 2021 fleet (cost increases relative to the MY 2015 fleet). The updated CAFE model suggests that under no further increasses to stringency beyond MY 2018, manufacturers would spend $136 million—an industry average of $180 per vehicle—on technologies that improve fuel economy in MY 2021. The additonal baseline costs are not distributed across all manufacturers proportional to their fleet size. The average technology costs of an individual manufacturer fleet range from $80 per vehicle for Fiat/Chrysler to $350 per vehicle for General Motors. In order to explain this heterogeneity it is important to

[DD] 49 USC 32902(k)(2).

consider the sources of increased technology costs: compliance actions, inheritance from heavy duty vehicles, spillover inheritance from the light-duty vehicles, and voluntary overcompliance.

Table 10-31 MY2021 Costs (2013$) under Alternative 1b (Central Baseline) for 2b/3 Market

Manufacturer	Average per Vehicle Technology Cost (2013$)	Total Technology Cost (million 2013$)	Estimated MY 2015 Fuel Consumption (g/100 mi)	Estimated MY 2018 Standard (g/100 mi)
Daimler	$150	$3	4.50	4.84
FCA	$80	$10	6.23	5.95
Ford	$90	$33	6.00	5.76
GM	$350	$86	6.52	5.94
Nissan	$230	$3	6.01	5.63
Industry	$180	$136	6.18	5.83

One reason manufacturers incur technology costs in the baseline for MY 2021 vehicles is to achieve compliance with Phase 1 standards, which end their stringency increases in MY 2018. Manufacturers will have different standards and different starting positions relative to these standards. In order to indicate which manufacturers make compliance actions which increase their baseline technology costs, Table 10-31includes the MY 2015 estimated average fuel consumption and the estimated MY 2018 fuel consumption standard—manufacturers with higher average fuel consumption in MY 2015 than the estimated MY 2018 fuel consumption standard, will apply technology costs to comply with the final MY 2018 standards. The fuel consumption standards are determined by setting work factor based targets and computing the manufacturer's sales-weighted average of these targets. While the individual vehicle targets based on work factor are the same for all vehicles of the same work factor for model years 2018 and beyond, the overall fuel efficiency standard for a manufacturer may change from model year to model year with changes to the work factors of individual vehicle models, as well as changes in relative production volumes of each vehicle model. The model does not capture all means by which a manufacturer's average fuel efficiency standard may change under the MY 2018 attribute-based standards, but does capture changes to work factor—and therefore individual vehicle targets—due to application of mass reduction. The model also predicts changes to the fleet mix of each manufacturer using inputs created from AEO2015 and 2015 IHS/Polk production projections. The technology cost for a manufacturer to meet MY 2018 standards is primarily driven by the fuel consumption gap between the MY 2015 (baseline) compliance level and the 2018 standard. From Table 10-38it can be seen that only Daimler meets its most-stringent fuel consumption standard in 2015 and does not have to apply technology in the baseline to comply with Phase 1 standards.

A second source of technology costs is from inheritance; vehicles with shared platforms are assumed to inherit technologies applied to the platform leader at their next redesign or refresh to avoid creating a new body or engine platform[EE], even if these actions are no longer necessary

[EE] For a more complete discussion of inheritance in the model see Chapter 6, Section C.

to reach compliance. Manufacturers produce a limited set of engine and body platforms as a strategy to reduce their costs; there is no reason to indicate they will modify this strategy to comply with standards, for this reason this is an important constraint in the CAFE model. A similar source of technology costs are costs associated with spillover from the light-duty MY 2017-2021 standards. Regulatory agencies distinctly define the heavy duty and light duty classes, but from the manufacturer perspective these classes are not clearly delineated. They share some engine and body platforms across regulatory classes, and sometimes the most cost-effective choice to comply with standards will involve making changes to these shared platforms. Comments in the NPRM recommended that we run the model with the ability to capture this spillover effect between the light-duty and heavy-duty fleets—in response to these comments, in the current analysis we run the two fleets together with all existing standards from the light-duty fleet included for all scenarios. Since the MY 2017-2021 light-duty CAFE standards are final, these and their effects are included in the baseline of the model—they will be in effect whether or not additional action is taken with heavy-duty standards. While we have included the ability for the standards from one fleet to affect the other, our modeling has shown that the spilloever effect from the light-duty fleet into the heavy-duty fleet, and from the heavy-duty fleet into the light-duty fleet is small. We hope to further develop the model's ability to capture the spillover effects in future versions of the model.

The final way that manufacturers might accrue additional technology costs in the MY 2021 dynamic baseline scenario is through voluntary overcompliance. As already discussed: in the baseline case of the central analysis it is assumed that manufacturers will apply technologies which payback in fuel savings within 6 months of operation, regardless of whether or not the standards increase in stringency. Depending on the existing technologies and vehicles in a manufacturer's fleet, they may voluntarily overcomply by adding different technologies, or none at all.

The MY 2021 costs of the dynamic baseline scenario are lower in the updated analysis than they were in the NPRM for all manufacturers other than Nissan and Daimler. The average technology costs across the industry are less than half the NPRM costs—dropping from $440/vehicle to $180/vehicle. The largest drop in average costs across the manufacturers is for GM; their costs dropped from $780/vehicle to $350/vehicle. The modeled costs for Nissan dropped from $280 to $230, and for FCA, from $280 to $80.

While considering MY 2021 allows for comparision to the NPRM analysis, not all baseline costs are incurred in MY 2021. Figure 10-11 shows the baseline total technology costs, and Figure 10-12, the average technology costs, by manufacturer for all model years. Like the NPRM analysis assumes manufacturers will likely apply most technologies as part of vehicle redesign or freshening; as a result their technology application comes in discrete blocks. GM applies $20 million in total technolgy for their MY 2016 fleet, and an additional $60 million in for MY 2018—their total technology costs vary slightly after this point with the projection of their fleet size and with the effects of technology learning. Similarly, Ford applies $30 million for MY 2017 and an additional $80 million in 2027. Chrysler/Fiat, Daimler, and Nissan apply technology in only one year—Chrysler/Fiat applies $11 million in MY 2018, Daimler $3 million for MY 2020, and Nissan $3 million for MY 2021. While the total technology costs vary between manufacturers, the per-vehicle baseline costs range between $0-350 for all manufacturers and model years.

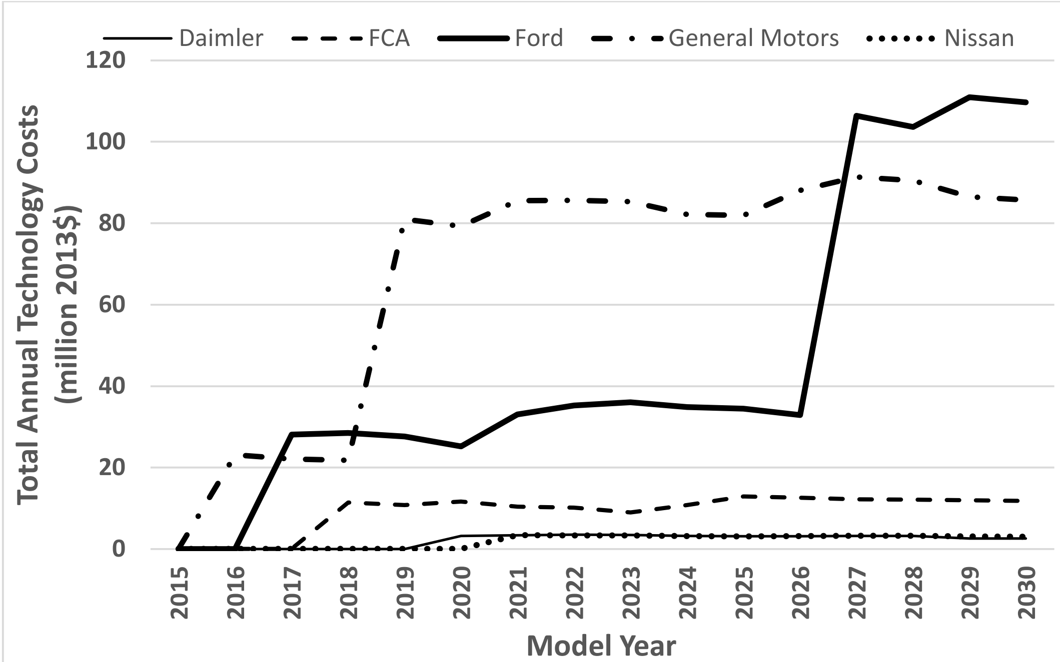

Figure 10-11 Total Annual Baseline Technology Costs (million 2013$) by Model Year and Manufacturer

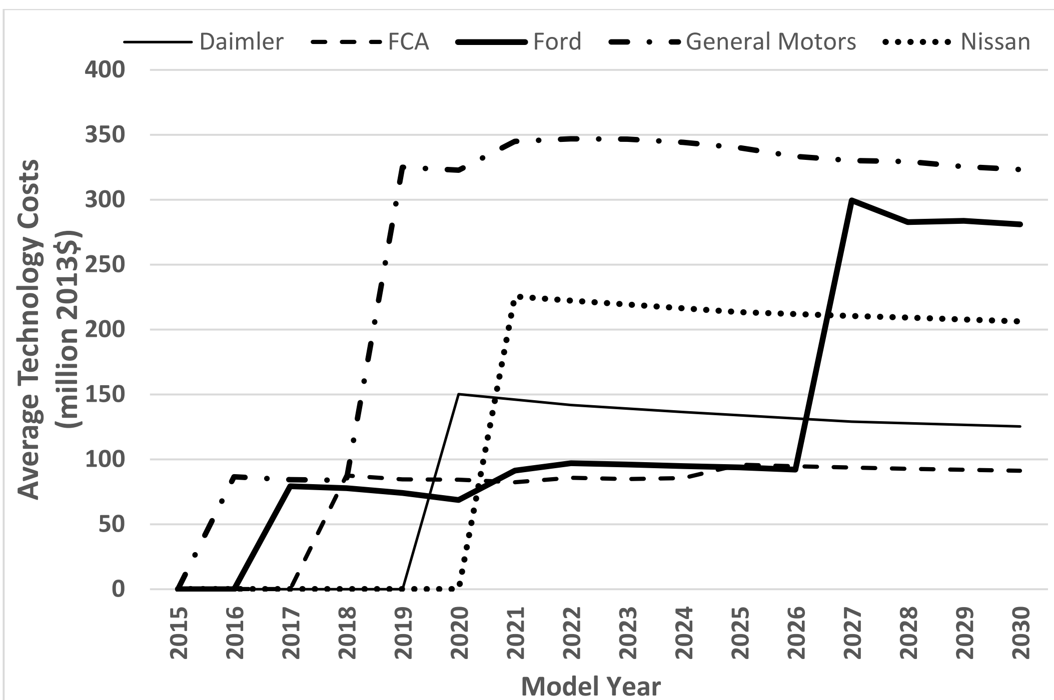

Figure 10-12 Per Vehicle Baseline Technology Costs (million 2013$) by Model Year and Manufacturer

10.2.2 Relevant Model Updates

There are changes to model that help explain the decrease in baseline technology costs for the current analysis. The current analysis uses the synergies simulated by Argonne for the light-duty fleet, while the NPRM analysis uses a limited set of synergy values (also initially estimated for the light-duty fleet. The changes in these synergy factors could impact which technologies are chosen, and how effective the model calculates them to be.[FF] Changes to the model input costs from the NPRM to the current analysis could also change which technologies get picked by the model, and the projected costs. One of the major changes to costs is a switch from the ICM cost mark-up methodology used in the NPRM to the RPE cost mark-up methodology of the current analysis.[GG] A more specific change to the input costs is a change to the mass reduction curve to be based off of the newer 2014 Silverado study, which suggests that 5 percent and 10 percent mass reduction is significantly more expensive than was assumed in the NPRM.[HH]

The final major input change is that the current model uses the 2015 fleet as its reference point, while the NPRM uses the 2014 fleet. This affects the starting point of each manufacturer in the model, and could change their predicted standard (through changes in sales mix and work factor). In order to consider the impacts of using the 2015 reference fleet it is helpful to consider the sales-weighted fuel economy and work factor distributions across the two reference fleets.

Figure 10-13 shows the sales-weighted empirical cumulative distribution function (CDF) for GM's work factor and fuel economy for the two reference fleets. The dashed line shows the values for the 2014 reference fleet, and the solid, for the 2015 reference fleet. The y-axis shows the cumulative share of the manufacturer's fleet against the two measures. For GM, the work factor CDF shifted to the right for work factors between 3500 and 5500, suggesting that the proportion of the fleet with work factors in this range increased in the GM fleet. Since increases in work factor will decrease the target value for individual vehicles, this average change in work factor decreases GM's initial CAFE standard.

It should also be noted that some methods of increasing work factor (mainly, decreasing curb weight) can increase the fuel efficiency of a vehicle, while others (increasing the power) can decrease fuel efficiency. The empirical CDF for GM's sales-weighted fuel consumption shows GM's 2015 fleet as having more vehicles with fuel consumption below 6.3 gal/100 mi, fewer with fuel consumption around 6.3 gal/100 mi, significantly more vehicles with fuel consumption around 7.0 gal/100 mi. The average fuel consumption of GM's 2014 fleet was 6.27 gal/100 mi, where the average fuel consumption of GM's 2015 fleet is 6.52 gal/100 mi. The overall increase in GM's average fuel consumption diminishes the effect of the increase in work factor from MY 2014 to MY 2015 at improving their starting position in MY 2015 relative to MY 2014—their MY 2015 standard using the 2014 fleet was 6.36, and using the 2014 fleet and is 6.59. Considering this, their initial shortfall is about the same using either reference fleet.

[FF] For a more complete discussion of the changes to the Argonne simulation synergies see Chapter 6, Section C.
[GG] For further discussion on the switch from ICM to RPE for the final analysis see Chapter 6, Section C.
[HH] More discussion of the change in mass reduction curves is present in Chapter 6, Section C.

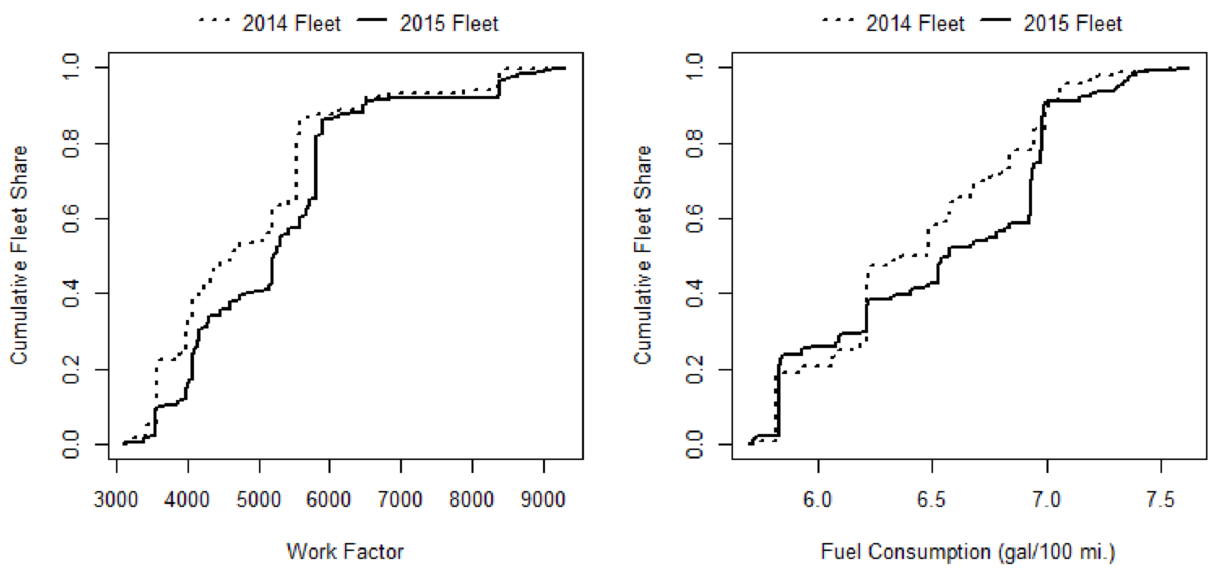

Figure 10-13 2014 vs. 2015 Reference Fleet Work Factor and Fuel Efficiency for General Motors.

Figure 10-14 shows the same for Ford. There is a similar pattern of a higher proportion of heavy duty vehicles in Ford's fleet with work factors between 3500 and 5000. This will decrease Ford's initial standard in the model. Ford also shows a decrease in the proportion of heavy duty vehicles with higher fuel consumption, which will result in an overall lower fuel consumption for the 2015 fleet. The result is that Ford will start with a lower standard by using the 2015 fleet rather than the 2014 fleet, and start with a higher fuel efficiency level—both of which will work in the same direction to decrease Ford's shortfall to MY 2018 standards. This suggests that Ford will not need to apply as much technology to comply, and helps to explain their lower baseline technology costs in the current analysis.

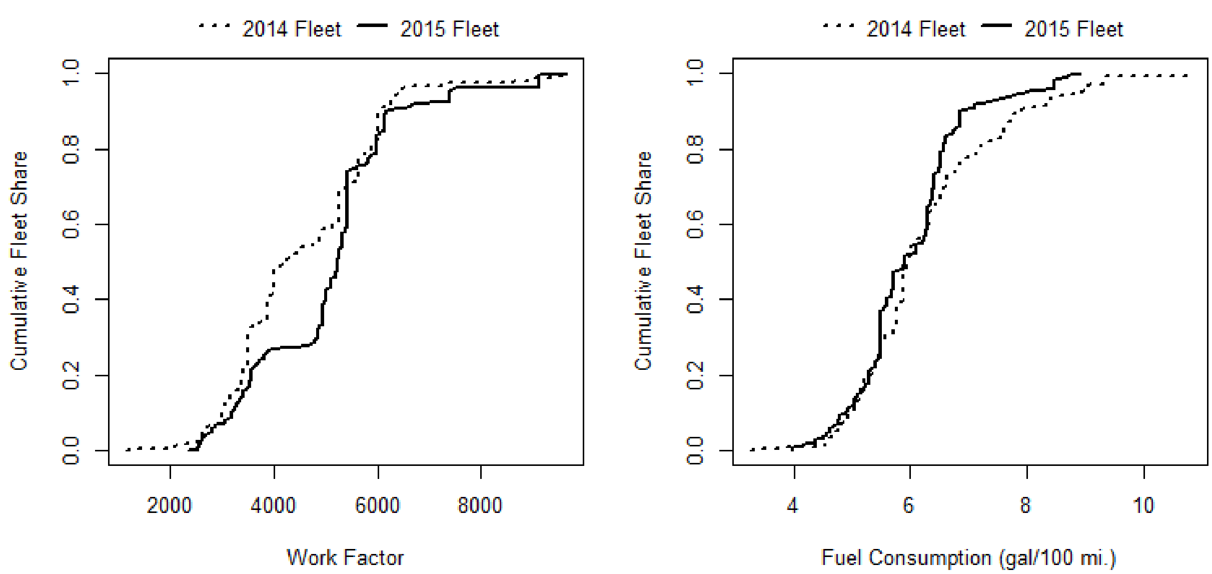

Figure 10-14 2014 vs. 2015 Reference Fleet Work Factor and Fuel Economy for Ford

Figure 10-15 shows the cumulative distribution function for the work factor of Fiat/Chrysler. Although there is some increase in the left tail of the distribution of FCA's work factor for MY 2015 relative to MY 2014, it is smaller than for the Ford and GM fleets. The CDF of fuel efficiency also shows that Fiat/Chrysler shows nearly identical distribution of fuel consumption between the 2014 and 2015 fleets. These two factors combine to explain why Fiat/Chrysler did not show increases in costs from the NPRM to the current analysis—they did not have as much of a change in shortfall to MY 2018 standards as both GM and Ford.

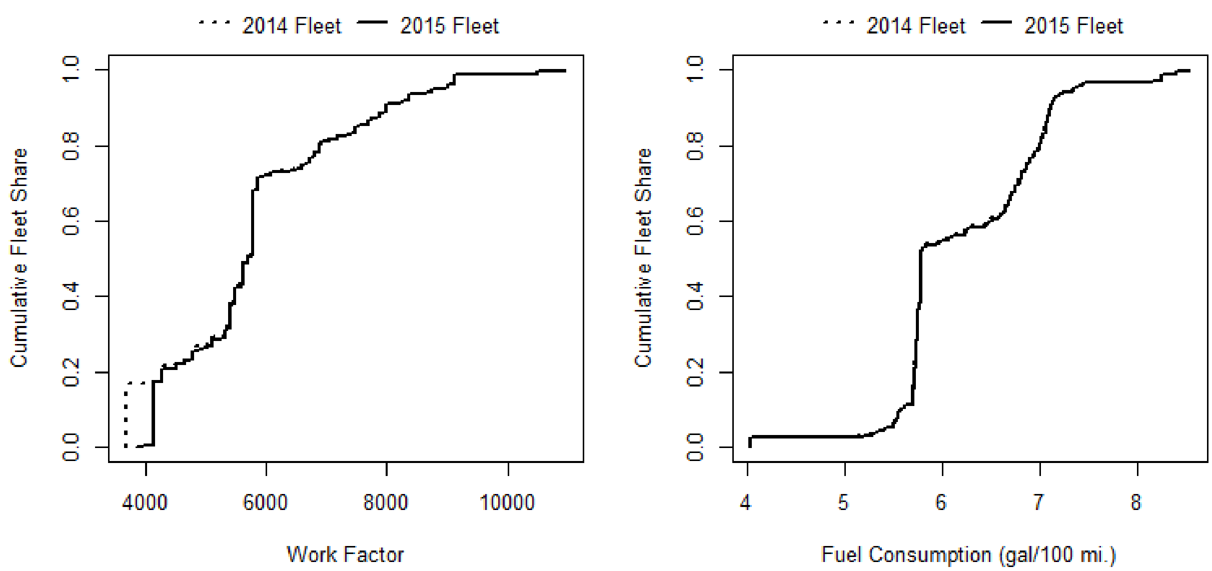

Figure 10-15 2014 vs. 2015 Reference Fleet Work Factor and Fuel Economy for Fiat/Chrysler

Figure 10-16 shows the same empirical distribution functions for Nissan. Both the distribution of work factor and fuel consumption are comparable for Nissan's 2014 and 2015 fleets. This helps explain the small change in Nissan's baseline costs between the two analyses.

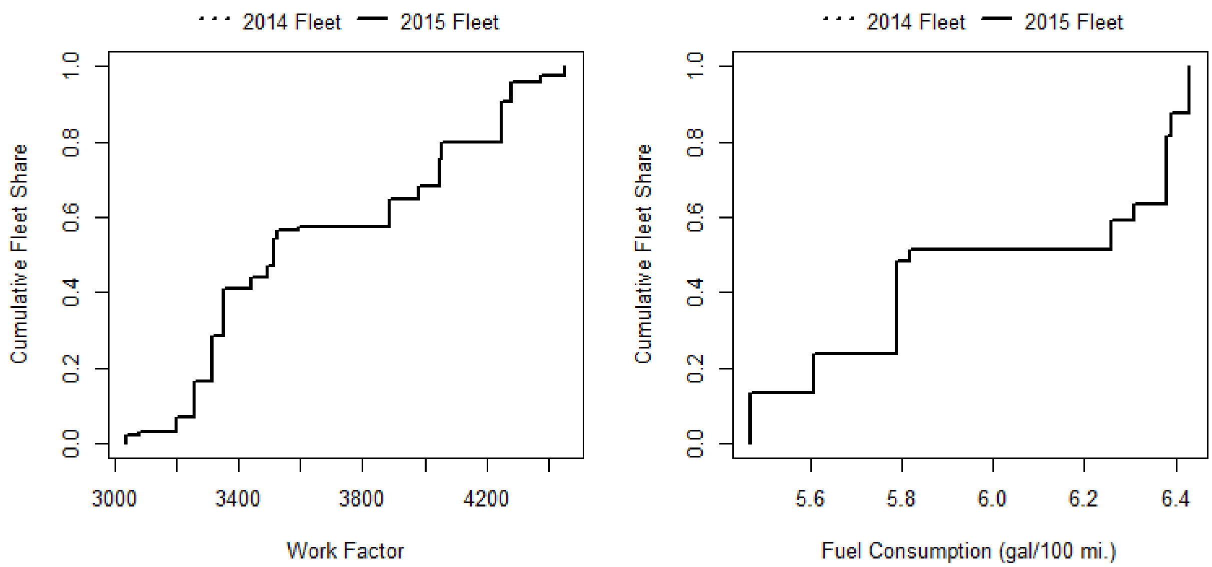

Figure 10-16 2014 vs. 2015 Reference Fleet Work Factor and Fuel Economy for Nissan

Figure 10-17 shows the cumulative distribution function for work factor and fuel consumption for Daimler for both the 2014 and 2015 fleets. The distribution of work factor shifted right for work factors above 3500. The fuel consumption curve shifted right for all fuel consumptions. This suggests that Daimler will face a lower standard using the 2015 reference fleet, but that they may also start with a lower initial fuel efficiency level. The change to the 2015 reference fleet does not have clear implications on the relative starting point of Daimler in the analysis relative to the NPRM analysis.

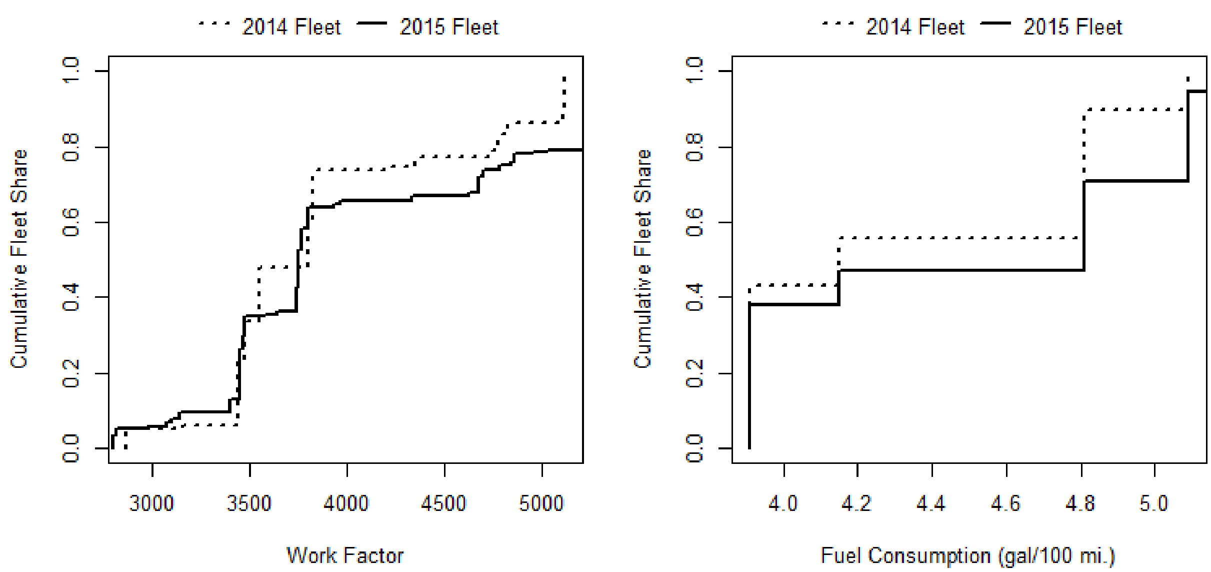

Figure 10-17 2014 vs. 2015 Reference Fleet Work Factor and Fuel Economy for Daimler

10.2.3 Industry-Level Results of Regulatory Alternatives

Table 10-32, below, summarizes the stringency of standards, the estimated required fuel efficiency the estimated achieved fuel efficiency, as well as the impacts of each alternative for the overall industry for MY 2030. Using the updated fleet and analysis, the MY 2030 stringency is slightly less that in the NPRM (4.91 gallons/100 mile in today's analysis compared to 4.86 gallons/100 mile in the NPRM for the preferred alternative). As has been noted, the standards are set based in part on the work factor of vehicles; by changing the average work factor of their fleet, manufacturers can change the average stringency of their standard. While the model does not simulate changes to work factor which would increase the power or GVWR, it does simulate changes in work factor due to mass reduction. By lowering the curb weight and holding power constant, manufacturers can increase the payload of a vehicle; since payload is a component in calculating the work factor, by lowering curb weight manufacturers can increase their work factor for a vehicle model and reduce its target. However, the average absolute and proportional curb weight reduction in the current analysis is less than it was in the NPRM analysis across all alternatives, which can be explained by the higher mass reduction costs under the current curve. This suggests that the change in the average overall industry standard in today's analysis is likely due in major part to changes in the work factor between the 2014 and 2015 reference fleet, and not to changes in the work factor simulated within the model runs.

Table 10-32 Summary of Impacts on the MY2030 HD Industry Fleet (vs. Alternative 1b)

Alternative	**2**	**3**	**4**	**5**
Stringency of Standards				
Annual Increase in Stringency Beginning in MY 2021	2.0%	2.5%	3.5%	4.0%
Increases Until	MY2025	MY2027	MY2025	MY2025
Total Increase in MY2030 Stringency Relative to Final Phase 1Standards [a]	9.6%	15.6%	15.6%	17.9%
Estimated Average Fuel Economy (miles per gallon)				
Required in MY 2030	19.03	20.37	20.38	20.95
Achieved in MY 2030	19.20	20.47	20.45	20.98
Average Fuel Consumption (gallons/100 miles)				
Required in MY 2030	5.25	4.91	4.91	4.77
Achieved in MY 2030	5.21	4.88	4.89	4.77
Estimated Average Greenhouse Gas Emissions (grams per mile)				
CO_2 Required in MY 2030	494	462	462	450
CO_2 Achieved in MY 2030	490	460	460	449
Technology Penetration in MY 2030 (percent)				
VVT and/or VVL	56	56	56	56
Cylinder Deactivation	4	4	4	4
Direct Injection Engine	17	27	26	29
Turbo Charged Engine	59	69	68	68
8 Speed Auto. Trans.	77	95	94	95
EPS, Accessories	52	80	80	96
12V Stop-start	0	0	3	11
Strong Hybrid	0	2	2	7
Aero. Improvements	46	80	80	98
Mass Reduction (vs. No-Action)				
Mass Reduction (lb.)	28	240	24	289
Mass Reduction (percent of curb weight)	0.43	3.6	3.7	4.3
Technology Costs (vs. No-Action)				
Average Vehicle ($)	$500	$1470	$1480	1890
Payback Period (m)[b]	19	30	31	33

Notes:
[a] This increase in stringency is based on the estimated percentage change in fuel consumption (gal/100mi) stringency projected by the model for the MY2030 fleet under the final Phase 2 standards relative to the continuation of Phase 2 standards. Note that if manufacturers' have applied mass reduction to an individual

vehicle model in the CAFÉ model that this will increase the work factor of that vehicle in the model, and make the individual target less stringent. Thus, where any mass reduction is applied in the model, the total increase in stringency of the fleet presented here will be lower than the total stringency increase of the fleet if no mass reduction were applied.
[b] Here payback period is calculated using estimated undiscounted retail fuel savings and the initial technology costs for MY2030.

Today's Method A analysis using the updated version of the CAFE model and updated inputs shows that regulatory Alternatives 3 and 4 could be met with a small application of strong (P2) HEVs. However, Alternative 5 could be met with the considerably greater application of strong HEVs. Although there is some increase in the penetration rates between alternatives as stringency increases, the current analysis suggests that under all alternatives, nearly all of the MY 2030 heavy-duty fleet could use 8-speed transmissions, VVT/VVL improvements and turbo-charged engines with application across more than half of the fleet, direct injection could be present in a quarter of the fleet, and cylinder deactivation could play a minor part in the HD fleet. EPS and improved electrical accessories vary more between alternatives; present in 52 percent of the fleet in Alterative 2, 80 percent in Alternatives 3 and 4, and 96 percent in Alternative 5. Aerodynamic improvements and mass reduction follow a similar pattern; with a larger penetration of these technologies with Alternative 3 than with Alternative 2, a similar penetration under Alternatives 3 and 4, and a higher in penetration in Alternative 5.

A way to measure the cost-effectiveness of the technologies on consumers is to look at the payback period. In this context, the payback period is defined as the number of months of driving it will take a consumer to earn back the increased technology costs by the amount they save in fuel by driving a more fuel efficient vehicle. Under the current analysis, the average additional technology cost will payback in fuel savings in under 17 months for Alternative 2, 27 months for Alternatives 3 and 4, and 30 months for Alternative 5. It is important to note that there are inputs other than the cost and effectiveness of technologies which could affect the payback period; the fuel prices and mileage accumulation schedules will affect how quickly the cost of a fuel-saving technology pays back.

The current analysis uses updated fuel price estimates from AEO 2015 that are lower than in the NPRM analysis. Lower fuel prices will decrease the absolute amount of fuel savings (assuming the same number of gallons is consumed) and increase the payback period if the technologies, their cost, and their effectiveness are unchanged. Further, we have updated the vehicle use schedule (vehicle miles traveled, or VMT) based on actual vehicle odometer readings from IHS/Polk data as shown in Figure 13.9. While the overall survival-weighted schedules show 6.5 percent fewer lifetime miles for heavy-duty vehicles, they show more annual miles driven for the first 5-years of use for heavy-duty vehicles. The result is that the overall lifetime fuel savings will decrease, but the fuel savings will be higher for the first 5 years. Since the payback periods under both analyses are shorter than 5 years, using the updated vehicle schedules will show a shorter payback period (if other factors are unchanged) than in the NPRM analysis. The changes in fuel prices and the change in the mileage accumulation schedule work in opposite directions on the payback period; the total change in payback period is attributable to both of these input changes as well as to the changes in the cost[II] and effectiveness[JJ] of the different technology inputs, and the changes in the reference fleet.

Industry costs in MY 2030 provide one perspective on technology costs. Industry cost in each model year provides additional perspective on the timing, pace and the amount of resources and spending that would need to be allocated to implement technologies and is important in the consideration of the feasibility of the alternatives. Figure 10-18 and Figure 10-19 show the total and average additional and total additional technology costs for the industry by model year and alternative. Note that the trend of the total and average costs are very similar, this is because the fleets size the AEO projections suggest a relatively constant fleet size during the considered MY's. The total and average technology costs increase with alternative stringency. It is important to note that Alternatives 3 and 4 both increase total stringency for the MY2030 industry fleet by 15.6 percent. Also note that these estimations of stringency increases include the model projections of how the application of mass reduction will alter work factor and individual vehicle targets.[KK] The annual average and total technology costs of Alternative 3 approach those of Alternative 4 by MY 2029 when both alternatives have reached maximum stringency. If manufacturers are to reach the same stringency level over a longer horizon, they will likely make similar technology choices, but be given longer to implement them. This will make the total technology costs lower, but should unsurprisingly make the marginal technology costs for model years where both standards have matured very similar.

[II] The costs now use RPE rather than ICM, and we updated the mass reduction curve to the 2014 Silverado.
[JJ] Nominal effectiveness input values are as for the NPRM analysis. Synergy factors applied to adjust fuel consumption impacts for specific combinations of technologies reflect current vehicle simulation work conducted for NHTSA by Argonne National Laboratory.
[KK] The final Phase 2 standard target curves increase in stringency by 16.2 percent compared to final Phase 1 standards, as discussed in Section VI.B.

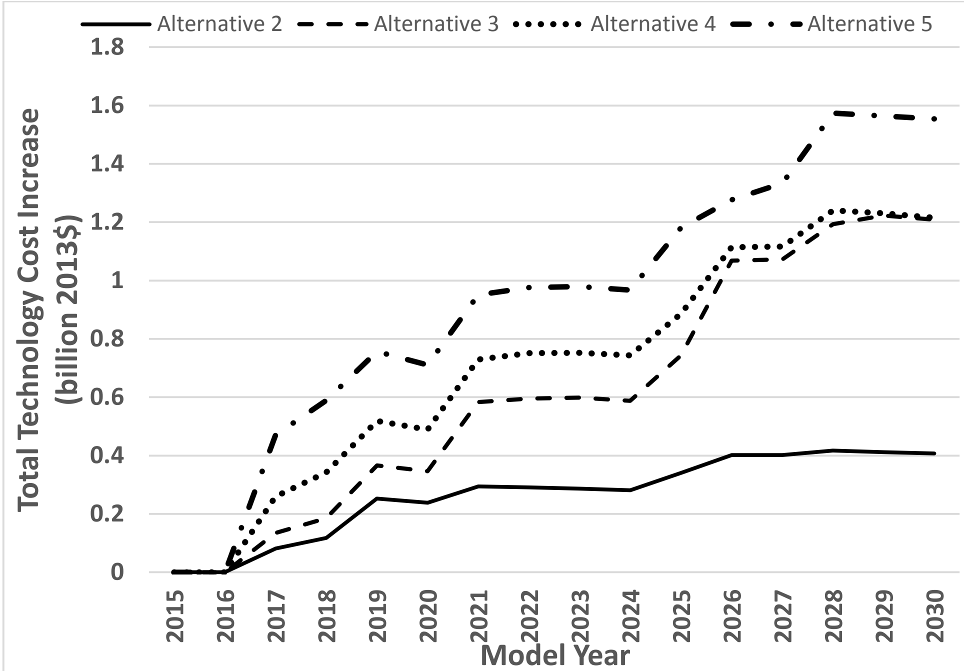

Figure 10-18 Industry Total Technology Cost Increase by Model Year and Alternative

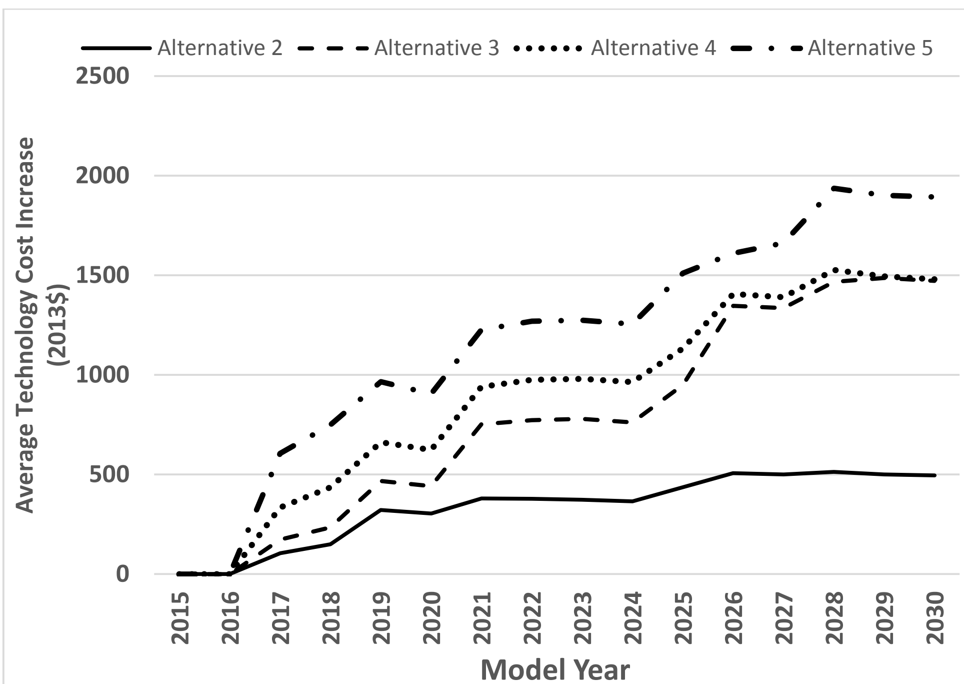

Figure 10-19 Industry Average Technology Cost Increase by Model Year and Alternative

The average incremental industry technology costs mature to around $500 under Alternative 2, $1500 under Alternatives 3 and 4, and $1900 under Alternative 5. Figure 10-20 shows the cumulative total industry costs by model year fleet. $4.2 billion in additional technology costs for model years 2016-2030 are associated with Alternative 2, $9.9 billion with Alternative 3, $11.4 billion with Alternative 4, and $14.9 billion with Alternative 5. While the marginal technology costs of Alternative 3 approach those of Alternative 4 as the total stringencies converge, the total costs of Alternative 4 are $1.5 billion more by MY2030. It is particularly noteworthy that costs and the rate of increase in costs would be significantly different in the MYs 2017 – 2021 timeframe among the alternatives. This identifies the significant differences in the resources and capital that would be required to implement the technologies required to comply with each of the alternatives during this period, as well as the reduction in lead time to implement the technologies which increases reliability risk. These differences are an important consideration for the feasibility of the alternatives and for the selection of the final standards, as discussed further below.

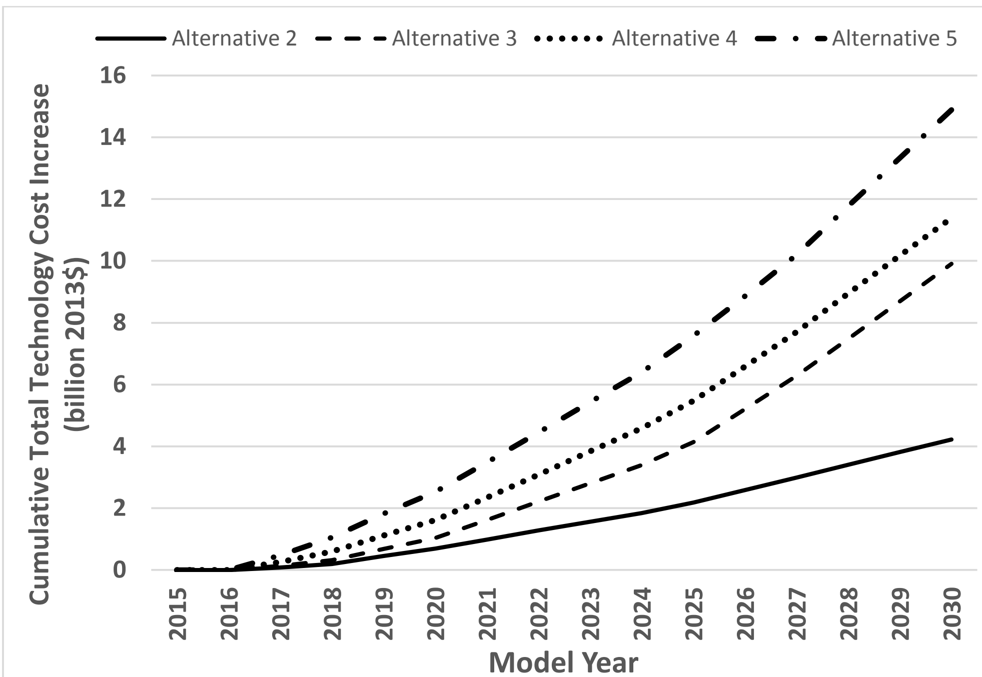

Figure 10-20 Industry Cumulative Total Technology Cost Increase by Model Year and Alternative

10.2.4 Manufacturer-Specific Results of Regulatory Alternatives

In addition to varying across scenario and model year, the impacts of the standards vary across manufacturers. Manufacturers will have different compliance strategies based on which technologies they have already invested in, in both their heavy-duty and light-duty fleets, and based on the effectiveness of new technology applications specific to the vehicles in their heavy duty fleets. Table 10-33 summarizes the initial technology utilization in the 2015 fleet by manufacturer. Ford uses direct injection for 8 percent of their fleet, cylinder deactivation for 13 percent of their fleet, and turbo-charged engines for 8 percent of their fleet. Daimler has already invested to equip all of its fleet with 8-speed automatic transmissions. These differences in initial technology levels affect the new investments each manufacturer would need to further improve the fuel efficiency of their fleets.

Table 10-33 Summary of MY2015 Reference Fleet Technology Penetration

Technology	GM	Ford	FCA	Daimler	Nissan	Industry
	Technology Penetration (percent)					
Cylinder Deactivation	0	0	13	0	0	2
Direct Injection Engine	0	8	0	0	0	4
Turbo Charged Engine	0	8	0	0	0	4
8 Speed Auto. Trans.	0	0	0	100	0	3
EPS, Accessories	0	0	0	0	0	0
12V Stop-start	0	0	0	0	0	0
Strong Hybrid	0	0	0	0	0	0
Aero. Improvements	0	0	0	0	0	0

10.2.4.1 General Motors

Table 10-34 summarizes the alternatives, and a technology pathway General Motors could use to comply with each of the alternatives. The pathway includes implementing 8 speed automatic transmissions across its entire fleet. For Alternatives 2 and 3, no stop-start or HEVs are added to GM’s fleet, for Alternative 4, 1 percent of GM’s fleet uses stop-start, and for Alternative 5, 2 percent uses stop-start and 13 percent are HEVs. For all alternatives, nearly all of the GM’s fleet would use electric power steering and improved electric accessories.

For all alternatives, VVT/VVL is applied to 65 percent of its engines. For Alternative 2, none of its engines get direct injection and 43 percent get turbocharging and downsizing, while for Alternatives 3-5, direct injection is applied to 28 percent of its engines and turbocharging and downsizing is applied to 61 percent of its engines. For all alternatives, all of GM’s fleet gets aerodynamic improvements. The average mass reduction is 52 lbs. (0.78 percent of the average curb weight) under Alternative 2, and 350-380 lbs. (5.2-5.7 percent of the average curb weight) under Alternatives 3-5. Similar technology is applied for Alternatives 3 and 4 in MY 2030, but there are significantly more strong hybrids under Alternative 5.

Table 10-34 Summary Impacts on General Motors HD Fleet by Alternative (vs. Alternative 1b)

Alternative	**2**	**3**	**4**	**5**
Alternative Stringency				
Annual Increase in Stringency Beginning in MY 2021	2.0%	2.5%	3.5%	4.0%
Increases Until	MY2025	MY2027	MY2025	MY2025
Total Increase in MY2030 Stringency Relative to Final Phase 1 Standards [a]	9.6%	15.2%	15.4%	17.7%
Estimated Average Fuel Economy (miles per gallon)				
Required in MY 2030	18.69	19.92	19.96	20.53
Achieved in MY 2030	18.70	20.04	20.04	20.6
Average Fuel Consumption (gallons/100 miles)				
Required in MY 2030	5.35	5.02	5.01	4.87
Achieved in MY 2030	5.35	4.99	4.99	4.85
Estimated Average Greenhouse Gas Emissions (grams per mile)				
CO_2 Required in MY 2030	498	467	466	453
CO_2 Achieved in MY 2030	496	464	464	452
Technology Penetration in MY 2030 (percent)				
VVT and/or VVL	65	65	65	65
Cylinder Deactivation	0	0	0	0
Direct Injection Engine	0	28	28	28
Turbo Charged Engine	33	61	61	61
8 Speed Auto. Trans.	100	100	100	100
EPS, Accessories	100	100	100	100
12V Stop-start	0	0	2	2
Strong Hybrid	0	0	0	13
Aero. Improvements	100	100	100	100
Mass Reduction (vs. No-Action)				
Curb Weight Mass Reduction (lb.)	52	384	384	340

Mass Reduction (percent of curb weight)	0.78	5.7	5.7	5.1

Note:
[a] This increase in stringency is based on the estimated percentage change in fuel consumption (gal/100mi) stringency projected by the model for the MY2030 fleet under the final Phase 2 standards relative to the continuation of Phase 1 standards. Note that if manufacturers' have applied mass reduction to an individual vehicle model in the CAFÉ model that this will increase the work factor of that vehicle in the model, and make the individual target less stringent. Thus, where any mass reduction is applied in the model, the total increase in stringency of the fleet presented here will be lower than the total stringency increase of the fleet if no mass reduction were applied.

Figure 10-21 and Figure 10-22 show the total and average incremental technology costs by alternative. Under Alternative 2 General Motors' incremental technology cost is $140M in MY 2019, increasing to $180M in MY2021. The pathways for Alternatives 3 and 4 are very similar, which again should not be surprising given that the standards result in the same total stringency increase in MY 2027 and beyond and the long redesign cycles in the segment. GM's incremental technology cost is $190M in MY 2019, increasing to $400M in MY 2021, and $530M in MY2028. Under Alternative 5 GM could have a similar compliance strategy as Alternative 3 and 4, but incremental technology cost is$650M in MY2028. The highest annual average technology cost for GM is: $750 under Alternative 2, $1940 under Alternatives 3 and 4, and $2370 under Alternative 5. In the case of GM, the added lead time of Alternative 4 does not significantly change the cost of their compliance strategy.

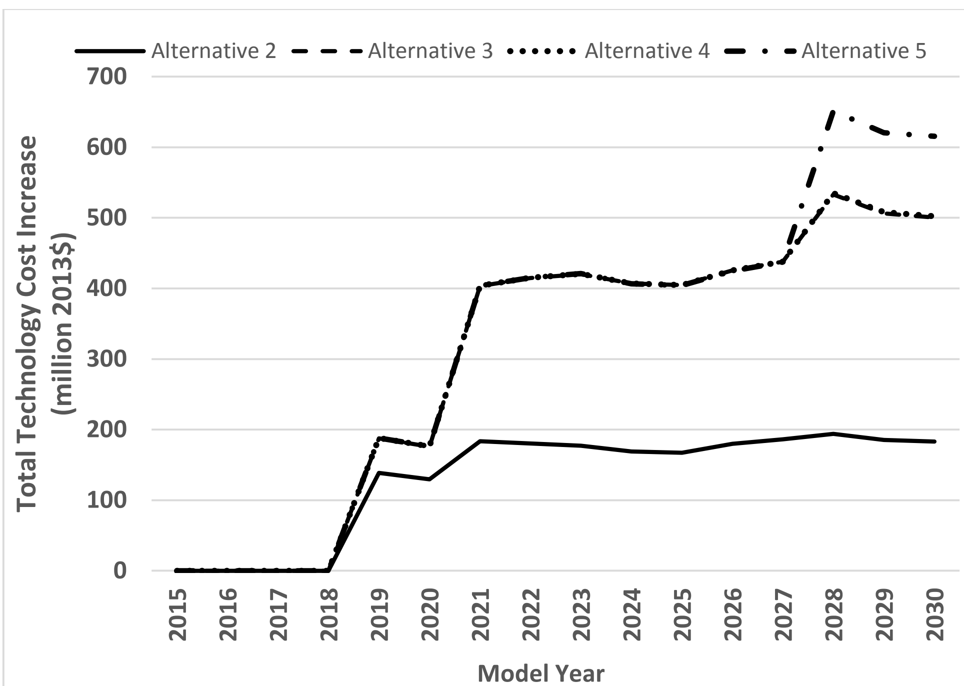

Figure 10-21 Total Technology Cost Increase for General Motors by Model Year and Alternative

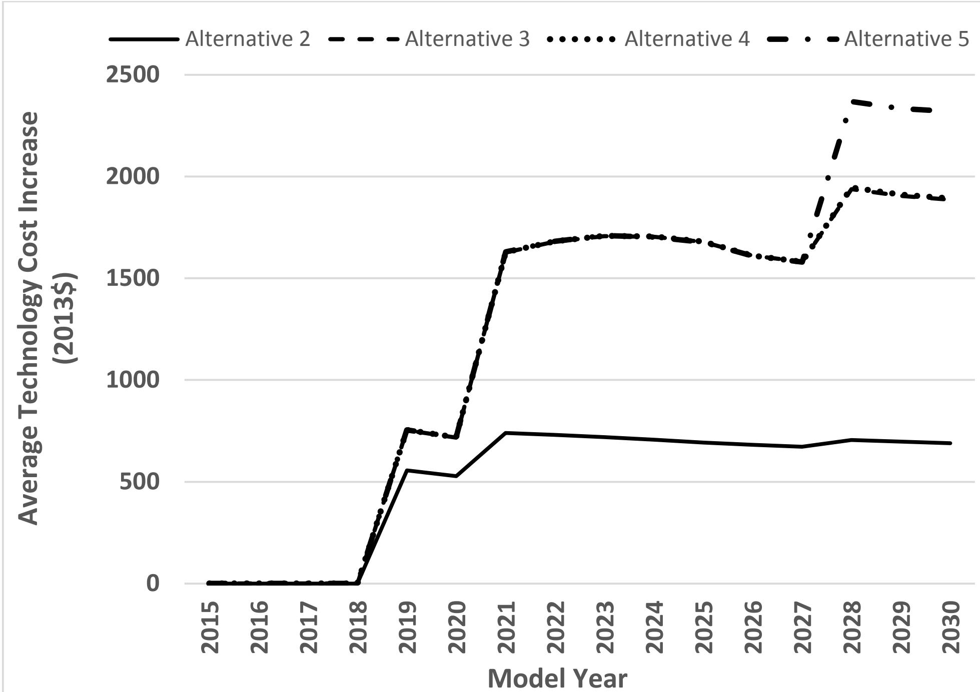

Figure 10-22 Average Technology Cost Increase for General Motors by Model Year and Alternative

Figure 10-23 shows the cumulative total incremental costs for GM under all alternatives. The total costs to comply with Alternative 2 for GM for MY's 2016-2030 is $2.1 billion, for Alternatives 3 and 4 it is $4.8 billion, and for Alternative 5 it is $5.2 billion.

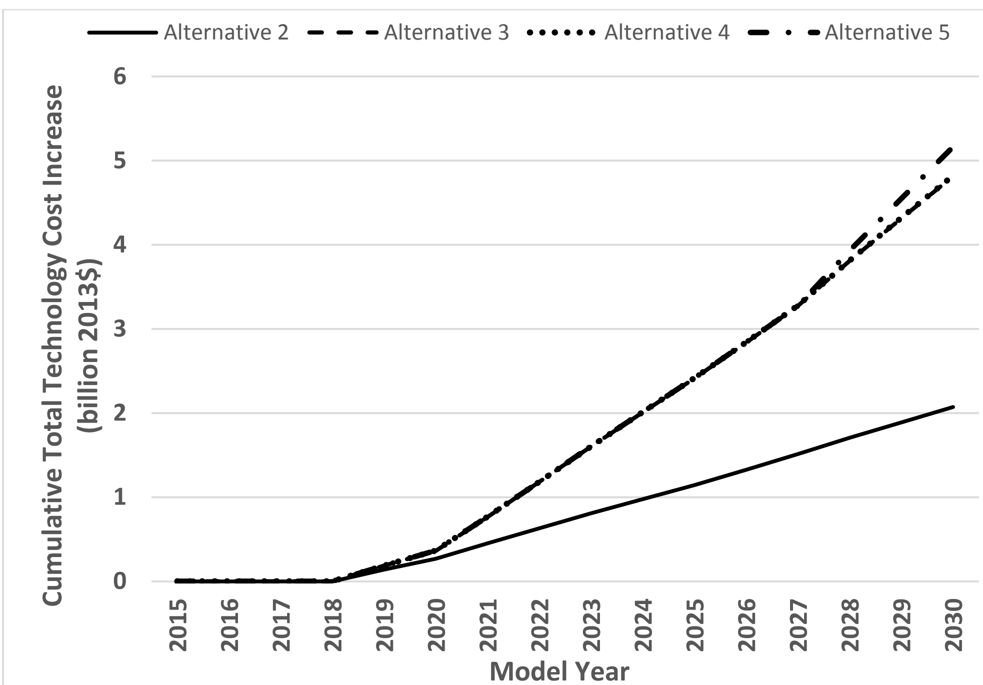

Figure 10-23 General Motors Cumulative Total Technology Cost Increase by Model Year and Alternative

10.2.4.2 Ford

Table 10-35 gives the same summary of a potential compliance strategy for Ford's heavy-duty fleet. Similar to GM, to reach compliance Ford uses 8 speed automatic transmissions in their entire fleet. For Alternatives 3 and 4, Ford uses hybrid technologies in 4 percent of their fleet, and for Alternative 5, they use hybrid technologies in 7 percent of their fleet. In addition to strong hybrids, Ford uses 12v stop-start in 4 percent of their fleet in Alternative 4, and 12v stop-start in 19 percent of their fleet in Alternative 5. The compliance strategy in the NPRM analysis shows Ford using significantly more hybrids and 12v stop-start systems in Alternatives 4 and 5 than the current analysis which likely explains part of the lowered cost for Ford in the current analysis.

Under the current analysis possible compliance strategy, the application of engine technologies for Ford come in discrete chunks, as with GM. Ford uses VVT/VVL in 58 percent of their fleet under all alternatives by MY2030; they started with 8 percent direct-injection engines, and end with 27 percent; they also started with 8 percent turbo-charged engines, but end with 69 percent for all scenarios. The application of EPS and improved accessories vary across the compliance strategies of different regulatory alternatives; under Alternative 2, only 13 percent of Ford's fleet improves these electrical features, while under Alternatives 3-4, 64 percent, and Alternative 5, 96 percent.

For body-platform technologies, Ford applies in discrete chunks to the same platforms across some Alternatives. They apply an average of 77 lb. (1.2 percent) mass reduction across their fleet in Alternative 2 and 132-142 lb. (2.0-2.2 percent) in Alternative 3-5. Progressively less mass reduction is applied under Alternatives 4 and 5—this is likely because more of the fleet was hybridized and mass reduction to small platforms was no longer necessary to comply. Aerodynamic improvements are not applied in Alternative 2, but are applied to 64 percent of the fleet in Alternative 3 and 4, and to all of the fleet in Alternative 5.

Table 10-35 Summary of Impacts on Ford HD Fleet by Alternative (vs. Alternative 1b)

Alternative	**2**	**3**	**4**	**5**
Alternative Stringency				
Annual Increase in Stringency Beginning in MY 2021	2.0%	2.5%	3.5%	4.0%
Increases Until	MY2025	MY2027	MY2025	MY2025
Total Increase in MY2030 Stringency Relative to Final Phase 1 Standards [a]	9.6%	15.7%	15.7%	18.1%
Estimated Average Fuel Economy (miles per gallon)				
Required in MY 2030	19.23	20.62	20.62	21.23
Achieved in MY 2030	19.36	20.61	20.63	21.21
Average Fuel Consumption (gallons/100 miles)				
Required in MY 2030	5.2	4.85	4.85	4.71
Achieved in MY 2030	5.16	4.85	4.85	4.71
Estimated Average Greenhouse Gas Emissions (grams per mile)				
CO_2 Required in MY 2030	488	456	455	443
CO_2 Achieved in MY 2030	485	455	455	443
Technology Penetration in MY 2030 (percent)				
VVT and/or VVL	58	58	58	58
Cylinder Deactivation	0	0	0	0
Direct Injection Engine	27	27	27	27
Turbo Charged Engine	69	69	69	69
8 Speed Auto. Trans.	64	100	100	100
EPS, Accessories	13	64	64	96
12V Stop-start	0	0	4	19
Hybridization	0	4	4	7
Aero. Improvements	0	64	64	100
Mass Reduction (vs. No-Action)				
Curb Weight Mass Reduction (lb.)	77	142	140	132

Mass Reduction (percent of curb weight)	1.2	2.2	2.1	2.0

Note:
[a] This increase in stringency is based on the estimated percentage change in fuel consumption (gal/100mi) stringency projected by the model for the MY2030 fleet under the final Phase 2 standards relative to the continuation of Phase 1 standards. Note that if manufacturers' have applied mass reduction to an individual vehicle model in the CAFÉ model that this will increase the work factor of that vehicle in the model, and make the individual target less stringent. Thus, where any mass reduction is applied in the model, the total increase in stringency of the fleet presented here will be lower than the total stringency increase of the fleet if no mass reduction were applied.

Figure 10-24 and Figure 10-25 show the total and average incremental technology costs for Ford by alternative and model year. Ford adds $80 million in technology costs for MY 2017 and an additional $40 million in MY 2026 in Alternative 2. For the Preferred Alternative, Ford adds $130 million in MY2017 and an additional $300 million in MY 2026. Under Alternative 4, Ford adds $260 million in MY 2017 and $180 million in MY 2026. Similar to the industry pattern, Ford's compliance strategy involves less annual technology costs early in Alternative 3 than Alternative 4, but their technology costs converge under the two alternatives as the final stringency level is reached under Alternative 3 in MY 2027.

It is important to note that the increase in costs and rate of the increase in costs is significantly different for MY 2017 among the alternatives—with the incremental total cost increase for MY 2017 being double those of Alternative 3 for Alternative 4, and more than double for Alternative 5. MY 2017 is the first redesign year and Ford does not have another scheduled redesign until MY 2026. Under the additional lead time of Alternative 3, the majority of Ford's cost increases occur in the MY 2026 redesign, while Alternatives 4 and 5 put most of the cost burden to reach compliance on the MY 2017 redesign (or would require an additional redesign be added between MY 2017 and 2026). NHTSA judges the lack of lead time would make Alternatives 4 and 5 beyond maximum feasibility for Ford because its designs for MY 2017 are essentially complete and substantial resources and very high costs would be required to add another vehicle redesign between MY 2017 and MY 2026 to implement the technologies that would be needed to comply with those alternatives.

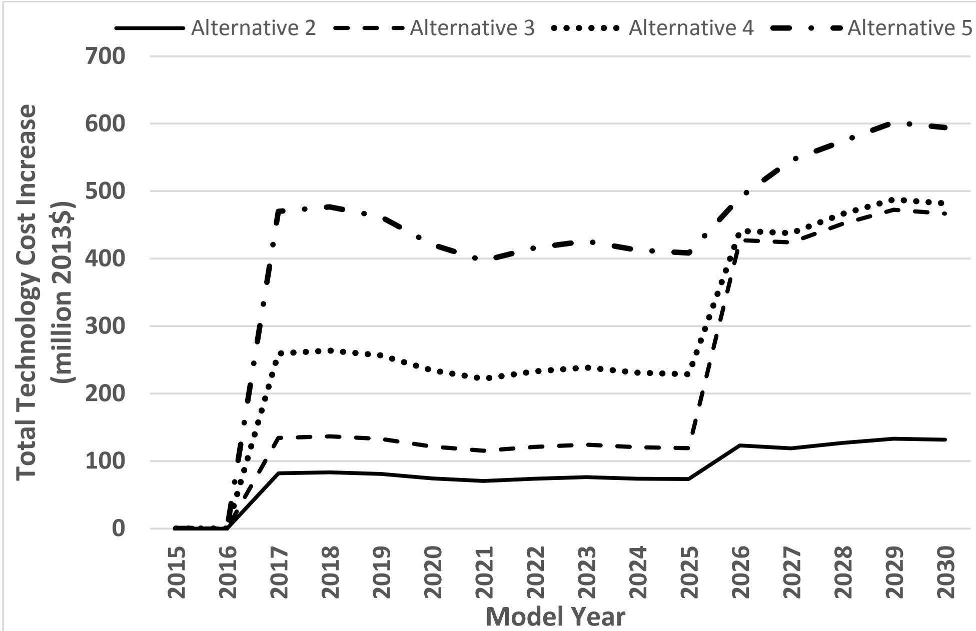

Figure 10-24 Total Technology Cost Increase for Ford by Model Year and Alternative

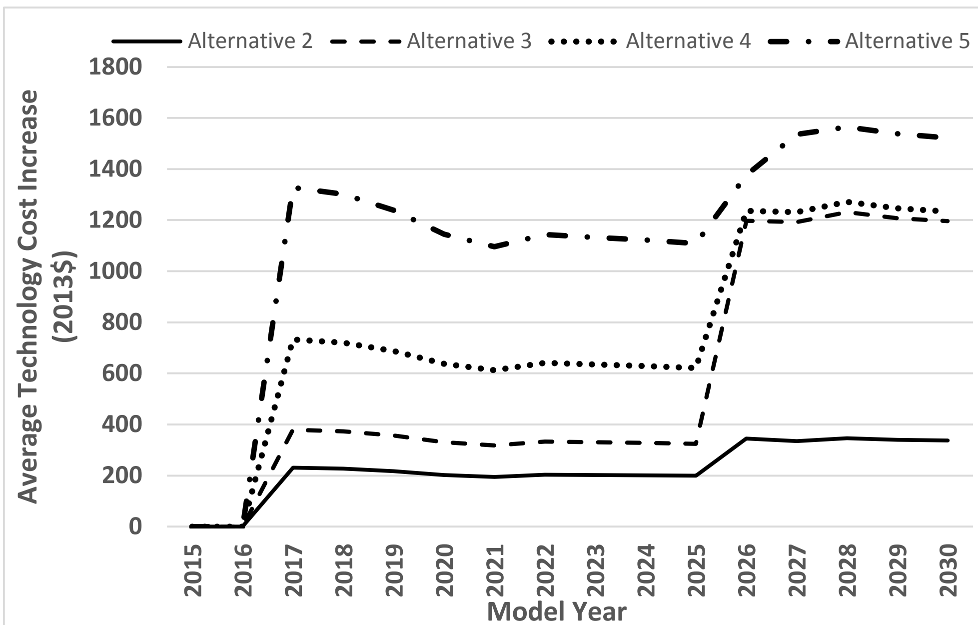

Figure 10-25 Average Technology Cost Increase for Ford by Model Year and Alternative

Figure 10-26 below shows the cumulative total costs for Ford under all action alternatives. The total costs for MY's 2015-2030 under Alternative 2 are $1.3 billion, under Alternative 3 they are $3.4 billion, for Alternative 4 they are $4.5 billion, and finally for Alternative 5 they are $6.7 billion. This further illustrates the point that manufacturers act to minimize costs over multiple model years. The added lead time from Alternative 4 allows them to delay some actions, which will allow them more time to make sure that they are well-implemented.

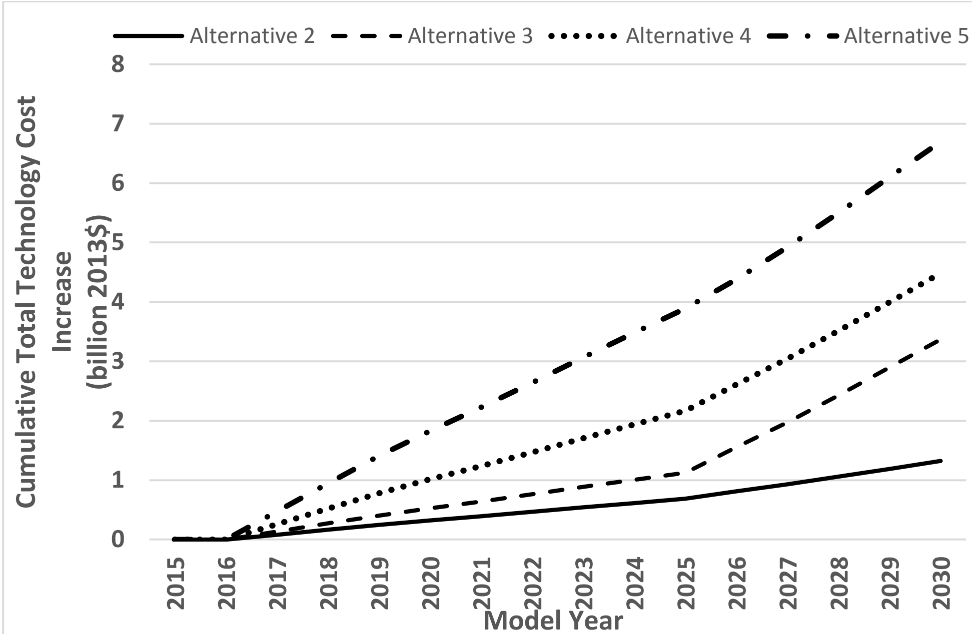

Figure 10-26 Ford Cumulative Technology Cost Increase by Model Year and Alternative

10.2.4.3 Fiat/Chrysler

Table 10-36shows the MY 2030 summary for Fiat/Chrysler. Fiat/Chrysler is the only manufacturer which uses cylinder deactivation in their reference fleet, and they are the only manufacturer to use cylinder deactivation as a part of their possible compliance strategy. Under all scenarios, FCA increases their initial cylinder deactivation utilization of 13 percent to 24 percent. Under all scenarios turbo-charged engines are applied to 76 percent of FCA's fleet by MY 2030. Other technologies are applied to the FCA equally across all scenarios; 37 percent of their fleet uses VVT and/or VVL, and 64 percent uses 8-speed automatic transmissions under all scenarios.

The additional stringency from Alternative 2 to Alternatives 3-5 results in other increased technology applications in the FCA fleet. Under Alternatives 3-5, the presence of EPS/electrical accessories increases from the 82 percent to the entirety of the FCA fleet. Similarly, increased aerodynamic improvements increase from 84 percent of the fleet to all of it. Finally, 12v stop-start enters 3 percent of the fleet under Alternatives 3-5. Alternatives 3 and 4 look much the same, except that Alternative 3 is the only alternative to use any (1 percent) SHEV-P2 hybrids. Alternative 5 uses twice as much mass reduction than Alternatives 3-4; it uses 37 percent direct injection versus the 24 percent in Alternatives 2-4. The resulting costs are comparable under Alternatives 3 and 4, and almost 50 percent higher under Alternative 5.

Table 10-36 Summary of Impacts on Fiat/Chrysler HD Fleet by Alternative (vs. Alternative 1b)

Alternative	**2**	**3**	**4**	**5**
Alternative Stringency				
Increases Until	MY2025	MY2027	MY2025	MY2025
Total Increase in MY2030 Stringency Relative to Final Phase 1 Standards [a]	9.6%	15.8%	15.8%	17.6%
Total Increase in Stringency Relative to Final Phase 1 Standards	MY2025	MY2027	MY2025	MY2025
Estimated Average Fuel Economy (miles per gallon)				
Required in MY 2030	18.59	19.96	19.96	20.41
Achieved in MY 2030	18.97	20.06	20.04	20.42
Average Fuel Consumption (gallons/100 miles)				
Required in MY 2030	5.38	5.01	5.01	4.9
Achieved in MY 2030	5.27	4.99	4.99	4.9
Estimated Average Greenhouse Gas Emissions (grams per mile)				
CO_2 Required in MY 2030	520	485	485	474
CO_2 Achieved in MY 2030	509	482	482	474
Technology Penetration in MY 2030 (percent)				
VVT and/or VVL	37	37	37	37
Cylinder Deactivation	24	24	24	24
Direct Injection Engine	24	24	24	37
Turbo Charged Engine	76	76	76	76
8 Speed Auto. Trans.	64	64	64	64
EPS, Accessories	82	100	100	100
12V Stop-start	0	3	3	3
Hybridization	0	1	0	0
Aero. Improvements	84	100	100	100
Mass Reduction (vs. No-Action)				
Curb Weight Mass Reduction (lb.)	29	330	333	694

Mass Reduction (percent of curb weight)	0.4	4.6	4.6	9.6

Note:
[a] This increase in stringency is based on the estimated percentage change in fuel consumption (gal/100mi) stringency projected by the model for the MY2030 fleet under the final Phase 2 standards relative to the continuation of Phase 1 standards. Note that if manufacturers' have applied mass reduction to an individual vehicle model in the CAFÉ model that this will increase the work factor of that vehicle in the model, and make the individual target less stringent. Thus, where any mass reduction is applied in the model, the total increase in stringency of the fleet presented here will be lower than the total stringency increase of the fleet if no mass reduction were applied.

Figure 10-27and Figure 10-28 show the incremental total and average technology costs for Chrysler/Fiat by model year and regulatory stringency. Chrysler/Fiat shows more technology costs for higher stringency alternatives, with annual technology costs of Alternative 3 approaching Alternative 4 annual technology costs as the Alternative 3 approaches the final stringency level in MY 2027. Under all alternatives Chrysler/Fiat incurs increased technology costs starting in MY 2018 and MY2025, because they are estimated redesign years. The maximum annual technology costs for Chrysler are $92M in Alternative 2, $213M in Alternative 3, $227M in Alternative 4, and $330M in Alternative 5. This results in average technology costs of: $680, $1640, $1690, and $2460, respectively.

As with Ford, the costs and the rate of increase in costs are significantly different in the MY 2018 timeframe among the alternatives, because MY 2018 is the first estimated model year for redesign, and the next estimated redesign opportunity is in MY 2025. Figure 10-27identifies the significant differences in the resources and capital that would be required to implement the technologies required to comply with each of the alternatives—with the estimated MY 2018 technology cost increases being 48M under Alternative 3, 78M under Alternative 4, and 112M under Alternative 5. NHTSA judges the short lead time would make Alternatives 4 and 5 beyond maximum feasible for FCA because its designs for MY 2018 are nearing completion and substantial resources and very high costs would be required to add another vehicle redesign between MY 2018 and MY 2025 to implement the technologies that would be needed to comply with those alternatives.

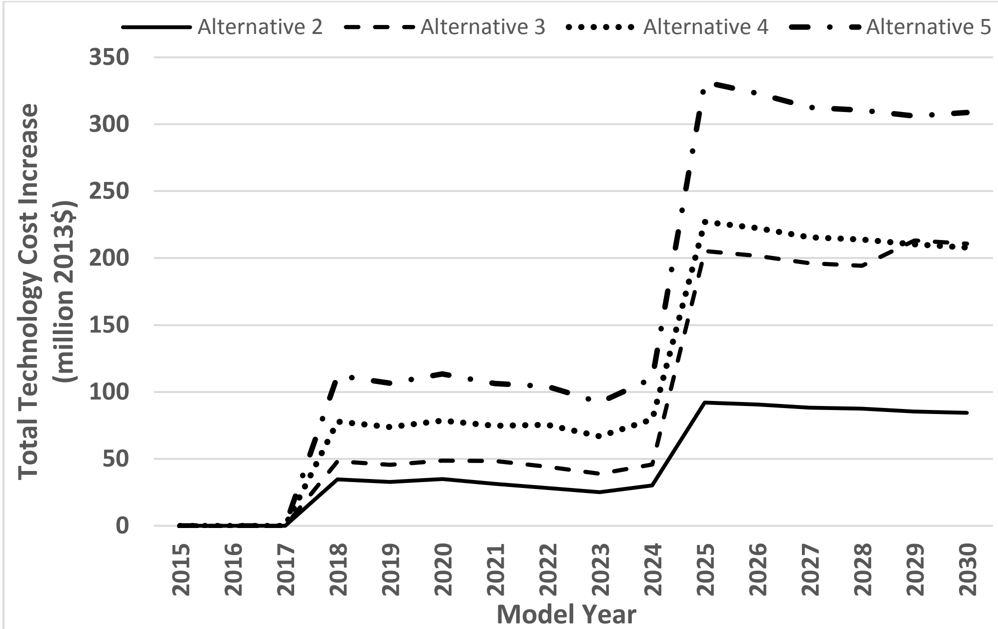

Figure 10-27 Total Technology Cost Increase for Fiat/Chrysler by Model Year and Alternative

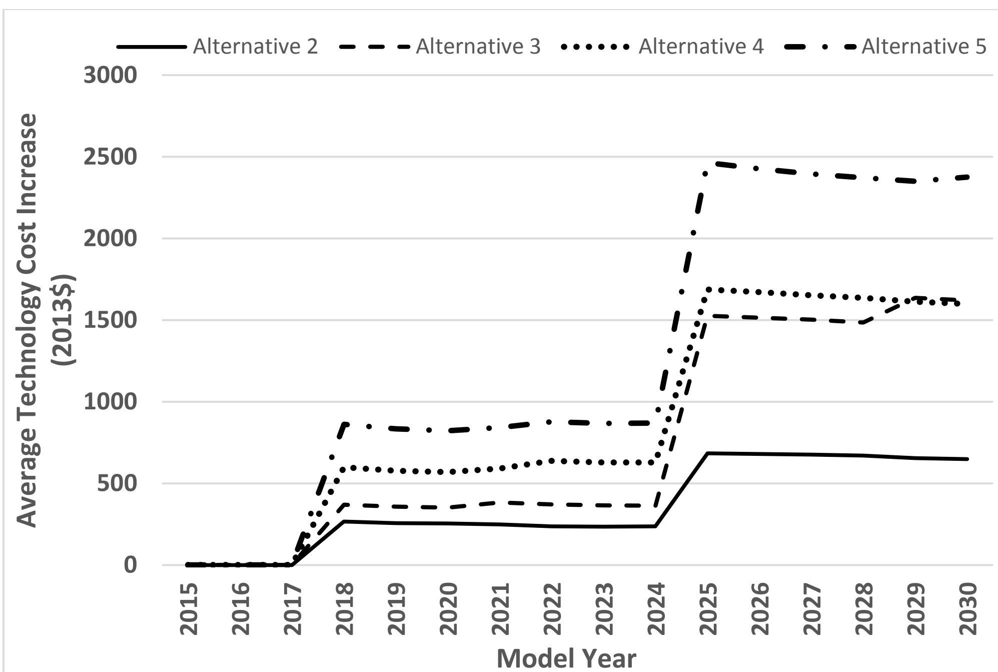

Figure 10-28 Average Technology Cost Increase for Fiat/Chrysler by Model Year and Alternative

The cumulative technology costs attributable to the action alternatives for FCA are represented in Figure 10-29, below. The total costs for MY's 2016-2030 under alter Alternative 2 are $750 million, under Alternative 3, they are $1.5 billion, for Alternative 4, $1.8 billion, and for Alternative 5 they are $2.6 billion.

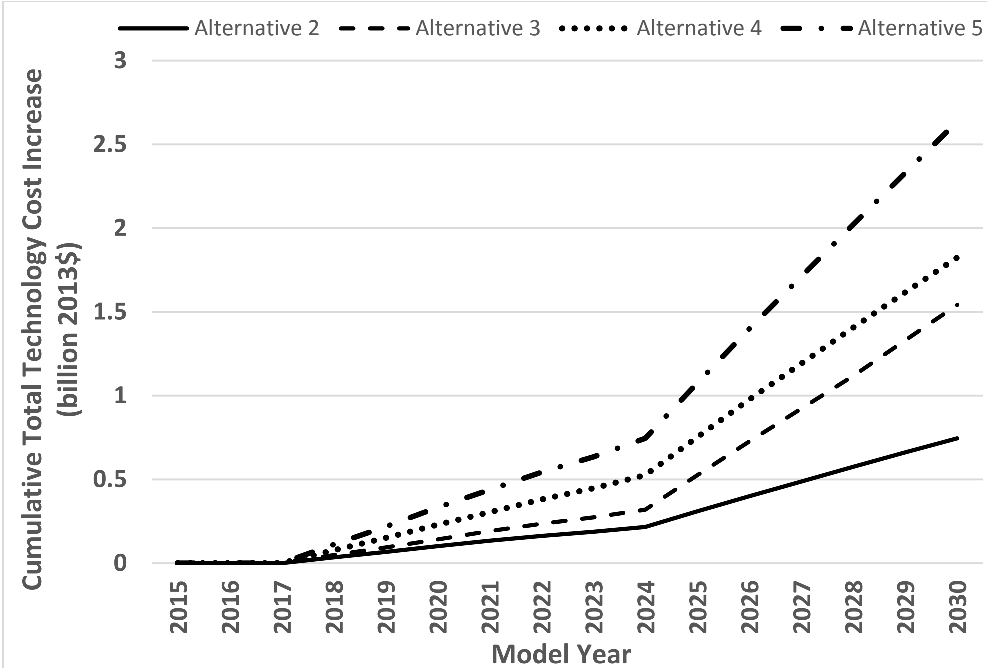

Figure 10-29 Fiat/Chrysler Cumulative Technology Cost Increase by Model Year and Alternative

10.2.4.4 Nissan

Table 10-37 shows the manufacturer-specific MY2030 summary for Nissan. Nissan's 2015 reference fleet uses VVT and/or VVL on all of their heavy-duty vehicles. Their fleet uses two engines on only one body-style platform. As a result, technologies applied to Nissan's fleet are applied to large proportions of their fleet. Under all scenarios, their entire fleet gains 8-speed automatic transmissions. Under Alternatives 3-5, all of their fleet gets level-2 body-level aerodynamic improvements and all of their fleet gets electric accessory and/or EPS improvements. Under Alternatives 2, 4, and 5, one of Nissan's two heavy-duty engines gets direct-injection, while under Alternative 3, both engines get the technology. Direct injection of their entire fleet is the most cost-effective way to reach compliance under Alternative 2, applying 5 percent mass reduction to their entire fleet and direct injection of one of their engines is the most cost-effective strategy under Alternative 4, and applying 10 percent mass reduction to their entire fleet, direct injection to one of their engines, and making their other engine hybrid is the most cost-effective strategy under Alternative 5.

Note that without a change in the work factor or fleet mix, a manufacturer will face the same MY2030 standard under Alternatives 3 and 4, and a more stringent standard under Alternative 5. However, by applying 5 percent mass reduction in Alternative 4, Nissan is able to reduce their standard by .27 MPG, and by applying 10 percent mass reduction in Alternative 5 to have the same MY2030 standard under Alternatives 3 and 5. The result is that the CAFE level for Nissan is highest under Alternative 2, where direct injection of their entire fleet is the most cost-effective compliance strategy. We assume that manufacturers are able to make technologies more cost-effectively the longer they are on the market—this is called "learning." A likely reason that the model prefers direct injection in Alternative 3 but not in Alternatives 4 and 5, is that the longer horizon of the stringency increase (until MY2027) results in direct injection that is more cost-effective than the shorter time span of Alternatives 4 and 5.

Table 10-37 Summary of Impacts on Nissan HD Fleet by Alternative (vs. Alternative 1b)

Alternative	**2**	**3**	**4**	**5**
Alternative Stringency				
Annual Increase in Stringency Beginning in MY 2021	2.0%	2.5%	3.5%	4.0%
Increases Until	MY2025	MY2027	MY2025	MY2025
Total Increase in MY2030 Stringency Relative to Final Phase 1 Standards [a]	9.6%	16.2%	15.1%	16.2%
Estimated Average Fuel Economy (miles per gallon)				
Required in MY 2030	19.65	21.19	20.92	21.19
Achieved in MY 2030	19.63	23.12	21.05	21.46
Average Fuel Consumption (gallons/100 miles)				
Required in MY 2030	5.09	4.72	4.78	4.72
Achieved in MY 2030	5.09	4.32	4.75	4.66
Estimated Average Greenhouse Gas Emissions (grams per mile)				
CO_2 Required in MY 2030	452	419	425	420
CO_2 Achieved in MY 2030	453	384	422	414
Technology Penetration in MY 2030 (percent)				
VVT and/or VVL	100	100	100	100
Cylinder Deactivation	0	0	0	0
Direct Injection Engine	51	100	51	51
Turbo Charged Engine	51	100	51	51
8 Speed Auto. Trans.	100	100	100	100
EPS, Accessories	37	100	100	100
12V Stop-start	0	0	0	49
Hybridization	0	0	0	0
Aero. Improvements	0	100	100	100
Mass Reduction (vs. No-Action)				

Curb Weight Mass Reduction (lb.)	0	0	307	615
Mass Reduction (percent of curb weight)	0	0	5	10

Note:
[a] This increase in stringency is based on the estimated percentage change in fuel consumption (gal/100mi) stringency projected by the model for the MY2030 fleet under the final Phase 2 standards relative to the continuation of Phase 1 standards. Note that if manufacturers' have applied mass reduction to an individual vehicle model in the CAFÉ model that this will increase the work factor of that vehicle in the model, and make the individual target less stringent. Thus, where any mass reduction is applied in the model, the total increase in stringency of the fleet presented here will be lower than the total stringency increase of the fleet if no mass reduction were applied.

Figures Figure 10-30and Figure 10-31show the total and average incremental technology costs for Nissan across the different regulatory alternatives. Nissan applies technology in all alternatives in MY2021; this is a redesign year for much of their fleet. As might be expected, they incur less technology cost in less stringent scenarios at this redesign. However, under Alternative 3 they apply more technology in MY2029, making their marginal technology costs under Alternative 3 for MY2029 and after higher than the marginal technology costs under Alternative 4. They incur less technology costs in the early years and more in MY's 2029 and beyond. In order to explain why the model predicts this action of Nissan it is useful to look at the cumulative total incremental costs in Figure 10-32.

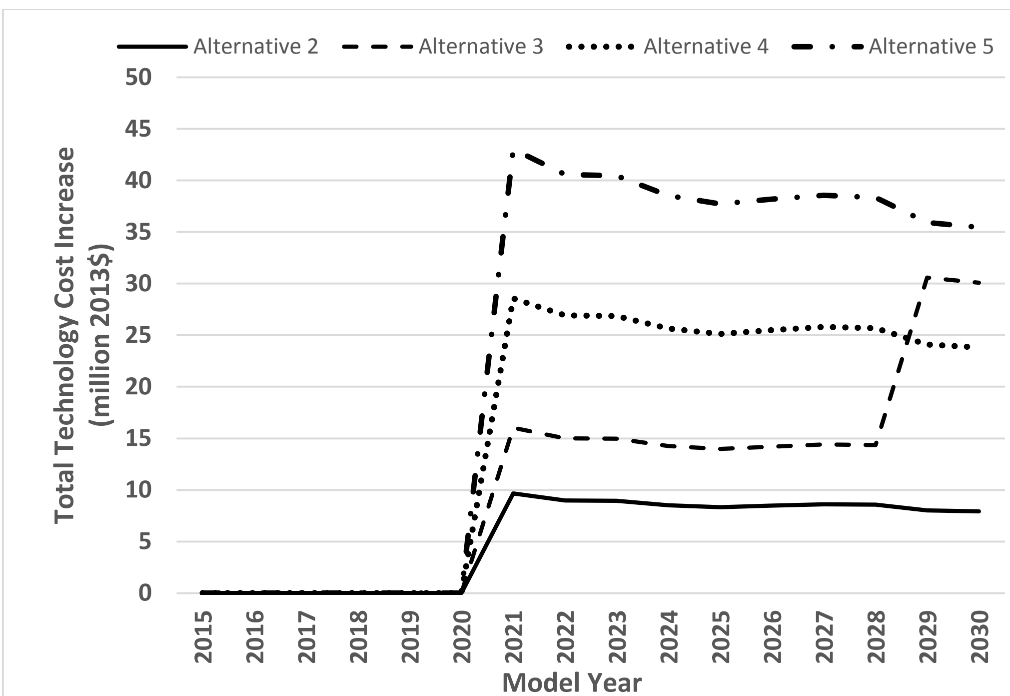

Figure 10-30 Total Technology Cost Increase for Nissan by Model Year and Alternative

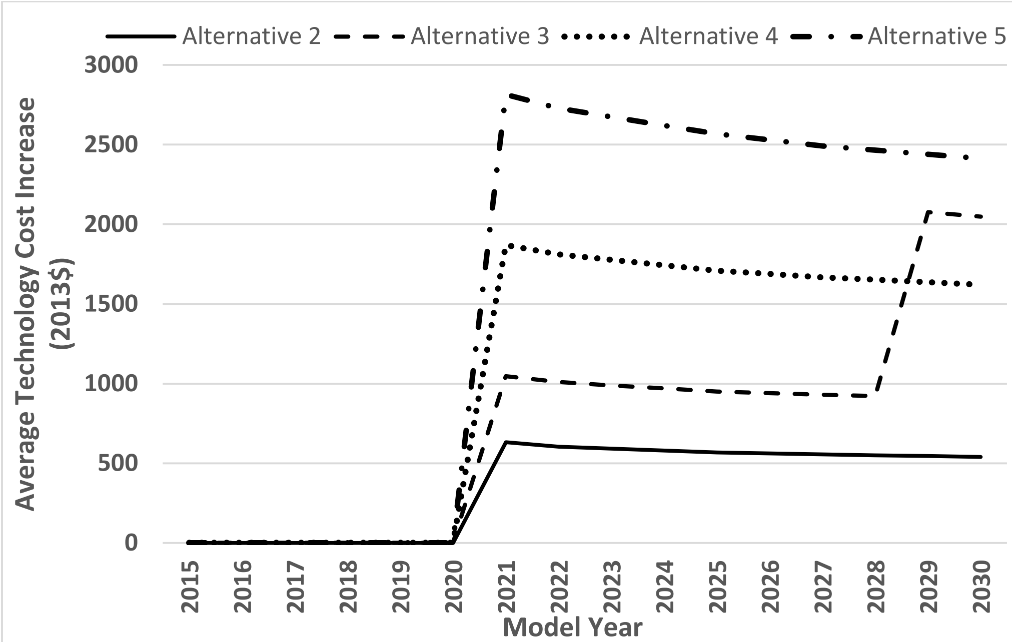

Figure 10-31 Average Technology Cost Increase for Nissan by Model Year and Alternative

By incurring less technology cost early, and more technology cost later, Nissan has a lower cumulative total cost for MY's 2016-2030 under Alternative 3 than Alternative 4. The total cumulative cost for MY's 2016-2030 of Alternative 2 is $86 million, $178 million for Alternative 3, $258 for Alternative 4, and $387 for Alternative 5. Since Nissan is trying to minimize their total cost under all model years, and not their marginal cost under any single model year, the model chooses a compliance strategy in this case which shows higher marginal costs for Nissan in Alternative 3 than 4 for some model years, but lower cumulative total costs over all model years.

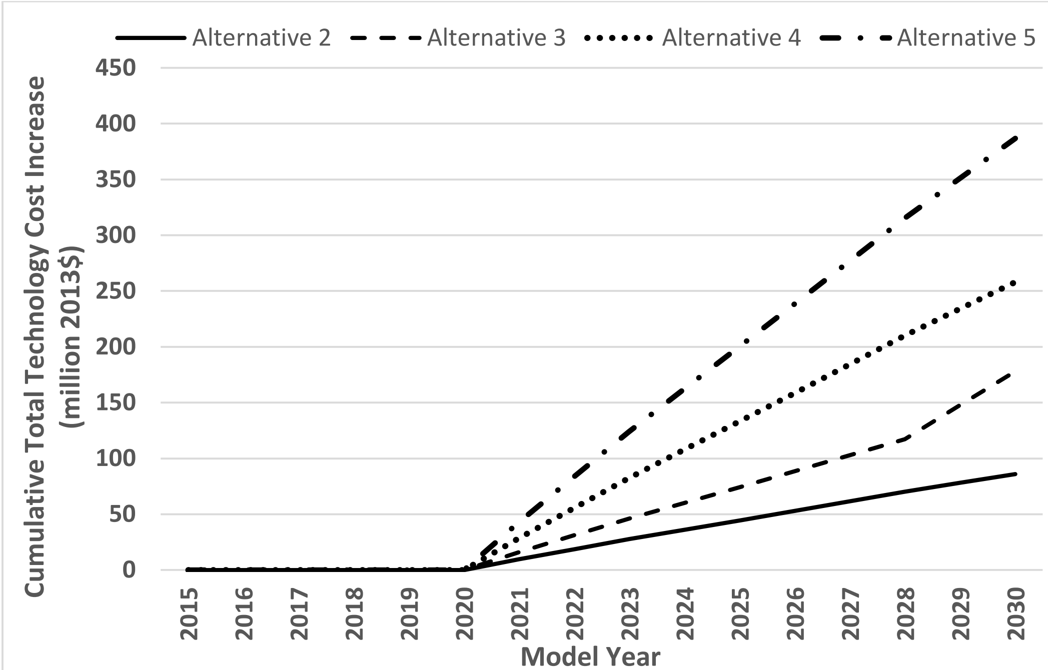

Figure 10-32 Nissan Cumulative Technology Cost Increase by Model Year and Alternative

Nissan's first redesign is in MY 2020, and they do not have another redesign scheduled until 2029. Under Alternative 4 and 5 all of their technological application is done in MY 2020, but under Alternative 3 the application can be spread out between the two redesign cycles. NHTSA judges the short lead time to apply technology would make Alternatives 4 and 5 beyond maximum feasibility for Nissan because it puts the burden of all technological application on the MY 2020 redesign. Substantial resources and costs would be required to do so or to add another vehicle redesign between MY 2020 and MY 2029. Since manufacturers must spread out their capital for such deployment endeavors between the light and heavy duty fleets, the ability to spread costs between model years is important to consider.

10.2.4.5 Daimler

Table 10-38 shows a MY2030 summary for Daimler. Daimler came into the analysis with all of their fleet using 8-speed automatic transmissions. Their initial CAFE level in MY2020 of 25.68 was sufficient to meet their standard under Alternatives 2-5. Their only action to turbo-charge all the engines in their fleet occurs in the dynamic baseline. As a result, no additional actions or costs are incurred under any of the alternatives. For this reason, a figure of their annual technology costs, nor their cumulative total technology costs has not been provided—if it were, it would be a horizontal line showing zero costs for all model years.

Table 10-38 Summary of Impacts on Daimler HD Fleet by Alternative (vs. Alternative 1b)

Alternative	**2**	**3**	**4**	**5**
Alternative Stringency				
Annual Increase in Stringency Beginning in MY 2021	2.0%	2.5%	3.5%	4.0%
Increases Until	MY2025	MY2027	MY2025	MY2025
Total Increase in Stringency Relative to Final Phase 1 Standards [a]	9.7%	16.3%	16.3%	18.4%
Estimated Average Fuel Economy (miles per gallon)				
Required in MY 2030	22.88	24.69	24.69	25.32
Achieved in MY 2030	25.68	25.68	25.68	25.68
Average Fuel Consumption (gallons/100 miles)				
Required in MY 2030	4.37	4.05	4.05	3.95
Achieved in MY 2030	3.89	3.89	3.89	3.89
Estimated Average Greenhouse Gas Emissions (grams per mile)				
CO_2 Required in MY 2030	445	413	412	402
CO_2 Achieved in MY 2030	396	396	396	396
Technology Penetration in MY 2030 (percent)				
VVT and/or VVL	0	0	0	0
Cylinder Deactivation	0	0	0	0
Direct Injection Engine	0	0	0	0
Turbo Charged Engine	100	100	100	100
8 Speed Auto. Trans.	100	100	100	100
EPS, Accessories	0	0	0	0
12V Stop-start	0	0	0	0
Hybridization	0	0	0	0
Aero. Improvements	0	0	0	0
Mass Reduction (vs. No-Action)				
Curb Weight Mass Reduction (lb.)	0	0	0	0
Mass Reduction (percent of curb weight)	0	0	0	0

Note:
[a] This increase in stringency is based on the estimated percentage change in fuel consumption (gal/100mi) stringency projected by the model for the MY2030 fleet under the final Phase 2 standards relative to the continuation of Phase I standards. Note that if manufacturers' have applied mass reduction to an individual vehicle model in the CAFÉ model that this will increase the work factor of that vehicle in the model, and make the individual target less stringent. Thus, where any mass reduction is applied in the model, the total increase in stringency of the fleet presented here will be lower than the total stringency increase of the fleet if no mass reduction were applied.

10.2.5 Summary of Consumer/Operator Impacts

Table 10-39 summarizes the impacts of the regulation on the consumer/operator of the heavy-duty vehicles. Consumers of more fuel efficient vehicles will benefit in several ways: they will spend less on fuel to operate vehicles for the same amount of travel, some will drive more because their per-mile travel costs less, and they will spend less time refueling vehicles. In order to estimate the fuel savings for each regulatory alternative, future gasoline prices must be predicted and the rebound effect (per-mile elasticity of operating a vehicle) must be assumed to account for the cost of additional driving. In the main analysis, the rebound effect is assumed to be 10 percent, so that, for example, a 10 percent reduction in the per-mile travel costs will result in a 1percent increase in the amount of miles driven. Since the literature has also supported other rebound effects, NHTSA tests several sensitivity cases assuming different rebounds: 5 percent, 15 percent, and 20 percent. Based on the average miles driven of 2b/3 vans and trucks, the expected lifetime fuel savings for a heavy-duty vehicle under the preferred scenario is $3636.

The other benefits of to the consumer of increasing fuel economy are increased mobility and a decreased amount of time spent refueling the vehicle. Because increasing the efficiency of a vehicle makes per-mile travel cheaper to the operator, consumers of these vehicles can travel more, at less than the total amount they are willing to pay—this increase in welfare that is not accounted for by the cost of travel is the consumer surplus. The estimated mobility benefit is $394 under the preferred alternative. The avoided time refueling also has a value. In order to estimate this value we make several assumptions outlined in more detail of the NPRM description of the model assumptions (Section E). Over the lifetime of a MY2030 vehicle, we estimate the refueling surplus at $94 under the preferred alternative.

It is also important to note that the average manufacturer costs will not be spread proportionally across the fleet—some vehicles will have incurred more technology costs than others. How manufacturers distribute costs among models will largely depend on the elasticity of particular models and the importance of fleet mix in meeting standards and on total profits. Without privy to this sort of information, we use average technology cost increase as a proxy for measuring the industry and consumer costs across different scenarios. The average technology cost increase is $1472 under the preferred alternative. We assume that all of this cost will be passed onto the consumer in the form of an increase in price. However, we also consider that an increase in price will have other costs to the operator of the vehicle.

More expensive vehicles will have higher taxes/fees associated with their purchase, will be more expensive to insure (these costs are related to the purchase price or value of a vehicle) and will be more expensive to finance (higher loan values will be taken out which result in higher amounts paid in total interest). The total additional costs to the average consumer from the sum of these sources is $589 under the preferred alternative. It is important to keep in mind that the additional cost to finance a more expensive vehicle will have different effects depending on the budget constraint of the consumer. For consumers who are budget-constrained, they will finance more of the vehicle and the costs of financing will be higher for these already-constrained consumers. For consumers who do not have to finance the vehicle, there will be no costs—and therefore, no additional costs—to finance the vehicle. Since budget-constrained consumers likely have a more elastic demand for new vehicles, the increase in price and the heterogeneous increase in financing might work in the same direction to price proportionally more of the most budget-constrained consumers out of the new vehicle market.

Considering all the costs and benefits the standards will have to the consumer, the result is a net benefit to the consumer under all the considered alternatives. The net benefit to the consumer is $2063 under the preferred alternative, higher than the net benefit under alternative 4. The payback period is another measure of the effect of the rule on consumers-for all alternatives the payback period is under 3 years—suggesting that consumers that own vehicles for at least 3 years will receive a net benefit from the preferred regulatory action.

Table 10-39 Summary of Consumer/Operator Impacts for MY 2030 (vs. Alternative 1b)

Alternative	**2**	**3**	**4**	**5**
Alternative Stringency				
Annual Increase	2.0%	2.5%	3.5%	4.0%
Increases Until	MY2025	MY2027	MY2025	MY2025
Average Value of Lifetime Fuel Savings, $2013 (vs. No-Action)				
Pretax	$1713	$3256	$3229	$3804
Tax	$200	$381	$377	$448
Total	$1913	$3636	$3607	$4252
Average Value of Additional Economic Benefits, $2013 (vs. No-Action)				
Mobility Increase	$220	$394	$390	$453
Avoided Refueling	$49	$94	$93	$112
Average New Vehicle Purchase (vs. No-Action)				
Price Increase ($)	$496	$1472	$1481	$1893
Additional Costs ($) [a]	$198	$589	$592	$757
Payback (months) [b]	20	33	33	38
Net Lifetime Consumer/Operator Benefits (vs. No-Action)				
Total Net Benefit ($)	$1488	$2063	$1989	$2167

Notes:
[a] Additional Costs include additional taxes, fees, maintenance costs, financing costs, and insurance costs incurred under the regulatory alternatives.
[b] The payback period from the consumer perspective uses a 7% discount rate of retail fuel savings starting at the time of purchase. The cost increases paid back include: technology costs, maintenance costs, taxes, and fees.

10.2.6 Summary of Societal Impacts

Table 10-40 summarizes the overall societal impacts of the regulation under different scenarios (relative to the 1b baseline). Net social benefits increase with the stringency of the standards. The net benefits for the preferred alternative are $18.8 billion. The largest benefit of the program comes in the form of fuel savings. The fuel savings reported above do not include fuel tax savings, as taxes are considered a transfer, and not a loss, of societal well-being. The fuel savings are associated with a fuel security externality, which monetizes the economic risk associated with potential fuel price spikes—as fewer gallons of oil are necessary for transportation, this risk decreases. The carbon externality represents the reduced cost of carbon damage when fuel economy increases (and carbon emissions decrease), and is also related directly with fuel savings.

Table 10-40 Summary of Lifetime Total Societal Impacts of MY's 2015-2029 (vs. Alternative lb)

Alternative	**2**	**3**	**4**	**5**
Alternative Stringency				
Annual Increase	2.0%	2.5%	3.5%	4.0%
Increases Until	MY2025	MY2027	MY2025	MY2025
Fuel Purchases vs. No-Action (billion 2013$)				
Pretax Savings	$11.1	$17.8	$20.2	$22.7
Fuel-Related Externalities vs. No-Action (billion 2013$)				
Energy Security	$0.7	$1.2	$1.4	$1.5
CO_2 Emissions	$2.4	$3.8	$4.4	$4.9
VMT-Related Externalities vs. No-Action (billion 2013$)				
Driving Surplus	$1.3	$2.0	$2.3	$2.5
Refueling Surplus	$0.3	$0.6	$0.6	$0.7
Congestion	-$0.3	-$0.5	-$0.5	-$0.6
Crashes	-$0.2	-$0.2	-$0.3	-$0.3
Noise	$0.0	$0.0	$0.0	$0.0
Fatalities	-$0.7	-$0.3	-$0.4	$0.7
Criteria Emissions	$0.7	$1.2	$1.4	$1.5
Vehicle Purchase/Operating Costs vs. No-Action (billion 2013$)				
Technology Costs	$2.9	$6.5	$7.7	$10.2
Maintenance Costs	$0.1	$0.3	$0.3	$0.5
Cost-Benefit Summary vs. No-Action (billion 2013$)				
Total Social Cost	$4.2	$7.8	$9.2	$11.6
Total Social Benefit	$16.5	$26.6	$30.3	$34.5
Net Social Benefit	$12.3	$18.8	$21.1	$22.9

Increasing fuel economy decreases the cost of per-mile travel. Since this reduction in the cost of travel results in an increase of total travel, it also results in an increase of externalities associated with increased total VMT. Of these, the driving surplus represents the societal net increase in benefit from increased mobility consumer surplus—the sum of the benefit to all operators of increased travel which is not captured by the total cost of travel. Defined from the societal perspective, the refueling benefit is the sum of all the value of the time saved on refueling by increasing the average fuel efficiency of the heavy duty fleet. Congestion represents the societal cost of increases in congestion on the roads—the lost value of additional time spent in traffic. The crash externality is the cost of the damage done by the additional crashes that will happen with more VMT exposure, and the noise externality represents the cost of a change in noise related to increases in vehicle travel (in this analysis, it is negligible for all alternatives).

Some VMT-related externalities are not always positive or negative, but depend on the stringency of the standards. For this analysis the criteria pollutant externality is always a benefit, but this need not be the case. Reduction in overall fuel consumed reduces emissions associated with production and distribution of fuels. Increases in VMT will result in more emission of vehicle criteria pollutants and more associated damages. However, increasing fuel-economy though vehicle technologies, such as aerodynamics, mass reduction and improved tire rolling resistance, will result in a decrease in vehicle emissions of and damages from criteria pollutants. Shifts in technologies towards electric and hybrid-electric alternatives can increase the emissions of certain pollutants, and reduce the emissions of others. The stringency increases considered in the heavy-duty analysis do not require these technologies to penetrate the market at such a level that this is visible in the results. For these reasons the externality associated with changes in criteria pollutant emissions is always positive for this analysis.

The vehicle mass reduction in HD pickup and vans is estimated to reduce the net incidence of highway fatalities. By reducing mass on some HD pickup and vans, the fatality rate associated with crashes involving at least one HD pickup or van vehicles decreases. However, the analysis anticipates that the indirect effect of the proposed standards, by reducing the operating costs, would lead to increased travel by HD pickups and vans and, therefore, more crashes involving these vehicles. The sign of the fatality externality varies with the stringency of the standards. Over the lifetime of MY's 2016-2029, for Alternatives 2 it is estimated approximately 120 additional fatalities could occur relative to the 30,200 heavy-duty crash-related fatalities in the baseline. For Alternatives 3 and 4 we estimate approximately 50 additional fatalities relative to the no-action alternative. The additional risk of fatality is represented as a social cost in Alternatives 2-4. For Alternative 5 we estimate approximately 110 fewer fatalities (represented as a positive externality). For Alternatives 2-4, the effect of removing mass from the heavier vehicles is less than the effect of increased VMT-exposure; for Alternative 5, it is larger, and the alternative could result in a decrease of fatalities.

The major direct costs of the program are increased technology costs and costs associated with the resultant increase in new vehicle prices and changes in technologies. The sum of technology costs across the industry increase under all increases of stringency, as do the increases in associated additional costs. Additional costs include: additional costs of maintenance associated with certain technologies. These costs will mostly be borne by the consumer, and paid back in the form of fuel savings.

10.2.7 Summary of Environmental Impacts

In addition to modeling the societal impacts from a monetary standpoint, the CAFE model also considers the absolute change in the physical emissions of various criteria pollutants across the Alternatives. Table 10-41 summarizes the total environmental impacts from increased fuel efficiency of MYs 2016-2030, taking into consideration the reduction in emissions from increased efficiency, the additional emissions associated with the increased VMT from cheaper per-mile travel, and changes in emissions due to the production and distribution of heavy-duty vehicles. Across all scenarios, the absolute reduction in emissions increases. For context, the percentage change of emissions relative to the baseline emission levels is also provided. The proportional reduction in criteria pollutants greatly varies; the greenhouse gases—carbon dioxide, methane, and nitrous oxide—as well as the criteria pollutants—sulfur dioxide and diesel particulate matter—show the largest proportional reductions across all scenarios.

Table 10-41 Summary of Lifetime Emission Impacts of MY's 2015-2029 (vs. Alternative 1b)

Alternative	**2**	**3**	**4**	**5**
Annual Increase	2.0%	2.5%	3.5%	4.0%
Increases Until	MY2025	MY2027	MY2025	MY2025
Greenhouse Gas Emissions Reductions vs. No-Action				
CO_2 (mmt)	66	107	120	135
CH_4 and N_2O (tons)	97,925	160,044	180,557	202,666
Greenhouse Gas Emissions Percent Reduction vs. No-Action				
CO_2	3.8%	6.1%	6.9%	7.7%
CH_4 and N_2O	0.7%	1.2%	1.3%	1.5%
Other Emissions Absolute Reduction vs. No-Action				
CO (tons)	13,747	22,828	26,375	29,589
VOC and NO_X (tons)	33,324	56,100	63,237	70,957
PM25 (tons)	1,320	2,213	2,498	2,806
SO_2 (tons)	10,713	17,877	20,172	22,669
Air Toxics (tons)	53	75	84	94
Diesel PM10 (tons)	2,357	3,944	4,450	5,004
Other Emissions Percent Reduction vs. No-Action				
CO	0.2	0.4	0.4	0.5
VOC and NO_X	1.6	2.8	3.1	3.5
PM25	1.9	3.3	3.7	4.1
SO_2	3.7	6.2	6.9	7.8
Air Toxics	0.2	0.2	0.2	0.3
Diesel PM10	3.5	5.8	6.5	7.3

10.2.8 Sensitivity Analysis Evaluating Different Inputs to the NHTSA CAFE Model

This section describes some of the principal sensitivity results, obtained by running the various scenarios describing the policy alternatives with alternative inputs. OMB Circular A-4 indicates that "it is usually necessary to provide a sensitivity analysis to reveal whether, and to what extent, the results of the analysis are sensitive to plausible changes in the main assumptions and numeric inputs."[LL] Considering this guidance, a number of sensitivity analyses were performed using analysis Method A to examine important assumptions and inputs, including the following, all of which are discussed in greater detail in the accompanying RIA:

1. Payback Period: In addition to the 0 and 6 month payback periods discussed above, also evaluated cases involving payback periods of 12, 18, and 24 months.
2. Fuel Prices: Evaluated cases involving fuel prices from the AEO 2015 low and high oil price scenarios. (See AEO-Low and AEO-High in the tables).
3. Fuel Prices and Payback Period: Evaluated one side case involving a 0 month payback period combined with fuel prices from the AEO 2015 low oil price scenario, and one side case with a 24 month payback period combined with fuel prices from the AEO 2014 high oil price scenario.
4. Benefits to Vehicle Buyers: The main Method A analysis assumes there is no loss in value to owner/operators resulting from vehicles that have an increase in price and higher fuel economy. NHTSA performed this sensitivity analysis assuming that there is a 25, or 50 percent loss in value to owner/operators – equivalent to the assumption that owner/operators will only value the calculated benefits they will achieve at 75, or 50 percent, respectively, of the main analysis estimates. (These are labeled as 75pctOwner/Operator Benefit and 50pctOwner/Operator Benefit).
5. 7 Pct Discount Rate: The main analysis results are considered using either a 0 or 3 percent discount rate. We also considered an alternative case where future savings/costs are discounted 7 percent annually.
6. Value of Avoided GHG Emissions: Evaluated side cases involving lower and higher valuation of avoided CO_2 emissions, expressed as the social cost of carbon (SCC).
7. Rebound Effect: Evaluated side cases involving rebound effect values of 5 percent, 15 percent, and 25 percent. (These are labeled as 05PctReboundEffect, 15PctReboundEffect and 25PctReboundEffect).
8. ICM-based Markup: Evaluated a side case using a retail price equivalent (ICM) markup factor.
9. Mass-Safety Effect: Evaluated side cases with the mass-safety impact coefficient at the values defining the 5th and 95th percent points of the confidence interval estimated in the underlying statistical analysis. (These are labeled MassFatalityCoeff05pct and MassFatalityCoeff95pct.).
10. VMT Schedules: Evaluated side cases considering the NHTS considered in the NPRM analysis as a high-VMT case, and another considered schedule as a low-VMT case.
11. Strong HEVs: Evaluated a side case in which strong HEVs were excluded from the set of technology estimated to be available for HD pickups and vans through model year 2030. As in Section VI.C. (8), this "no SHEV" case allowed turbocharging and downsizing on all GM vans to provide a lower-cost path for compliance.

Table 10-42, below, summarizes key metrics for each of the cases included in the sensitivity analysis using Method A for the alternative. The table reflects the percent change in the metrics (columns) relative to the main analysis, due to the particular sensitivity case (rows)

[LL] Available at http://www.whitehouse.gov/omb/circulars_a004_a-4/.

for the alternative 3. For each sensitivity run, the change in the metric can we described as the difference between the baseline and the preferred alternative for the sensitivity case, minus the difference between the preferred alternative and the baseline in the main analysis, divided by the difference between the preferred alternative and the baseline in the main analysis. Or,

$$Table\ Metric = \frac{\Delta_{Alt\ sen\ case} - \Delta_{Alt\ main\ run}}{\Delta_{Alt\ main\ run}} \cdot 100$$

Each metric represents the sum of the impacts of the preferred alternative over the model years 2015-2029, and the percent changes in the table represent percent changes to those sums. More detailed results for all alternatives are available in the accompanying RIA Chapter 10.

Table 10-42 Sensitivity Analysis Results from CAFE Model in the HD Pickup and Van Market Segment using Method A and versus the Dynamic Baseline, Alternative 1b (2.5 % growth in stringency: Cells are percent change from base case) [a]

Sensitivity Case	Fuel Savings (gallons)	CO_2 Savings (MMT)	Fuel Savings ($)	Social Costs ($billion)	Social Benefits ($billion)	Social Net Benefits ($billion)
0 Month Payback	8.4%	8.0%	7.7%	8.0%	7.8%	7.7%
12 Month Payback	-13%	-14%	-15%	-2.8%	-14%	-19%
18 Month Payback	-30%	-31%	-32%	-16%	-31%	-38%
24 Month Payback	-47%	-47%	-48%	-32%	-48%	-54%
AEO-Low	-5.4%	-5.8%	-31%	-19%	-26%	-29%
AEO-High	-27%	-28%	18%	-2.8%	13%	20%
AEO-Low, 0 Month Payback	35%	33%	33%	42%	34%	30%
AEO-High, 24 Month Payback	-50%	-50%	-51%	-37%	-51%	-57%
7pct Discount Rate	0.0%	0.0%	-41%	-31%	-35%	-37%
50pct Owner/Operator Benefit	0.0%	0.0%	-50%	0.0%	-34%	-48%
75pct Owner/Operator Benefit	0.0%	0.0%	-25%	0.0%	-17%	-24%
Low SCC	0.0%	0.0%	0.0%	0.0%	-11%	-16%
High SCC	0.0%	0.0%	0.0%	0.0%	8.2%	12%
Very High SCC	0.0%	0.0%	0.0%	0.0%	30%	43%
5pct Rebound	4.6%	4.6%	4.6%	-13%	0.37%	5.5%
15pct Rebound	-4.6%	-4.6%	-4.6%	12%	-0.37%	-5.5%
25pct Rebound	-14%	-14%	-14%	37%	-1.1%	-17%
5^{th} Percentile Mass Fatality Coefficient	0.0%	0.0%	0.0%	-11%	0.0%	4.6%
95^{th} Percentile Mass Fatality Coefficient	0.0%	0.0%	0.0%	15%	0.0%	-6.0%
No SHEV-P2's	0.18%	0.29%	0.29%	-1.3%	0.26%	0.88%
Non-CO_2eq GHG Values	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ICM-Based Mark-Up	-5.7%	-6.0%	-6.1%	-16%	-6.0%	-1.8%
High VMT	8.6%	7.4%	5.9%	0.11%	6.2%	8.7%
Low VMT	-7.7%	-8.3%	-8.0%	-14%	-7.8%	-5.4%

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Section X.A.1.

For some of the cases for which results are presented above, the sensitivity of results to changes in inputs is simple, direct, and easily observed. For example, changes to valuation of avoided GHG emissions impact only this portion of the estimated economic benefits; manufacturers' responses and corresponding costs are not impacted. Similarly, a higher discount rate does not affect physical quantities saved (gallons of fuel and metric tons of CO_2 in the table), but reduces the value of the costs and benefits attributable to these standards in an intuitive way. Higher rebound results in fewer volumetric fuel savings and social net benefits, as drivers are assumed to be more responsive in their driving habits to changes in the cost per mile of travel. Some other cases warrant closer consideration:

First, cases involving alternatives to the reference case involving voluntary overcompliance of technologies that pay back in six-months involve different degrees of fuel consumption improvement. Increasing the length of the payback period assumption for voluntary overcompliance amounts to increasing fuel economy improvements in the absence of the rule (the baseline), and manufacturers are compelled to add less technology in order to comply with the standards (in the regulatory alternatives). Because all estimated impacts of these standards are shown as incremental values relative to this baseline, longer voluntary overcompliance payback periods correspond to smaller estimates of incremental impacts.

Table 10-43 shows the effect of varying the voluntary overcompliance assumption from the consumer perspective. The baseline over-compliance payback period is as described above—the number of months within which a technology must pay back to the consumer in the form of undiscounted retail fuel savings for a manufacturer to voluntarily apply that technology without regulatory action. The incremental per-vehicle technology cost is the average additional cost of technology applied to MY 2030 vehicles under the final regulation (incremental to the baseline) of each sensitivity case. The per-vehicle lifetime fuel savings is the average lifetime retail value of fuel savings under each sensitivity case discounted at 7 percent annually starting at the time of purchase (MY 2030). Compliance payback period is the number of months of ownership it would take the average consumer to recoup the additional technology costs in discounted fuel savings[MM].

As can be seen, the baseline voluntary overcompliance assumption changes how much of the technology costs and fuel savings are attributed to the regulation; both fewer fuel savings and fewer technology costs are attributed to the regulatory alternative as the payback period defining voluntary overcompliance increases. Further, because the model only applies the technologies with the shortest payback periods (the most cost-effective technologies) in the baseline, the fuel savings decrease at a greater proportion than the technology costs. The result is that the payback period of the regulatory alternative increases (and at an increasing rate) as manufacturers are assumed to apply more technology in the baseline.

[MM] This is based on the VMT schedules of average miles driven by age of MDHD pickups and vans and AEO fuel price projections.

Table 10-43 Sensitivity Analysis of the Voluntary Overcompliannce Assumption on Compliance Payback Period and Key Consumer Impacts for the MY 2030 MDHD Fleet

Baseline Over-compliance Payback (months)	Incremental Per-Vehicle Technology Cost	Per-Vehicle Lifetime Fuel Savings	Technology Cost Payback Period (months)[a]
0	$1,471	$3,966	28
6	$1,472	$3,636	31
12	$1,317	$3,031	33
18	$1,214	$2,556	38
24	$944	$1,684	45

Note:
[a] Here the payback period uses a 7% discount rate of retail fuel savings starting at the time of purchase and only considers the additional costs of technology application.

Cases involving different fuel prices similarly involve different degrees of fuel economy improvement in the absence of the standard, as more, or less, improvement occurs as a result of more, or fewer, technologies appearing cost effective to owner/operators. Low fuel prices change the amount of fuel savings for each technology, since the choice in technology application also involves both the size of the cost and the fuel savings, lower fuel prices can change the rank of the technologies. Under low fuel prices, the model applies fewer SHEV-P2's. The result is a reduction in volumetric fuel savings, and an even larger reduction in monetary fuel savings, because the fuel savings are worth less. There is also a reduction in social costs, and social net benefits. Higher fuel prices correspond to reductions in the volumetric fuel savings attributable to these standards as, but lead to increases in the value of fuel saved (and net social benefits) because each gallon saved is worth more when fuel prices are high.

The low price and 0-month payback case leads to a significant increase in volumetric savings compared to the main analysis. Note that the fuel savings are higher than in the 0-month payback case alone. Part of the reason for this is that the lower fuel price case takes into consideration that when fuel prices are lower, consumers buy more heavy-duty vehicles (this is estimated from the AEO2015 low fuel price case). Another piece of the explanation is that the lower fuel prices result in a different technology cost-effectiveness ranking of technologies, and that the 0 month payback baseline results in no voluntary over compliance in the baseline. Different technologies are picked than in the 0 month pay back sensitivity alone, and the most cost effective that would have been applied in the baseline, are now attributed to the preferred alternative. Similarly, the high price and 24-month payback case results in large reductions to volumetric savings that can be attributed to these standards because more is applied in the baseline. Further, the presence of high fuel prices is not sufficient to lead to increases in either the dollar value of fuel savings or net social benefits.

The case which involves the VIUS-based VMT schedules (the high VMT case) results in greater volumetric fuel and GHG-savings attributable to the standards. Under this case the higher estimate of VMT results in more fuel consumption in the baseline, and a higher absolute change in fuel consumption when fuel-saving technologies are applied in the preferred alternative. These higher amount of gallons saved, results in more monetary fuel savings, comparable social costs, and an increase in overall net social benefits attributed to the standards.

The low-VMT schedule, developed as an alternative to the adopted VMT-schedule from the IHS/Polk odometer readings, results in lower volumetric fuel consumption and GHG reductions under the preferred alternative. Lower VMT estimates result in less fuel consumption in the baseline, and a lower absolute change in fuel consumption under the preferred alternative. This schedule attributes lower costs to the standards—the lower fuel savings under the low-VMT schedule changes the technology application decisions of the model, since fewer fuel savings are considered in measure the cost-effectiveness of technologies. The result is lower absolute technology costs, but also lower social net benefits.

The case which makes SHEV-P2's unavailable involves relatively small increases to volumetric fuel savings and CO_2 reductions—not surprising, since SHEV-P2's play only a minor role in the compliance strategy of the preferred alternative in the central analysis. These small increases in fuel savings are associated with small increases in social benefits, slightly larger proportional increases in social costs, but still result in a small increase in social net benefit.

The case that uses the ICM mark-up methodology rather than the RPE methodology results in a reduction of volumetric fuel savings and GHG reductions. The reduction in fuel savings is accompanied by a reduction in monetary fuel savings, social benefits, social costs, and social net benefits. This is likely due to shifts in technology applications due to different costs mark-ups associated with different types of technologies under the ICM mark-up methodology.

If, instead of using the values in the main analysis, each sensitivity case were itself the main analysis, the costs and benefits attributable to the final rule will be as they appear in Table 10-44, below.

Table 10-44 Costs and Benefits of Standards for MY 2015-2029 HD Pickups and Vans under Alternative Assumptions

Sensitivity Case	Fuel Savings (billion gallons)	CO_2 Reduction (MMT)	Fuel Savings ($billion)	Social Costs ($billion)	Social Benefits ($billion)	Net Social Benefits ($billion)
6 Month Payback	9.2	110	18	7.8	27	19
0 Month Payback	10	120	19	8.2	28	20
12 Month Payback	8.0	92	15	7.3	22	15
18 Month Payback	6.4	74	12	6.4	18	12
24 Month Payback	4.9	56	9.3	5.2	14	8.5
AEO-Low	8.7	100	12	6.1	19	13
AEO-High	6.7	77	21	7.3	30	22
AEO-Low, 0 Month Payback	12	140	24	11	35	24
AEO-High, 24 Month Payback	4.7	53	8.8	4.8	13	8.0
7pct Discount Rate	9.2	110	11	5.2	17	12
50pct Owner/Operator Benefit	9.2	110	8.9	7.5	17	9.7
75pct Owner/Operator Benefit	9.2	110	13	7.5	22	14
Low SCC	9.2	110	18	7.5	23	16
High SCC	9.2	110	18	7.5	28	21
Very High SCC	9.2	110	18	7.5	34	27
5pct Rebound	9.7	110	19	6.6	26	20
15pct Rebound	8.8	100	17	8.5	26	18
25pct Rebound	8.0	92	15	10	26	16
5^{th} Percentile Mass Fatality Coefficient	9.2	110	18	6.7	26	19
95^{th} Percentile Mass Fatality Coefficient	9.2	110	18	8.7	26	18
No SHEV-P2's	9.3	110	18	7.5	26	19
Non-CO_2eq GHG Values	9.2	110	18	7.5	26	19
ICM-Based Mark-Up	8.7	100	17	6.3	25	18
High-VMT	10	110	19	7.6	28	20
Low-VMT	8.5	98	16	6.5	24	18

10.2.9 Discussion of the Maximum Feasibility of the Adopted Standards

As noted above, EPCA and EISA require NHTSA to "implement a commercial medium- and heavy-duty on-highway vehicle and work truck fuel efficiency improvement program designed to achieve the maximum feasible improvement" and to establish corresponding fuel consumption standards “that are appropriate, cost-effective, and technologically feasible.”[NN] In order to determine which of the regulatory alternatives meets the requirements of the statute NHTSA has considered both the modeling results of “Method A” and comments offered on the proposed rulemaking.

10.2.9.1 Consideration of Modeling Results

For both the NPRM and the current analysis of potential standards for HD pickups and vans, NHTSA applied NHTSA’s CAFE Compliance and Effects Modeling System (sometimes referred to as “the CAFE model” or “the Volpe model”), which DOT’s Volpe National Transportation Systems Center (Volpe Center) developed, maintains, and applies to support NHTSA CAFE analyses and rulemakings. NHTSA used this model in its Method A analysis to evaluate regulatory alternatives for Phase 2 standards applicable to HD pickups and vans, and used results of this analysis to inform its selection of the regulatory alternative that will achieve the maximum feasible improvement in HD pickup and van fuel efficiency. This analysis, includes several updates to the model and to accompanying inputs, as discussed above in this section.

In the proposal, the agencies proposed to adopt Alternative 3 from among the five regulatory alternatives under consideration.[OO] As discussed in the NPRM, the agencies found that Alternative 2 would unduly forego significant fuel savings and avoided GHG emissions, and that Alternative 5 could involve rapid and early cost increases and necessitate significant application of the most advanced technologies considered by the agencies, 80 FR 40494-95. The agencies have estimated the cost and efficacy of fuel-saving technologies assuming performance and utility will be held constant or improved. In particular, we have assumed payload will be preserved (and possibly improved via reduced vehicle curb weight); however, some fuel-saving technologies, such as hybrid electric vehicles, could reduce payload via increased curb weight (due to the added electrical machine, batteries and controls, and because of the physical size of those components). If the increase in weight from the hybrid system is not offset with a weight reduction elsewhere in the vehicle, the payload capability will be reduced resulting in lost utility but also an increase in stringency due to changes in work factor. Further, it is also possible that applications such as vans where the advanced technologies of downsized gasoline and diesel engines could be used in conjunction with strong hybridization, extended high power demand resulting from a vehicle at full payload or towing, certain types of hybrid powertrains could experience a temporary loss of towing capacity if the capacity of the hybrid’s energy storage device (e.g., batteries, hydraulic accumulator) is insufficient for the extended power demand required to maintain expected vehicle speeds.

The Method A analysis shows in the short term, MY 2017 – 2021 timeframe, that there are significant differences in the rate at which technologies would need to be applied among the alternatives. NHTSA believes the rates of technology application require for Alternatives 4 and 5 are beyond maximum feasible when considering the availability of manufacturers’ resources

[NN] 49 USC 32902(k)(2).
[OO] These Alternatives are defined in Section C(6).

and capital to implement the technologies in that timeframe, and that Alternatives 4 and 5 would not provide adequate lead time for the industry to fully address reliability considerations.

Like the NPRM analysis (i.e. the Method B analysis), Method A indicates Alterative 4 would achieve little benefit beyond that achieved by Alternative 3. For example, as shown in the following graph of estimated total fuel consumed by HD pickups and vans over time under the various regulatory alternatives, outcomes under Alternative 4 are nearly indistinguishable from those under Alternative 3. By 2030, the two are less than 0.5 percent apart.

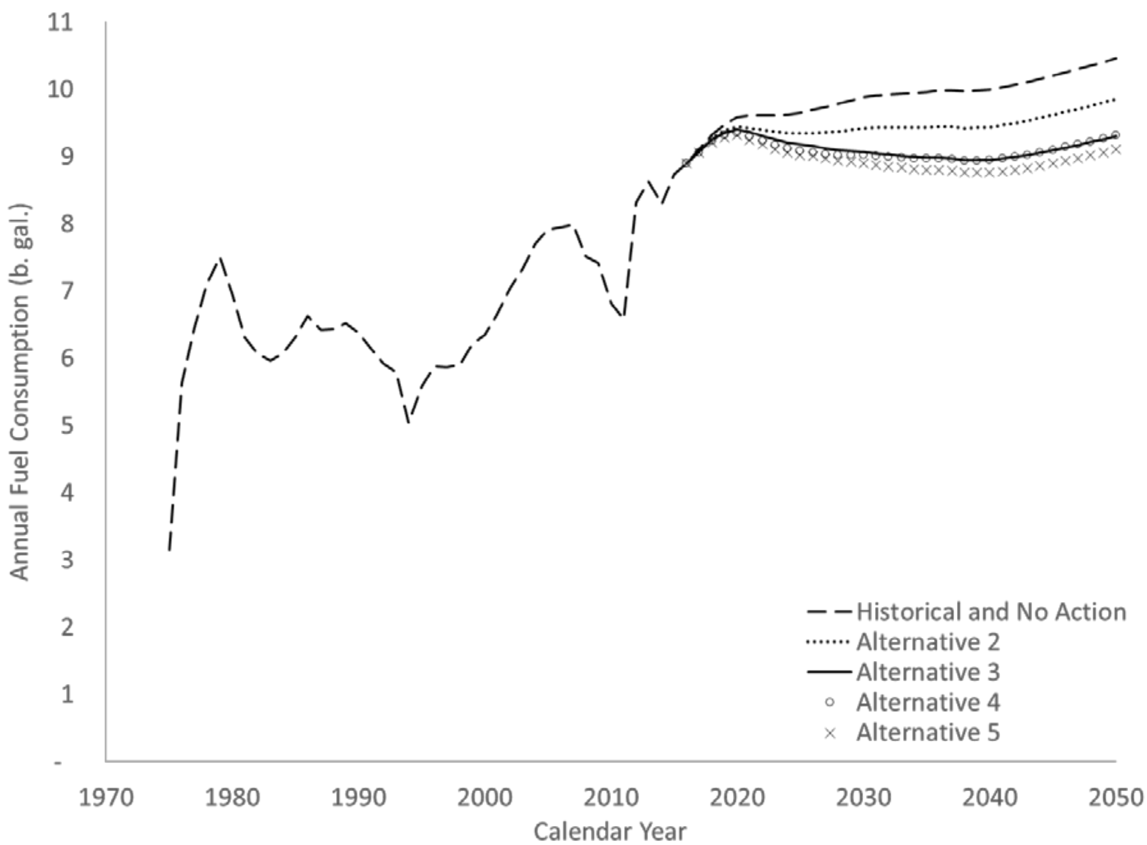

Figure 10-33 Method A Annual Fuel Consumption across Regulatory Alternatives

Weighing against the small additional benefit estimated to be potentially available under Alternative 4, NHTSA also considered the estimated additional costs. Method A analysis shows overall incremental costs (i.e., costs beyond the No Action Alternative) under Alternative 4 to be about 12 percent more than under Alternative 3.

As mentioned above, these estimated differences were mostly small on a relative basis. Averaged over all model years included in the analysis, estimated incremental costs are $106 higher under Alternative 4 than under Alternative 3. For Daimler and General Motors, there is little or no estimated difference in costs under these two Alternatives. For FCA, Ford, and Nissan, differences are somewhat larger, averaging $120, $173, and $272, respectively. However, as explained in greater detail above NHTSA's method A analysis shows considerably greater total and average additional costs in earlier model years under Alternative 4 than under Alternative 3.

Although NHTSA's Method Analysis also indicates that some manufacturers could need to apply additional technology as soon as MY2016 under baseline standards defining the No-Action Alternative, average estimated costs (versus continuation today's technology) in MY2017 are two thirds more under Alternative 4 than under the No Action Alternative.

Beyond these directly-estimated costs, the agencies also considered factors beyond those addressed quantitatively in either the NPRM analysis or the updated analysis. In general, these other factors reflect risk and uncertainty involved with standards for HD pickups and vans. These risks and uncertainty appear considerably greater than for light-duty vehicles. The HD pickup and van market has significantly fewer vehicle models than the light-duty market making forecasting uncertainty a greater risk to compliance. All current manufacturers of HD pickups and vans also produce light-duty vehicles. These manufacturers' light-duty offerings span wide ranges of models, configurations, shared vehicle platforms, engines, transmissions, and design schedules. As a result, if some specific aspects of production do not progress as initially planned for light-duty vehicles (e.g., if mass reduction on some platform does not achieve as much benefit as planned, or if a new engine does not perform as well as projected, or if limited engineering resources make it necessary to delay a redesign), these manufacturers should have ample opportunity to comply with light-duty CAFE and GHG standards by making adjustments among other models, platforms, engines, and transmissions. This is not the case for HD pickups and vans. Current HD PUV manufacturers offer products spanning only 1-3 platforms, at most half a dozen engines or transmissions, and only 1-3 schedules for redesigns. As summarized below, this provides 5-10 times less flexibility than for light-duty vehicles.

Table 10-45 MY 2015 Body and Engine Platforms by Manufacturer for Light- and Heavy-Duty Pickups

	PLATFORMS		ENGINES		TRANSMISSIONS		DESIGN SCHEDULES	
	Light-Duty	HD PUV	Light-Duty	HD PUV	Light-Duty	HD PUV	Light-Duty	HD PUV
Daimler	12	1	29	2	20	2	18	1
FCA	15	3	24	5	21	6	24	3
Ford	9	2	22	5	27	3	18	2
General Motors	17	2	26	5	39	3	21	2
Nissan	6	1	13	2	21	2	23	1

Considering further that credits from other manufacturers are not potentially available as for light-duty vehicles (e.g., Honda, Toyota, and some other manufacturers currently have excess light-duty CAFE credits that could be traded to other OEMs), this means that overestimating the industry's capability to improve fuel efficiency and reduce GHG emissions, and consequently setting standards at too high of a level, poses a much greater compliance risk for HD PUV fleets than for light-duty fleets. If the factors discussed here, for which the agencies are currently unable to account in our analysis, lead manufacturers to fail to comply with the standards, then the additional benefits of setting standards slightly higher would be lost. In the agencies' judgment, even setting aside the somewhat higher estimated costs under Alternative 4, the very small additional benefit that could be achieved under Alternative 4 do not warrant the increased exposure to this risk.

Regarding Alternative 5, the Method A analysis shows somewhat greater benefits than under Alternatives 3 or 4, but Alternative 5 entails considerably greater costs and dependence on strong hybrid technology, as well as even greater exposure to the above-mentioned uncertainties and risks. Under the Method A analysis for Alternative 5, incremental costs averaged across all model years considered are estimated to be about $400 higher (about 46 percent) than under Alternative 3, and that analysis shows an overall fleet application of approximately 7 percent strong hybrids, with General Motors applying approximately 13 percent and Ford approximately 7 percent.

We have also assumed that fuel-saving technologies will be no more or less reliable than technologies already in production. However, if there is insufficient lead-time to fully develop new technologies, they could prove to be less reliable, perhaps leading to increased repair costs and out-of-service time. If the fuel-saving technologies considered here ultimately involve reliability problems, overall costs will be greater than we have estimated. Method A analysis shows in the short term, MYs 2017 – 2021 timeframe, there are significant differences in the rate at which technologies would need to be applied among the alternatives. Figure 10-18and Figure 10-19, above, shows the progression in average and total technology costs and the rate of increase in those costs among the alternatives using Method A. They highlight the increases in resources and capital that would be required to implement the technologies required to comply with each of the alternatives, as well as the reduction in lead time to implement the technologies which increases reliability risk. As discussed further above in the manufacturer-specific effects, Ford and FCA are estimated to redesign vehicles in MYs 2017 and 2018 respectively, and vehicle designs for those model years are complete or nearly complete. The next estimated redesign for Ford is in MY 2026, and for FCA in MY 2025, and substantial resources and very high costs would be required to add another vehicle redesign between the estimated redesign model years to implement the technologies that would be needed to comply with those alternatives.

10.2.9.2 Consideration of Comments

NHTSA proposed that Alternative 3 represented the maximum feasible alternative under EISA, and EPA proposed that Alternative 3 reflected a reasonable consideration of the statutory factors of technology effectiveness, feasibility, cost, lead time, and safety for purposes of CAA sections 202 (a)(1) and (2). Although the agencies and commenters also found that Alternative 4 merited serious consideration, the agencies noted that Alternative 3 was generally designed to achieve the levels of fuel consumption and GHG stringency that Alternative 4 would achieve, but with several years of additional lead time, meaning that manufacturers could, in theory, apply new technology at a more gradual pace, with greater reliability and flexibility.

Some comments on the proposal called for adoption of standards more stringent and/or more rapidly advancing in stringency than those defining Alternative 3. For example, CARB argued that Alternative 4 would, compared to Alternative 3, achieve greater benefits comparably attractive in terms of cost effectiveness and while remaining less stringent than CAFE standards for light-duty trucks.[PP] UCS provided similar comments, indicating further that the standards should be technology forcing and therefore more aggressive than Alternative 4, they specifically suggested that gasoline vehicles could achieve up to a 23.6 percent improvement in MY 2027 while diesel vehicles can achieve an 18 percent improvement.[QQ] ACEEE similarly recommended increasing the stringency by 7 percent in MY 2027 and that standards should reflect increased use of cylinder deactivation, cooled EGR, and GDI and turbo downsizing in pickups. For diesels, ACEEE commented that additional reductions were possible, based on an estimate of 10 percent penetration of engine downsizing for pickups and 30 percent penetration for vans in 2027, and also assuming 6 percent penetration of hybrids in diesel vans.

Citing the potential for fuel-saving technology to migrate from light-duty pickups and vans to heavy-duty pickups and vans, CBD also called for more stringent HD pickup and van standards that would "close the gap" with light-duty standards, as any gap allows manufacturers to essentially choose to classify a pickup as heavy-duty to avoid more stringent requirements if it was classified as a light-duty vehicle.[RR] ICCT likewise commented that the proposed standards represent only a 2.2 and 1.6 percent year-over-year improvement for the gasoline and diesel fleets, respectively, from MYs 2014-2025 compared to an almost 3 percent per year improvement for light-duty trucks in the same time frame. ICCT recommended that the agencies' analysis incorporate the full analysis and inputs from the light-duty rulemaking and that the result would be improvements in the range of 35 percent over the MYs 2014-2025 rather than the proposed 23 percent improvement over this time frame.

On the other hand, some other reviewers commented that the proposed standards could be unduly aggressive considering the products and technologies involved. GM commented that any attempt to force more stringent regulations than proposed, such as Alternative 4, would be extremely detrimental to manufacturers, consumers, the U.S. economy, and the millions of transportation-related jobs. Daimler similarly commented that the proposed standards would be a challenge for automotive manufacturers. Under certain conditions, such a standard may necessitate hybridization of the affected vehicle fleet, which would require substantial development and material costs. All technologies taken into account for the class 2b/3 stringencies should reflect cost effectiveness calculations, especially alternative powertrains such as hybrids, battery, and fuel cell driven electric vehicles. Daimler recommends that the agencies adopt the proposed standard over Alternative 4, as the additional two years of lead-time will be critical for automotive manufacturers in developing the necessary technologies to achieve compliance. Nissan commented that the Alternative 4 3.5 percent per stringency level is simply not feasible, as it does not provide the necessary lead-time to enable manufacturers to balance competitive market constraints with the cost of applying new technologies to a limited product offering. Nissan further commented that to the extent that the more stringent alternative is predicated on the adoption of hybrid and electric powertrain technology, Nissan does not believe that such technology is feasible for this market segment.

The American Automotive Policy Council (AAPC, representing FCA, Ford, and General Motors) further commented that proposals for greater stringency than Alternative 3 are not

[PP] CARB, Docket No. NHTSA-2014-0132-0125at pages 52-53.
[QQ] UCS, Docket No. EPA-HQ-OAR-2014-0827-1329, at pages 23-25.
[RR] CBD, Docket No. NHTSA-2014-0132-0101, at pages 8-9.

supportable given the required early introduction of unproven technologies with their associated consumer acceptance risk, as well as the many implicit risks that impact stringency. AAPC commented that the proposed standards are aggressive and will challenge industry. AAPC noted that the baseline fleet includes a high percentage of advanced diesel technology such as SCR, making additional improvements considerably more challenging. In the light-duty fleet, diesel technology accounts for 3 percent of fleet whereas the heavy-duty fleet consists of over 50 percent diesel.

AAPC also noted that Phase 2 technologies are being used today. For example, FCA's modern gasoline engine has robust combustion with multiple spark plugs, variable cam phasing, cylinder deactivation, and cooled EGR. AAPC commented that even with this level of gasoline engine technology, FCA is challenged by the early year Phase 1 standards and will need to look at adding even more technology for Phase 2. AAPC also provided data showing that while smaller displacement boosted gasoline engine technology may be applicable in some variants of commercial vans, this technology is not suited for the pickup truck variants in this segment because of customer demands for towing capability. AAPC commented that concurrent stringency increases in Tier 3/LEV III criteria emission requirements will negatively impact CO_2 and fuel consumption. As an alternative to the standards proposed in the NPRM, the American Automotive Policy Council (AAPC, representing FCA, Ford, and General Motors) proposed standards that would achieve the stringency by model year 2027, but that would do so at a more gradual pace.[SS] As means of providing flexibility in complying with these standards, AAPC also commented that the agencies should allow credits to be banked for longer than 5 years, and should allow credits to be transferred between the light- and heavy-duty fleets.[TT]

10.2.9.3 Determination

Having considered these comments as well as the updated analysis summarized above, NHTSA is adopting standards under which the stringency of fuel consumption standards for HD pickups and vans advance at an annual rate of 2.5 percent during model years 2021-2027 relative to the 2018 MY Phase 1 standard level. In NHTSA's judgment, this pace of stringency increase will appropriately accommodate manufacturers' redesign workload and product schedules, especially in light of this sector's limited product offerings[UU] and long product cycles. Given the provided flexibility to carry credits forward (and back) between model years, this approach strikes a balance between, on one hand, meaningful early fuel efficiency improvements and, on the other, providing manufacturers appropriate lead time.

Compared to Alternative 3, Alternative 2 would forego significant cost-efficient opportunities to apply conventional and moderately advanced technology in order to reduce fuel consumption and emissions. Also, although the updated analysis summarized above shows costs for Alternative 3 (as costs incremental to the No Action Alternative) somewhat higher than estimated in the NPRM analysis, the agencies find that under either the Method A or Method B

[SS] AAPC, Docket No. NHTSA-2014-0132-0103], at pages 12-13.
[TT] AAPC, Docket No. NHTSA-2014-0132-0103 at pages 13-16.
[UU] Manufacturers generally have only one pickup platform and one van platform in this segment.

analyses, AAPC's proposed more gradual progression leading up to MY 2027 would also forego cost-effective improvements which are readily feasible in the lead time provided.

Furthermore, the Method A analysis indicates that the standards defining Alternative 3 can likely be met with minimal reliance on hybrid technologies. Considering this, NHTSA also find it unnecessary to extend the lifespan of banked credits or adopt other credit related flexibilities to mitigate the stringency increases under Alternative 3.

10.3 What Industry Impacts Did EPA's "Method B" Analysis Show for Regulatory Alternatives?

The analysis fleet provides a starting point for estimating the extent to which manufacturers might add fuel-saving (and, therefore, CO_2-avoiding) technologies under various regulatory alternatives, including the no-action alternative that defines a baseline against which to measure estimated impacts of new standards. The analysis fleet is a forward-looking projection of production of new HD pickups and vans, holding vehicle characteristics (e.g., technology content and fuel consumption levels) constant at model year 2014 levels, and adjusting production volumes based on recent DOE and commercially-available forecasts. This analysis fleet includes some significant changes relative to the market characterization that was used to develop the of Phase 1 standards applicable starting in model year 2014; in particular, the analysis fleet includes some new HD vans (e.g., Ford's Transit and Fiat/Chrysler's Promaster) that are considerably more fuel-efficient than HD vans these manufacturers have previously produced for the U.S. market.

While the Phase 2 standards are scheduled to begin in model year 2021, the requirements they define are likely to influence manufacturers' planning decisions several years in advance. This is true in light-duty planning, but accentuated by the comparatively long redesign cycles and small number of models and platforms offered for sale in the 2b/3 market segment. Additionally, manufacturers will respond to the cost and efficacy of available fuel consumption improvements, the price of fuel, and the requirements of the Phase 1 standards that specify maximum allowable average fuel consumption and GHG levels for MY2014-MY2018 HD pickups and vans (the final standard for MY2018 is held constant for model years 2019 and 2020). The forward-looking nature of product plans that determine which vehicle models will be offered in the model years affected by these standards lead to additional technology application to vehicles in the analysis fleet that occurs in the years prior to the start of these standards. From the industry perspective, this means that manufacturers will incur costs to comply with these standards in the baseline and that the total cost of the regulations will include some costs that occur prior to their start, and represent incremental changes over a world in which manufacturers will have already modified their vehicle offerings compared to today.

Table 10-46 MY2021 Method B Baseline Costs for Manufacturers in 2b/3 Market Segment in the Dynamic Baseline, or Alternative 1b

MANUFACTURER	AVERAGE TECHNOLOGY COST ($)	TOTAL COST INCREASE ($M)
Chrysler/Fiat	275	27
Daimler	18	0
Ford	258	78
General Motors	782	191
Nissan	282	3
Industry	442	300

As Table 10-46 shows, the industry as a whole is expected to add about $440 of new technology to each new vehicle model by 2021 under the no-action alternative defined by the Phase 1 standards. Reflecting differences in projected product offerings in the analysis fleet, some manufacturers (notably Daimler) are significantly less constrained by the Phase 1 standards than others and face lower cost increases as a result. General Motors (GM) shows the largest increase in average vehicle cost, but results for GM's closest competitors (Ford and Chrysler/Fiat) do not include the costs of their recent van redesigns, which are already present in the analysis fleet (discussed in greater detail below).

The above results reflect the assumption that manufacturers having achieved compliance with standards might act as if buyers are willing to pay for further fuel consumption improvements that "pay back" within 6 months (i.e., those improvements whose incremental costs are exceeded by savings on fuel within the first six months of ownership). It is also possible that manufacturers will choose not to migrate cost-effective technologies to the 2b/3 market segment from similar vehicles in the light-duty market. Resultant technology costs in model year 2021 results for the no-action alternative, summarized in Table 10-47 below, are quite similar to those shown above for the 6-month payback period. Due to the similarity between the two baseline characterizations, results in the following discussion represent differences relative to only the 6-month payback baseline.

Table 10-47 MY2021 Method B Baseline Costs for HD Pickups and Vans in the Flat Baseline, or Alternative 1a

MANUFACTURER	AVERAGE TECHNOLOGY COST ($)	TOTAL COST INCREASE ($M)
Chrysler/Fiat	268	27
Daimler	0	0
Ford	248	75
General Motors	767	188
Nissan	257	3
Industry	431	292

The results below represent the impacts of several regulatory alternatives, including those defined by the Phase 2 standards, as incremental changes over the baseline, where the baseline is defined as the state of the world in the absence of this regulatory action (but, of course, including the Phase 1 standards). Large-scale, macroeconomic conditions like fuel prices are constant across all alternatives, including the baseline, as are the fuel economy improvements under the no-action alternative defined by the Phase 1 rule that covers model years 2014 – 2018 and is constant from model year 2018 through 2020. In the baseline scenario, the Phase 1 standards are assumed to remain in place and at 2018 levels throughout the analysis (i.e. MY 2030). The only difference between the definitions of the alternatives is the stringency of these standards starting in MY 2021 and continuing through MY 2025 or MY 2027, and all of the differences in outcomes across alternatives are attributable to differences in the standards.

The standards vary in stringency across regulatory alternatives (1 – 5), but as discussed above, all of the standards are based on the curve developed in the Phase 1 standards that relate fuel economy and GHG emissions to a vehicle's work factor. The alternatives considered here represent different rates of annual increase in the curve defined for model year 2018, growing from a 0 percent annual increase (Alternative 1, the baseline or "no-action" alternative) up to a 4 percent annual increase (Alternative 5). Table 10-48 shows a summary of outcomes by alternative incremental to the baseline (Alternative 1b) for Model Year 2030[VV], with the exception of technology penetration rates, which are absolute.

The technologies applied as inputs to the CAFE model (in either its Method B or A iterations) have been grouped (in most cases) to give readers a general sense of which types of technology are applied more frequently than others, and are more likely to be offered in new class 2b/3 vehicles once manufacturers are fully compliant with the standards in the alternative. Model year 2030 was chosen to account for technology application that occurs once the standards have stabilized, but manufacturers are still redesigning products to achieve compliance – generating technology costs and benefits in those model years. The summaries of technology penetration are also intended to reflect the relationship between technology application and cost increases across the alternatives. The table rows present the degree to which specific technologies are predicted to be present in new class 2b and class 3 vehicles in 2030, and correspond to: variable valve timing (VVT) and/or variable valve lift (VVL), cylinder deactivation, direct injection, engine turbocharging, 8-speed automatic transmissions, electric power-steering and accessory improvements, micro-hybridization (which reduces engine idle, but does not assist propulsion), full hybridization (integrated starter generator or strong hybrid that assists propulsion and recaptures braking energy), and aerodynamic improvements to the vehicle shape. In addition to the technologies in the following tables, there are some lower-complexity technologies that have high market penetration across all the alternatives and manufacturers; low rolling-resistance tires, low friction lubricants, and reduced engine friction are examples.

[VV] As noted above, the CAFE model estimates that redesign schedules will "straddle" model year 2027, the latest year for which the agencies are increasing the stringency of fuel consumption and GHG standards. Considering also that today's analysis estimates some earning and application of "carried forward" compliance credits, the model was run extending the analysis through model year 2030.

Table 10-48 Summary of HD Pickup and Van Alternatives' Impact on Industry versus the Dynamic Baseline, Alternative 1b

ANNUAL STRINGENCY INCREASE	2.0%/Y	2.5%/Y	3.5%/Y	4.0%/Y
Stringency Increase Through MY	2025	2027	2025	2025
Total Stringency Increase	9.6%	16.2%	16.3%	18.5%
Average Fuel Economy (miles per gallon)				
Required	19.04	20.57	20.57	21.14
Achieved	19.14	20.61	20.83	21.27
Average Fuel Consumption (gallons /100 mi.)				
Required	5.25	4.86	4.86	4.73
Achieved	5.22	4.85	4.80	4.70
Average Greenhouse Gas Emissions (g/mi)				
Required	495	458	458	446
Achieved	491	458	453	444
Technology Penetration (%)				
VVT and/or VVL	46	46	46	46
Cylinder Deac.	29	21	21	21
Direct Injection	17	25	31	32
Turbocharging	55	63	63	63
8-Speed AT	67	96	96	97
EPS, Accessories	54	80	79	79
Stop Start	0	0	10	13
Hybridization[a]	0	8	35	51
Aero. Improvements	36	78	78	78
Mass Reduction (vs. No-Action)				
CW (lb.)	239	243	325	313
CW (%)	3.7	3.7	5.0	4.8
Technology Cost (vs. No-Action)				
Average ($) [b]	578	1,348	1,655	2,080
Total ($m) [c]	437	1,019	1,251	1,572
Payback period (m) [c]	25	31	34	38

Notes:
[a] Includes mild hybrids (ISG) and strong HEVs.
[b] Values used in Methods A & B
[c] Values used in Method A, calculated using a 3% discount rate.

In general, as stated above, the Method B model projected that the standards will cause manufacturers to produce HD pickups and vans that are lighter, more aerodynamic, and more technologically complex across all the alternatives. As Table 10-48 shows, there is a difference between the relatively small increases in required fuel economy and average incremental technology cost between the alternatives, suggesting that the challenge of improving fuel consumption and CO_2 emissions accelerates as stringency increases (i.e., that there may be a "knee" in the relationship between technology cost and reductions in the fuel consumption/GHG emissions.

The contrast between alternatives 3 and 4 is even more prominent, with an identical required fuel economy improvement projected to lead to price increases greater than 20 percent based on the more rapid rate of increase and shorter time span of Alternative 4, which achieves all of its increases by MY 2025 while Alternative 3 continues to increase at a slower rate until MY 2027. Despite these differences, the increase in average payback period when moving from Alternative 3 to Alternative 4 to Alternative 5 is fairly constant at around an additional three months for each jump in stringency.

Manufacturers offer few models, typically only a pickup truck and/or a cargo van, and while there are a large number of variants of each model, the degree of component sharing across the variants can make diversified technology application either economically impractical or impossible. This forces manufacturers to apply some technologies more broadly in order to achieve compliance than they might do in other market segments (passenger cars, for example). This difference between broad and narrow application – where some technologies must be applied to entire platforms, while some can be applied to individual model variants – also explains why certain technology penetration rates decrease between alternatives of increasing stringency (cylinder deactivation or mass reductions in Table 10-48, for example). For those cases, narrowly applying a more advanced (and costly) technology can be a more cost effective path to compliance and lead to reductions in the amount of lower-complexity technology that is applied.

One driver of the change in technology cost between Alternative 3 and Alternative 4 in the Method B analysis is the amount of hybridization projected to result from the implementation of the standards. While only about 5 percent full hybridization (defined as either integrated starter-generator or strong hybrid) is expected to be needed to comply with Alternative 3, the higher rate of increase and compressed schedule moving from Alternative 3 to Alternative 4 is enough to increase the percentage of the fleet adopting full hybridization by a factor of two. To the extent that manufacturers are concerned about introducing hybrid vehicles in the 2b and 3 market, it is worth noting that new vehicles subject to Alternative 3 achieve the same fuel economy as new vehicles subject to Alternative 4 by 2030, with less full hybridization projected under this Method B analysis as being needed to achieve the improvement.

The alternatives also lead to important differences in outcomes at the manufacturer level, both from the industry average and from each other. General Motors, Ford, and Fiat Chrysler, are expected to have approximately 95 percent of the 2b/3 new vehicle market during the years that these standards are being phased in. Due to their importance to this market and the similarities between their model offerings, these three manufacturers are discussed together and a summary of the way each is impacted by the standards appears below in Table 10-49, Table 10-50, and Table 10-51 for General Motors, Ford, and Chrysler/Fiat, respectively.

Table 10-49 Summary of Impacts on General Motors by 2030 in the HD Pickup and Van Market versus the Dynamic Baseline, Alternative 1b

ANNUAL STRINGENCY INCREASE	2.0%/Y	2.5%/Y	3.5%/Y	4.0%/Y
Stringency Increase Through MY	2025	2027	2025	2025
Average Fuel Economy (miles per gallon)				
Required	18.38	19.96	20	20.53
Achieved	18.43	19.95	20.24	20.51
Average Fuel Consumption (gallons /100 mi.)				
Required	5.44	5.01	5	4.87
Achieved	5.42	5.01	4.94	4.87
Average Greenhouse Gas Emissions (g/mi)				
Required	507	467	467	455
Achieved	505	468	461	455
Technology Penetration (%)				
VVT and/or VVL	64	64	64	64
Cylinder Deac.	47	47	47	47
Direct Injection	18	18	36	36
Turbocharging	53	53	53	53
8-Speed AT	36	100	100	100
EPS, Accessories	100	100	100	100
Stop Start	0	0	2	0
Hybridization[c]	0	19	79	100
Aero. Improvements	100	100	100	100
Mass Reduction (vs. No-Action)				
CW (lb.)	325	161	158	164
CW (%)	5.3	2.6	2.6	2.7
Technology Cost (vs. No-Action)				
Average ($) [a]	785	1,706	2,244	2,736
Total ($m, undiscounted) [b]	214	465	611	746

Notes:
[a] Values used in Methods A & B
[b] Values used in Method A, calculated at a 3% discount rate
[c] Includes mild hybrids (ISG) and strong HEVs.

Table 10-50 Summary of Impacts on Ford by 2030 in the HD Pickup and Van Market versus the Dynamic Baseline, Alternative 1b

ANNUAL STRINGENCY INCREASE	2.0%/Y	2.5%/Y	3.5%/Y	4.0%/Y
Stringency Increase Through MY	2025	2027	2025	2025
Average Fuel Economy (miles per gallon)				
Required	19.42	20.96	20.92	21.51
Achieved	19.5	21.04	21.28	21.8
Average Fuel Consumption (gallons /100 mi.)				
Required	5.15	4.77	4.78	4.65
Achieved	5.13	4.75	4.70	4.59
Average Greenhouse Gas Emissions (g/mi)				
Required	485	449	450	438
Achieved	482	447	443	433
Technology Penetration (%)				
VVT and/or VVL	34	34	34	34
Cylinder Deac.	18	0	0	0
Direct Injection	16	34	34	34
Turbocharging	51	69	69	69
8-Speed AT	100	100	100	100
EPS, Accessories	41	62	59	59
Stop Start	0	0	20	29
Hybridization[c]	0	2	14	30
Aero. Improvements	0	59	59	59
Mass Reduction (vs. No-Action)				
CW (lb.)	210	202	379	356
CW (%)	3.2	3	5.7	5.3
Technology Cost (vs. No-Action)				
Average ($) [a]	506	1,110	1,353	1,801
Total ($m, undiscounted) [b]	170	372	454	604

Notes:
[a] Values used in Methods A & B
[b] Values used in Method A, calculated at a 3% discount rate
[c] Includes mild hybrids (ISG) and strong HEVs.

Table 10-51 Summary of Impacts on Fiat Chrysler by 2030 in the HD Pickup and Van Market versus the Dynamic Baseline, Alternative 1b

ANNUAL STRINGENCY INCREASE	2.0%/Y	2.5%/Y	3.5%/Y	4.0%/Y
Stringency Increase Through MY	2025	2027	2025	2025
Average Fuel Economy (miles per gallon)				
Required	18.73	20.08	20.12	20.70
Achieved	18.83	20.06	20.10	20.70
Average Fuel Consumption (gallons /100 mi.)				
Required	5.34	4.98	4.97	4.83
Achieved	5.31	4.99	4.97	4.83
Average Greenhouse Gas Emissions (g/mi)				
Required	515	480	479	466
Achieved	512	481	480	467
Technology Penetration (%)				
VVT and/or VVL	40	40	40	40
Cylinder Deac.	23	23	23	23
Direct Injection	17	17	17	17
Turbocharging	74	74	74	74
8-Speed AT	65	88	88	88
EPS, Accessories	0	100	100	100
Stop-Start	0	0	0	0
Hybridization[c]	0	3	3	10
Aero. Improvements	0	100	100	100
Mass Reduction (vs. No-Action)				
CW (lb.)	196	649	648	617
CW (%)	2.8	9.1	9.1	8.7
Technology Cost (vs. No-Action)				
Average ($) [a]	434	1,469	1,486	1,700
Total ($m, undiscounted) [b]	48	163	164	188

Notes:
[a] Values used in Methods A & B
[b] Values used in Method A, calculated at a 3% discount rate
[c] Includes mild hybrids (ISG) and strong HEVs.

The fuel consumption and GHG standards require manufacturers to achieve an average level of compliance, represented by a sales-weighted average across the specific targets of all vehicles offered for sale in a given model year, such that each manufacturer will have a unique required consumption/emissions level determined by the composition of its fleet, as illustrated above. However, there are more interesting differences than the small differences in required fuel economy levels among manufacturers. In particular, the average incremental technology cost increases with the stringency of the alternative for each manufacturer, but the size of the cost increase from one alternative to the next varies among them, with General Motors showing considerably larger increases in cost moving from Alternative 3 to Alternative 4 than from either Alternative 2 to Alternative 3 or Alternative 4 to Alternative 5. Ford is estimated to have more uniform cost increases from each alternative to the next, in increasing stringency, though still benefits from the reduced pace and longer period of increase associated with Alternative 3 compared to Alternative 4..

The Method B simulation results show all three manufacturers facing cost increases when the stringency of the standards move from 2.5 percent annual increases over the period from MY 2021 – 2027 to 3.5 percent annual increases from MY 2021 - 2025, but General Motors has the largest at 75 percent more than the industry average price increase for Alternative 4. GM also faces higher cost increases in Alternative 2, about 50 percent more than either Ford or Fiat/Chrysler. And for the most stringent alternative considered, EPA estimates that General Motors will face average cost increases of more than $2,700, in addition to the more than $700 increase in the baseline – approaching nearly $3,500 per vehicle over today’s prices.

Technology choices also differ by manufacturer, and some of those decisions are directly responsible for the largest cost discrepancies. For example, in this Method B analysis, GM is estimated to engage in the least amount of mass reduction among the Big 3 after Phase 1, and much less than Chrysler/Fiat, but reduces average vehicle mass by over 300 pounds in the baseline – suggesting that some of GM’s easiest Phase 1 compliance opportunities can be found in lightweighting technologies. Similarly, Fiat Chrysler is projected to apply less hybridization than the others, and much less than General Motors, which is simulated in Alternative 4 to have full hybrids (either integrated starter generator or complete hybrid system) on all of its fleet by 2030, nearly 20 percent of which will be strong hybrids. . Because the analysis applies the same technology inputs and the same logic for selecting among available opportunities to apply technology, the unique situation of each manufacturer determined which technology path is projected as the most cost-effective.

In order to understand the differences in incremental technology costs and fuel economy achievement across manufacturers in this market segment, it is important to understand the differences in their starting position relative to these standards. One important factor, made more obvious in the following figures, is the difference between the fuel economy and performance of the recently redesigned vans offered by Fiat Chrysler and Ford (the Promaster and Transit, respectively), and the more traditionally-styled vans that continue to be offered by General Motors (the Express/Savannah). In MY 2014, Ford began the phase-out of the Econoline van platform, moving those volumes to the Euro-style Transit vans. The Transit platform represents a significant improvement over the existing Econoline platform from the perspective of fuel economy, and for the purpose of complying with the standards, the relationship between the Transit’s work factor and fuel economy is a more favorable one than the Econoline vans it replaces. Since the redesign of van offerings from both Fiat Chrysler and Ford occur in (or prior to) the 2014 model year, the costs, fuel consumption improvements, and reductions of vehicle mass associated with those redesigns are included in the analysis fleet, meaning they are not carried forward as part of the compliance modeling exercise. By contrast, General Motors is simulated to redesign their van offerings after 2014, such that there is a greater potential for these vehicles to incur additional costs attributable to new standards, unlike the costs associated with the recent redesigns of their competitors. The inclusion of these new Ford and Fiat Chrysler products in the analysis fleet is the primary driver of the cost discrepancy between GM and its competitors in both the baseline and Alternative 2 in this Method B analysis, when Ford and Fiat Chrysler have to apply considerably less technology to achieve compliance.

The remaining 5 percent of the 2b/3 market is attributed to two manufacturers, Daimler and Nissan, which, unlike the other manufacturers in this market segment, only produce vans. The vans offered by both manufacturers currently utilize two engines and two transmissions, although both Nissan engines are gasoline engines and both Daimler engines are diesels. Despite the logical grouping, these two manufacturers are projected to be impacted much differently by these standards. For the least stringent alternative considered, Daimler is projected to add no technology and incurs no incremental cost in order to comply with the standards. At stringency increases greater than or equal to 3.5 percent per year, Daimler only really improves some of their transmissions and improves the electrical accessories of its Sprinter vans. By contrast, Nissan's starting position is much weaker and their compliance costs closer to the industry average in Table 10-48. This difference could increase if the analysis fleet supporting the final rule includes forthcoming Nissan HD pickups.

Table 10-52 Summary of Impacts on Daimler by 2030 in the HD Pickup and Van Market versus the Dynamic Baseline, Alternative 1b

ANNUAL STRINGENCY INCREASE	2.0%/Y	2.5%/Y	3.5%/Y	4.0%/Y
Stringency Increase Through MY	2025	2027	2025	2025
Average Fuel Economy (miles per gallon)				
Required	23.36	25.19	25.25	25.91
Achieved	25.23	25.79	25.79	26.53
Average Fuel Consumption (gallons /100 mi.)				
Required	4.28	3.97	3.96	3.86
Achieved	3.96	3.88	3.88	3.77
Average Greenhouse Gas Emissions (g/mi)				
Required	436	404	404	393
Achieved	404	395	395	384
Technology Penetration (%)				
VVT and/or VVL	0	0	0	0
Cylinder Deac.	0	0	0	0
Direct Injection	0	0	0	0
Turbocharging	44	44	44	44
8-Speed AT	0	44	44	100
EPS, Accessories	0	0	0	0
Stop-Start	0	0	0	0
Hybridization[c]	0	0	0	0
Aero. Improvements	0	0	0	0
Mass Reduction (vs. No-Action)				
CW (lb.)	0	0	0	0
CW (%)	0	0	0	0
Technology Cost (vs. No-Action)				
Average ($) [a]	0	165	165	374
Total ($m, undiscounted) [b]	0	4	4	9

Notes:
[a] Values used in Methods A & B
[b] Values used in Method A, calculated at a 3% discount rate
[c] Includes mild hybrids (ISG) and strong HEVs.

Table 10-53 Summary of Impacts on Nissan by 2030 in the HD Pickup and Van Market versus the Dynamic Baseline, Alternative 1b

ANNUAL STRINGENCY INCREASE	2.0%/Y	2.5%/Y	3.5%/Y	4.0%/Y
Stringency Increase Through MY	2025	2027	2025	2025
Average Fuel Economy (miles per gallon)				
Required	19.64	21.19	20.92	21.46
Achieved	19.84	21.17	21.19	21.51
Average Fuel Consumption (gallons /100 mi.)				
Required	5.09	44.72	4.78	4.66
Achieved	5.04	4.72	4.72	4.65
Average Greenhouse Gas Emissions (g/mi)				
Required	452	419	425	414
Achieved	448	419	419	413
Technology Penetration (%)				
VVT and/or VVL	100	100	100	100
Cylinder Deac.	49	49	49	49
Direct Injection	51	51	51	100
Turbocharging	51	51	51	50
8-Speed AT	0	51	51	51
EPS, Accessories	0	100	100	100
Stop-Start	0	0	0	0
Hybridization[c]	0	0	0	28
Aero. Improvements	0	100	100	100
Mass Reduction (vs. No-Action)				
CW (lb.)	0	0	307	303
CW (%)	0	0	5	4.9
Technology Cost (vs. No-Action)				
Average ($) [a]	378	1,150	1,347	1,935
Total ($m, undiscounted) [b]	5	15.1	17.7	25.4

Notes:
[a] Values used in Methods A & B
[b] Values used in Method A, calculated at a 3% discount rate
[c] Includes mild hybrids (ISG) and strong HEVs.

As Table 10-52 and Table 10-53 show, Nissan is projected to apply more technology than Daimler in the less stringent alternatives and significantly more technology with increasing stringency. The Euro-style Sprinter vans that comprise all of Daimler's model offerings in this segment put Daimler in a favorable position. However, those vans are already advanced – containing downsized diesel engines and advanced aerodynamic profiles. Much like the Ford Transit vans, the recent improvements to the Sprinter vans occurred outside the scope of the compliance modeling so the costs of the improvements are not captured in the analysis.

Although Daimler's required fuel economy level is much higher than Nissan's (in miles per gallon), Nissan starts from a much weaker position than Daimler and must incorporate additional engine, transmission, platform-level technologies (e.g. mass reduction and aerodynamic improvements) in order to achieve compliance. In fact, more than 25 percent of Nissan's van offerings are projected to contain integrated starter generators by 2030 in Alternative 5.

References

[1] RTI International, "Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers," February 2009; EPA-420-R-09-003; http://www3.epa.gov/otaq/ld-hwy/420r09003.pdf.
[2] Rogozhin, A., et al., "Using indirect cost multipliers to estimate the total cost of adding new technology in the automobile industry," International Journal of Production Economics (2009), doi:10.1016/j.ijpe.2009.11.031.
[3] 80 FR 40137.

Chapter 11: Results of the Preferred and Alternative Standards

The heavy-duty truck segment is very complex. The sector consists of a diverse group of impacted parties, including engine manufacturers, chassis manufacturers, truck manufacturers, trailer manufacturers, truck fleet owners and the public. The standards are largely shaped to optimize the environmental and fuel savings benefits of the program, while balancing the relevant statutory factors and respecting the unique and varied nature of the sector. In developing this rulemaking, we considered a number of alternatives that could result in fewer or potentially greater GHG and fuel consumption reductions than the preferred alternative. This section summarizes the alternatives we considered and presents assessments of CO_2 reductions and fuel savings associated with each alternative. See the Preamble for a discussion of how the agencies balanced the relevant statutory factors to select the preferred alternative (in this action, the “final program”).

For this final rulemaking, the agencies used two analyses by employing both DOT’s CAFE model and EPA’s MOVES model. These models were used to project fuel consumption and GHG emissions impacts resulting from the standards. The agencies used EPA’s MOVES model to estimate fuel consumption and emissions impacts for tractor-trailers (including the engines which power the vehicle), and vocational vehicles (including the engine which powers the vehicle). For heavy-duty pickups and vans, the agencies performed separate analyses using the CAFE model (“Method A”) and the MOVES model (“Method B”) to estimate fuel consumption and emissions from these vehicles. For these methods, the agencies analyzed the impact of the final rules, relative to two different reference cases – ”flat” (Alternative 1a) and “dynamic” (Alternative 1b). The flat baseline projects very little improvement in new vehicles in the absence of new Phase 2 standards. In contrast, the dynamic baseline projects more improvements in vehicle fuel efficiency. See Chapter 5 for the discussion of the EPA’s MOVES model (which was used for both methods) and Chapter 10 for the discussion of the DOT’s CAFE model (which was used for Method A).

11.1 What Are the Alternatives that the Agencies Considered?

The five alternatives below represent a broad range of potential stringency levels, and thus a broad range of associated technologies, costs and benefits for a HD vehicle fuel efficiency and GHG emissions program.

In developing alternatives, NHTSA must consider EISA's requirement for the MD/HD fuel efficiency program noted above. 49 U.S.C. 32902(k)(2) and (3) contain the following three requirements specific to the MD/HD vehicle fuel efficiency improvement program: (1) The program must be “designed to achieve the maximum feasible improvement;” (2) the various required aspects of the program must be appropriate, cost-effective, and technologically feasible for MD/HD vehicles; and (3) the standards adopted under the program must provide not less than four model years of lead time and three model years of regulatory stability. In considering these various requirements, NHTSA will also account for relevant environmental and safety considerations.

Each of the alternatives presented by NHTSA and EPA represents, in part, a different way the agencies could establish a HD program pursuant to EISA and the CAA. The agencies are finalizing the Alternative 3 standards. The alternatives below represent a broad range of approaches under consideration for finalizing the HD vehicle fuel efficiency and GHG emissions standards.

Chapters 11.1.1 through 11.2 summarize the alternatives that were analyzed and how they were modeled.

11.1.1 Alternative 1: No Action (the Baseline for Phase 2)

OMB guidance regarding regulatory analysis indicates that proper evaluation of the benefits and costs of regulations and their alternatives requires agencies to identify a baseline:

> *"You need to measure the benefits and costs of a rule against a baseline. This baseline should be the best assessment of the way the world would look absent the proposed action. The choice of an appropriate baseline may require consideration of a wide range of potential factors, including:*
>
> *• evolution of the market*
>
> *• changes in external factors affecting expected benefits and costs*
>
> *• changes in regulations promulgated by the agency or other government entities*
>
> *• degree of compliance by regulated entities with other regulations*
>
> *It may be reasonable to forecast that the world absent the regulation will resemble the present. If this is the case, however, your baseline should reflect the future effect of current government programs and policies. For review of an existing regulation, a baseline assuming no change in the regulatory program generally provides an appropriate basis for evaluating regulatory alternatives. When more than one baseline is reasonable and the choice of baseline will significantly affect estimated benefits and costs, you should consider measuring benefits and costs against alternative baselines. In doing so you can analyze the effects on benefits and costs of making different assumptions about other agencies' regulations, or the degree of compliance with your own existing rules. In all cases, you must evaluate benefits and costs against the same baseline. You should also discuss the reasonableness of the baselines used in the sensitivity analyses. For each baseline you use, you should identify the key uncertainties in your forecast."*[1]

A no-action alternative is also required as a baseline against which to measure environmental impacts of the standards and alternatives. NHTSA, as required by the National Environmental Policy Act, is documenting these estimated impacts in the EIS published with this FRM.[2]

The No Action Alternative for today's analysis, alternatively referred to as the "baseline" or "reference case," assumes that the agencies do not issue new rules regarding MD/HD fuel efficiency and GHG emissions. That is, this alternative assumes that the Phase 1 MD/HD fuel efficiency and GHG emissions program's model year 2018 standards would be extended indefinitely and without change.

The agencies recognize that there are a number of factors that create uncertainty in projecting a baseline against which to compare the future effects of the alternatives. The composition of the future fleet—such as the relative position of individual manufacturers and the mix of products they each offer—cannot be predicted with certainty at this time. As reflected, in part, by the market forecast underlying the agencies' analysis, we anticipate that the baseline market for medium- and heavy-duty vehicles will continue to evolve within a competitive market that responds to a range of factors. Additionally, the heavy-duty vehicle market is diverse, as is the range of vehicle purchasers.

Heavy-duty vehicle manufacturers have reported that their customers' purchasing decisions are influenced by their customers' own determinations of minimum total cost of ownership, which can be unique to a particular customer's circumstances. For example, some customers (e.g., less-than-truckload or package delivery operators) operate their vehicles within a limited geographic region and typically own their own vehicle maintenance and repair centers within that region. These operators tend to own their vehicles for long time periods, and sometimes for the entire service life of the vehicle. Their total cost of ownership is influenced by their ability to better control their own maintenance costs, and thus they can afford to consider fuel efficiency technologies that have longer payback periods, outside of the vehicle manufacturer's warranty period. Other customers (e.g. truckload or long-haul operators) tend to operate cross-country, and thus must depend upon truck dealer service centers for repair and maintenance. Some of these customers tend to own their vehicles for about four to seven years, so that they typically do not have to pay for repair and maintenance costs outside of either the manufacturer's warranty period or some other extended warranty period. Many of these customers tend to require seeing evidence of fuel efficiency technology payback periods on the order of 18 to 24 months before seriously considering evaluating a new technology for potential adoption within their fleet (NAS 2010, Roeth et al. 2013, Klemick et al. 2014). Purchasing decisions, however, are not based exclusively on payback period, but also include the considerations discussed in this section. For the baseline analysis, the agencies use payback period as a proxy for all of these considerations, and therefore the payback period used for the baseline analysis may be shorter than the payback period industry uses as a threshold for the further consideration of a technology.

Some owners accrue relatively few vehicle miles traveled per year, such that they may be less likely to adopt new fuel efficiency technologies, while other owners who use their vehicle(s) with greater intensity may be even more willing to pay for fuel efficiency improvements. Regardless of the type of customer, their determination of minimum total cost of ownership involves the customer balancing their own unique circumstances with a heavy-duty vehicle's initial purchase price, availability of credit and lease options, expectations of vehicle reliability, resale value and fuel efficiency technology payback periods. The degree of the incentive to adopt additional fuel efficiency technologies also depends on customer expectations of future fuel prices, which directly impacts customer expectations of the payback period.

Another factor the agencies considered is that other federal and state-level policies and programs are specifically aimed at stimulating fuel efficiency technology development and deployment. Particularly relevant to this sector are DOE's 21st Century Truck Partnership, EPA's voluntary SmartWay Transport program, and California's AB32 fleet requirements.[3,4,5] The future availability of more cost-effective technologies to reduce fuel consumption could provide manufacturers an incentive to produce more fuel-efficient medium- and heavy-duty vehicles, which in turn could provide customers an incentive to purchase these vehicles. The availability of more cost-effective technologies to reduce fuel consumption could also lead to a substitution of less cost-effective technologies, where overall fuel efficiency could remain fairly flat if buyers are less interested in fuel consumption improvements than in reduced vehicle purchase prices and/or improved vehicle performance and/or utility.

We have also applied the EIA's AEO estimates of future fuel prices; however, heavy-duty vehicle customers could have different expectations about future fuel prices, and could therefore be more inclined or less inclined to apply new technology to reduce fuel consumption than might be expected based on EIA's forecast. We expect that vehicle customers will be uncertain about future fuel prices, and that this uncertainty will be reflected in the degree of enthusiasm to apply new technology to reduce fuel consumption.

Considering all of these factors, the agencies have approached the definition of the No Action Alternative separately for each vehicle and engine category covered by today's rule. Except as noted below, these baselines are largely the same as the proposed Alternatives 1a and 1b.

For trailers, the agencies considered two No Action alternatives to cover a nominal range of uncertainty. The trailer category is unique in the context of this rulemaking because it is the only heavy-duty category not regulated under Phase 1. The agencies project that in 2018, about half of new 53' dry van and reefer trailers will have technologies qualifying for the SmartWay label for aerodynamic improvements and about 90 percent would have the lower rolling resistance tires. About half also have automatic tire inflation systems to maintain optimal tire pressure. For Alternative 1a as presented in this action (referred to as the "flat" baseline), this technology adoption remains constant after 2018. In the second case, Alternative 1b, the agencies projected that the combination of EPA's voluntary SmartWay program, DOE's 21st Century Truck Partnership, California's AB32 trailer requirements for fleets, and the potential for significantly reduced operating costs should result in continuing improvement to new trailers. The agencies projected that the fraction of the in-use fleet qualifying for SmartWay will continue to increase beyond 2027 as older trailers are replaced by newer trailers. We projected that these improvements will continue until 2040 when 75 percent of new trailers will be assumed to include skirts.

For vocational vehicles, the agencies considered one No Action alternative. For the vocational vehicle category the agencies recognized that these vehicles tend to operate over fewer vehicle miles travelled per year. Therefore, the projected payback periods for fuel efficiency technologies available for vocational vehicles are generally longer than the payback periods the agencies consider likely to lead to their adoption based solely on market forces. This is especially true for vehicles used in applications in which the vehicle operation is secondary to the primary business of the company using the vehicle. For example, since the fuel consumption of vehicles used by utility companies to repair power lines would generally be a smaller cost relative to the other costs of repairing lines, fuel saving technologies would generally not be as strongly demanded for such vehicles. Thus, the agencies project that fuel-saving technologies will either not be applied or will only be applied as a substitute for more expensive fuel efficiency technologies, except as necessitated by the Phase 1 fuel consumption and GHG standards.

For tractors, the agencies considered two No Action alternatives to cover a nominal range of uncertainty. For Alternative 1a the agencies project that fuel-saving technologies will either not be applied or will only be applied as a substitute for more expensive fuel efficiency technologies to tractors (thereby enabling manufacturers to offer tractors that are less expensive to purchase), except as necessitated by the Phase 1 fuel consumption and GHG standards. In Alternative 1b the agencies estimated that some available technologies will save enough fuel to pay back fairly quickly – within the first six months of ownership. The agencies considered a range of information to formulate these two baselines for tractors.

Both public[6] and confidential historical information shows that tractor trailer fuel efficiency improved steadily through improvements in engine efficiency and vehicle aerodynamics over the past 40 years, except for engine efficiency which decreased or was flat between 2000 and approximately 2007 as a consequence of incorporating technologies to meet engine emission regulations. Today vehicle manufacturers, the Federal Government, academia and others continue to invest in research to develop fuel efficiency improving technologies for the future.

In public meetings and in meetings with the agencies, the trucking industry stated that fuel cost for tractors is the number one or number two expense for many operators, and therefore is a very important factor for their business. However, the pre-Phase 1 market suggests that, tractor manufacturers and operators could be slow to adopt some new technologies, even where the agencies have estimated that the technology would have paid for itself within a few months of operation. Tractor operators have told the agencies they generally require technologies to be demonstrated in their fleet before widespread adoption so they can assess the actual fuel savings for their fleet and any increase in cost associated with effects on vehicle operation, maintenance, reliability, mechanic training, maintenance and repair equipment, stocking unique parts and driver acceptance, as well as effects on vehicle resale value. Tractor operators often state that they would consider conducting an assessment of technologies when provided with data that show the technologies may payback costs through fuel savings within 18 to 24 months, based on their assumptions about future fuel costs. In these cases, an operator may first conduct a detailed paper study of anticipated costs and benefits. If that study shows likely payback in 18 to 24 months for their business, the fleet may acquire one or several tractors with the technology to directly measure fuel savings, costs and driver acceptance for their fleet. Small fleets may not have resources to conduct assessments to this degree and may rely on information from larger fleets or observations of widespread acceptance of the technology within the industry before adopting a technology. This uncertainty over the actual fuel savings and costs and the lengthy process to assess technologies significantly slows the pace at which fuel efficiency technologies are adopted.

The agencies believe that using the two baselines addresses the uncertainties we have identified for tractors. The six-month payback period of Alternative 1b reflects the agencies' consideration of factors, discussed above, that could limit—yet not eliminate—manufacturers' tendencies to voluntarily improve fuel consumption. In contrast, Alternative 1a reflects a baseline for vehicles other than trailers wherein manufacturers either do not apply fuel efficiency technologies or only apply them as a substitute for more expensive fuel efficiency technologies, except as necessitated by the Phase 1 fuel consumption and GHG standards.

For HD pickups and vans, the agencies considered two No Action alternatives to cover a nominal range of uncertainty: a flat baseline (designated Alternative 1a) where no improvements are modeled beyond those needed to meet Phase 1 standards and a dynamic baseline (designated Alternative 1b) where certain cost-effective technologies (i.e., those that payback within a 6 month period) are assumed to be applied by manufacturers to improve fuel efficiency beyond the Phase 1 requirements in the absence of new Phase 2 standards. In Alternative 1b the agencies considered additional technology application, which involved the explicit estimation of the potential to add specific fuel-saving technologies to each specific vehicle model included in the agencies' HD pickup and van fleet analysis, as discussed in Section VI of the Preamble. Estimated technology application and corresponding impacts depend on the modeled inputs. Also, under this approach a manufacturer that has improved fuel consumption and GHG emissions enough to achieve compliance with the standards is assumed to apply further improvements, provided those improvements reduce fuel outlays by enough (within a specified amount of time, the payback period) to offset the additional costs to purchase the new vehicle. These calculations explicitly account for and respond to fuel prices, vehicle survival and mileage accumulation, and the cost and efficacy of available fuel-saving technologies. Therefore, all else being equal, more technology is applied when fuel prices are higher and/or technology is more cost-effective. However, considering factors discussed above that could limit manufacturers' tendency to voluntarily improve HD pickup and van fuel consumption, Alternative 1b applies a 6-month payback period. In contrast, for Alternative 1a the agencies project that fuel-saving technologies would either not be applied or only be applied as a substitute for more expensive fuel efficiency technologies, except as necessitated by the Phase 1 fuel consumption and GHG standards. In terms of impacts under reference case fuel prices, the payback period input plays a more significant role under the No-Action Alternatives (defined by a continuation of model year 2018 standards) than under the more stringent regulatory alternatives for HD pickups and vans described next.

11.1.1.1 Alternative 1a

For an explanation of analytical Methods A and B identified in some of the following tables, please see Section I.D of the Preamble; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1 of the Preamble. The estimated reductions in energy rates[A] used in MOVES for Alternative 1a are presented in Table 11-1.

The projected use of diesel-powered auxiliary power units (APUs) during extended idling for Alternative 1a is presented in Table 11-2. The reductions in aerodynamic and tire rolling

[A] Note that the "reductions in energy rates" for tractors and vocational vehicles reflect changes in CO_2 emissions not represented by tire rolling resistance, aerodynamic drag, or vehicle weight.

resistance coefficients, and the absolute changes in average vehicle weight modeled in MOVES for Alternative 1a are presented in Table 11-3. Chapter 10 discusses the agencies' use of the CAFE model in greater detail.

Table 11-1 Estimated Reductions in Energy Rates for Alternative 1a using Analysis Method B [a]

VEHICLE TYPE	FUEL	MODEL YEARS	FUEL/CO_2 REDUCTION
Long-haul Tractor-Trailer and HHD Vocational	Diesel	2018+	0.4%
Short-haul Tractor-Trailer and HHD Vocational	Diesel	2018+	0 %
Single-Frame Vocational[b]	Diesel and CNG	2021-2023	0%
		2024+	0%
	Gasoline	2021-2023	0%
		2024+	0%
HD Pickup Trucks and Vans	Diesel and Gasoline	2021	0%
		2022	0%
		2023	0%
		2024	0%
		2025+	0%

Notes:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.
[b] Vocational vehicles modeled in MOVES include heavy heavy-duty, medium heavy-duty, and light heavy-duty vehicles. However, for light heavy-duty vocational vehicles, class 2b and 3 vehicles are not included in the inventories for the vocational sector. Instead, all vehicles with GVWR of less than 14,000 lbs were modeled using the energy rate reductions described below for HD pickup trucks and vans. In practice, many manufacturers of these vehicles choose to average the lightest vocational vehicles into chassis-certified families (i.e., heavy-duty pickups and vans).

Table 11-2 Assumed Diesel APU Use during Extended Idling for Combination Long-haul Tractor-Trailers for Alternative 1a

VEHICLE TYPE	MODEL YEARS	DIESEL APU PENETRATION
Combination Long-Haul Tractors	2010+	9%

Table 11-3 Estimated Reductions in Road Load Factors for Alternative 1a

VEHICLE TYPE	MODEL YEARS	REDUCTION IN TIRE ROLLING RESISTANCE COEFFICIENT	REDUCTION IN AERODYNAMIC DRAG COEFFICIENT	WEIGHT REDUCTION (LB)[a]
Combination Long-haul Tractor-Trailers	2018-2020	5.7%	2.8%	-69
	2021-2023	5.7%	2.8%	-69
	2024-2026	5.7%	2.8%	-69
	2027+	5.7%	2.8%	-69
Combination Short-haul Tractor-Trailers[b]	2018-2020	0.9%	0%	0
	2021-2023	0.9%	0%	0
	2024-2026	0.9%	0%	0
	2027+	0.9%	0%	0
Intercity Buses	2021-2023	0%	0%	0
	2024+	0%	0%	0
Transit and School Buses	2021-2023	0%	0%	0
	2024+	0%	0%	0
Refuse Trucks	2021-2023	0%	0%	0
	2024+	0%	0%	0
Single Unit Short-haul Trucks	2021-2023	0%	0%	0
	2024+	0%	0%	0
Single Unit Long-haul Trucks	2021-2023	0%	0%	0
	2024+	0%	0%	0
Motor Homes	2021-2023	0%	0%	0
	2024+	0%	0%	0

Notes:
[a] Negative weight reductions reflect an expected weight increase as a byproduct of the other vehicle and engine improvements.
[b] Vocational tractors are included in the short-haul tractor segment.

11.1.1.2 Alternative 1b

The estimated reductions in energy rates used in MOVES and the projected use of auxiliary power units (APUs) during extended idling for Alternative 1b are presented in Table 11-4 and Table 11-5, respectively. The reductions in aerodynamic and tire rolling resistance coefficients, and the absolute changes in average vehicle weight are presented in Table 11-6.

Table 11-4 Estimated Reductions in Energy Rates for Alternative 1b using Analysis Method B [a]

VEHICLE TYPE	FUEL	MODEL YEARS	FUEL/CO_2 REDUCTION
Long- and Short-Haul Tractor-Trailer and HHD Vocational	Diesel	2018+	0%
Single-Frame Vocational[b]	Diesel and CNG	2021+	0%
	Gasoline	2021+	0%
HD pickup trucks and vans	Diesel and Gasoline	2017	0.60%
		2018	0.79%
		2019	1.11%
		2020	1.13%
		2021	1.74%
		2022	2.41%
		2023	2.44%
		2024	2.47%
		2025	2.48%
		2026	2.43%
		2027	2.51%
		2028	2.53%
		2029	2.55%

Notes:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.
[b] Vocational vehicles modeled in MOVES include heavy heavy-duty, medium heavy-duty, and light heavy-duty vehicles. However, for light heavy-duty vocational vehicles, class 2b and 3 vehicles are not included in the inventories for the vocational sector. Instead, all vehicles with GVWR of less than 14,000 lbs were modeled using the energy rate reductions described below for HD pickup trucks and vans. In practice, many manufacturers of these vehicles choose to average the lightest vocational vehicles into chassis-certified families (i.e., heavy-duty pickups and vans).

Table 11-5 Assumed Diesel APU Use during Extended Idling for Combination Long-haul Tractor-Trailers for Alternative 1b

VEHICLE TYPE	MODEL YEARS	DIESEL APU PENETRATION
Combination Long-Haul Tractors	2010+	9%

Table 11-6 Estimated Reductions in Road Load Factors for Alternative 1b

TRUCK TYPE	MODEL YEARS	REDUCTION IN TIRE ROLLING RESISTANCE COEFFICIENT	REDUCTION IN AERODYNAMIC DRAG COEFFICIENT	WEIGHT REDUCTION (LB)[a]
Combination Long-haul Tractor-Trailers	2018	5.7%	2.8%	-69
	2019	5.9%	3.5%	-71
	2020	6.2%	4.1%	-74
	2021	6.4%	4.8%	-76
	2022	6.7%	5.4%	-78
	2023	6.9%	6.1%	-81
	2024	7.1%	6.7%	-83
	2025	7.4%	7.4%	-88
	2026	7.6%	8.1%	-92
	2027	7.9%	8.7%	-97
	2028	8.1%	10.1%	-105
Combination Short-haul Tractor-Trailers[b]	2018	0.9%	0.0%	0
	2019	1.2%	0.5%	0
	2020	1.5%	1.0%	0
	2021	1.8%	1.4%	0
	2022	2.1%	1.9%	0
	2023	2.4%	2.4%	0
	2024	2.7%	2.9%	0
	2025	3.0%	3.4%	0
	2026	3.2%	3.8%	0
	2027	3.5%	4.3%	0
	2028	3.8%	4.8%	0
Intercity Buses	2021-2023	0%	0%	0
	2024+	0%	0%	0
Transit and School Buses	2021-2023	0%	0%	0
	2024+	0%	0%	0
Refuse Trucks	2021-2023	0%	0%	0
	2024+	0%	0%	0
Single Unit Short-haul Trucks	2021-2023	0%	0%	0
	2024+	0%	0%	0
Single Unit Long-haul Trucks	2021-2023	0%	0%	0
	2024+	0%	0%	0
Motor Homes	2021-2023	0%	0%	0
	2024+	0%	0%	0

Notes:
[a] Negative weight reductions reflect an expected weight increase as a byproduct of the other vehicle and engine improvements.
[b] Vocational tractors are included in the short-haul tractor segment.

11.1.2 Alternative 2: Less Stringent than the Preferred Alternative

For vocational vehicles and combination tractor-trailers, Alternative 2 represents a stringency level which is approximately half as stringent overall as the final standards. The agencies developed Alternative 2 to reflect a continuation of the Phase 1 approach of– applying off-the-shelf technologies rather than requiring the development of new technologies or fundamental improvements to existing technologies. For tractors and vocational vehicles, this also involved less integrated optimization of the vehicles and engines. Alternative 2 would not set standards for MY 2027.

The agencies' decisions regarding which technologies could be applied to comply with Alternative 2 considered not only assuming the use of off-the shelf technologies, but also considered other factors, as well, such as how broadly certain technologies fit in-use applications and regulatory structure. The resulting Alternative 2 could be met with fewer technologies and lower penetration rates than those the agencies project will be used to meet the final Phase 2 standards. Alternative 2 is estimated to be achievable without the application of some technologies, at any level. These and other differences are described below by category. Overall, Alternative 2 for the final rules is conceptually similar to Alternative 2 in the NPRM. However, some changes have been made to reflect new information provided in public comments.

The agencies project that Alternative 2 combination tractor standards could be met by applying lower adoption rates of the projected technologies for Alternative 3. This includes a projection of slightly lower per-technology effectiveness for Alternative 2 versus 3. Alternative 2 also assumes that there would be little optimization of combination tractor powertrains.

The Alternative 2 for vocational vehicles assessed for these final rules does differ somewhat from the proposal because it reflects new duty cycles that weight idle emissions more heavily. The agencies project that the Alternative 2 vocational vehicle standard could be met without any use of strong hybrids or any other type of transmission technology. Rather, it could be met with off-the-shelf idle reduction technologies, low rolling resistance tires, and axle efficiency improvements.

The Alternative 2 trailer standards would apply to only 53-foot dry and refrigerated box trailers and could be met through the use of less effective aerodynamic technologies and higher rolling resistance tires versus what the agencies projected could be used to meet Alternative 3 (i.e. the final standards).

The HD pickup truck and van alternatives are characterized by an annual required percentage change (decrease) in the functions defining attribute-based targets for per-mile fuel consumption and GHG emissions. Under the HD pickup and van standards in Alternative 2 and each other alternative, a manufacturer's fleet would, setting aside any changes in production mix, be required to achieve average fuel consumption/GHG levels that increase in stringency every year relative to the standard defined for MY2018 (and held constant through 2020) that establishes fuel consumption/GHG targets for individual vehicles. A manufacturer's specific fuel consumption/GHG requirement is the sales-weighted average of the targets defined by the work-factor curve in each year. Therefore, although the alternatives involve steady increases in the functions defining the targets, stringency increases faced by any individual manufacturer may not be steady if changes in the manufacturer's product mix cause fluctuations in the average fuel consumption and GHG levels required of the manufacturer. See Section VI of the Preamble for additional discussion of this topic. Alternative 2 represents a 2.0 percent annual improvement in the target curve through 2025 in fuel consumption/GHG emissions relative to the work-factor curve in 2020. This would be 0.5 percent less stringent per year compared to the standards of Alternative 3 and would not increase in stringency for MYs 2026 or 2027. For HD pickups and vans the agencies project that most manufacturers could comply with the standards defining Alternative 2 by applying technologies similar to those that could be applied in order to comply with the final standards, but at lower application rates than could be necessitated by the standards.

The analytical inputs for Alternative 2 are shown in the following tables. The estimated reductions in energy rates used in MOVES and the projected use of auxiliary power units (APUs) during extended idling are presented in Table 11-7 and Table 11-8, respectively. The reductions in aerodynamic and tire rolling resistance coefficients, and the absolute changes in average vehicle weight are presented in Table 11-9.

Table 11-7 Estimated Reductions in CO_2 Emission Rates for Alternative 2 using Analysis Method B [a]

VEHICLE TYPE	FUEL	MODEL YEARS	FUEL/CO_2 REDUCTION
Long-haul Tractor-Trailer and HHD Vocational	Diesel	2018-2020	0.4%
		2021-2023	3.5%
		2024+	6.8%
Short-haul Tractor-Trailer and HHD Vocational	Diesel	2018-2020	0%
		2021-2023	3.0%
		2024+	6.5%
Single-Frame Vocational[b]	Diesel and CNG	2021-2023	4.0%
		2024+	7.6%
	Gasoline	2021-2023	2.9%
		2024+	4.7%
HD pickup trucks and vans	Diesel and Gasoline	2021	2.0%
		2022	3.96%
		2023	5.88%
		2024	7.76%
		2025+	9.61%

Notes:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.
[b] Vocational vehicles modeled in MOVES include heavy heavy-duty, medium heavy-duty, and light heavy-duty vehicles. However, for light heavy-duty vocational vehicles, class 2b and 3 vehicles are not included in the inventories for the vocational sector. Instead, all vehicles with GVWR of less than 14,000 lbs were modeled using the energy rate reductions described below for HD pickup trucks and vans. In practice, many manufacturers of these vehicles choose to average the lightest vocational vehicles into chassis-certified families (i.e., heavy-duty pickups and vans).

Table 11-8 Assumed Diesel APU Use during Extended Idling for Combination Long-haul Tractor-Trailers for Alternative 2

VEHICLE TYPE	MODEL YEARS	DIESEL APU PENETRATION
Combination Long-Haul Tractors	2010-2020	9%
	2021-2023	30%
	2024+	40%

Table 11-9 Estimated Reductions in Road Load Factors for Alternative 2

VEHICLE TYPE	MODEL YEARS	REDUCTION IN TIRE ROLLING RESISTANCE COEFFICIENT	REDUCTION IN AERODYNAMIC DRAG COEFFICIENT	WEIGHT REDUCTION (LB)[a]
Combination Long-haul Tractor-Trailers	2018-2020	6.0%	5.6%	-140
	2021-2023	7.5%	7.1%	-140
	2024+	8.5%	8.9%	-140
Combination Short-haul Tractor-Trailers[b]	2018-2020	0.9%	0%	0
	2021-2023	4.8%	0.9%	0
	2024+	5.5%	3.6%	0
Intercity Buses	2021-2023	6.5%	0%	0
	2024+	7.6%	0%	0
Transit and School Buses	2021-2023	0%	0%	0
	2024+	2.7%	0%	0
Refuse Trucks	2021-2023	0%	0%	0
	2024+	2.7%	0%	0
Single Unit Short-haul Trucks	2021-2023	4.8%	0%	0
	2024+	5.6%	0%	0
Single Unit Long-haul Trucks	2021-2023	6.5%	0%	0
	2024+	7.6%	0%	0
Motor Homes	2021-2023	3.0%	0%	0
	2024+	5.9%	0%	0

Notes:
[a] Negative weight reductions reflect an expected weight increase as a byproduct of the other vehicle and engine improvements.
[b] Vocational tractors are included in the short-haul tractor segment.

11.1.3 Alternative 3: Preferred Alternative and Standards

Alternative 3 represents the agencies' final program. This alternative consists of the final fuel efficiency and GHG standards for HD engines, HD pickup trucks and vans, Class 2b through Class 8 vocational vehicles, and Class 7 and 8 combination tractors. Details regarding modeling of this final program are included in Chapter 5 of this RIA as the control case (Chapter 5.3.2.3). Note that the impacts of the final program can be found in RIA Chapters 5, 6 and 8.

11.1.4 Alternative 4: Achieving Proposed Standards with Less Lead-Time

As indicated by its description in the title above, Alternative 4 represents standards that are effective on a more accelerated timeline in comparison to the timeline of in the proposed Alternative 3 standards. This alternative is unchanged from Alternative 4 in the proposal. The agencies believe that reanalyzing the same Alternative 4 provides a useful context for commenters who supported the proposed Alternative 4.

In the NPRM, Alternatives 3 and 4 were both designed to achieve similar fuel efficiency and GHG emission levels in the long term but with Alternative 4 being accelerated in its implementation timeline. Specifically, Alternative 4 reflects the same or similar standard stringency levels as the proposed Alternative 3, but 3 years sooner (2 years for heavy-duty pickups and vans), so that the final phase of the standards would occur in MY 2024, or (for heavy-duty pickups and vans) 2025.

The estimated reductions in energy rates used in MOVES and the projected use of auxiliary power units (APUs) during extended idling for Alternative 4 are presented in Table 11-10 and Table 11-11, respectively. The reductions in aerodynamic and tire rolling resistance coefficients, and the absolute changes in average vehicle weight are presented in Table 11-12.

Table 11-10 Estimated Reductions in Energy Rates for Alternative 4 using Analysis Method B [a]

VEHICLE TYPE	FUEL	MODEL YEARS	FUEL/CO_2 REDUCTION
Long-haul Tractor-Trailer and HHD Vocational	Diesel	2018-2020	1.3%
		2021-2023	6.6%
		2024+	10.4%
Short-haul Tractor-Trailer and HHD Vocational	Diesel	2018-2020	0.9%
		2021-2023	6.9%
		2024+	10.4%
Single-Frame Vocational[b]	Diesel and CNG	2021-2023	7.7%
		2024+	13.3%
	Gasoline	2021-2023	5.2%
		2024+	10.3%
HD pickup trucks and vans	Diesel and Gasoline	2021	3.50%
		2022	6.88%
		2023	10.14%
		2024	13.28%
		2025+	16.32%

Notes:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.
[b] Vocational vehicles modeled in MOVES include heavy heavy-duty, medium heavy-duty, and light heavy-duty vehicles. However, for light heavy-duty vocational vehicles, class 2b and 3 vehicles are not included in the inventories for the vocational sector. Instead, all vehicles with GVWR of less than 14,000 lbs were modeled using the energy rate reductions described below for HD pickup trucks and vans. In practice, many manufacturers of these vehicles choose to average the lightest vocational vehicles into chassis-certified families (i.e., heavy-duty pickups and vans).

Table 11-11 Assumed Diesel APU Use during Extended Idling for Combination Long-haul Tractor-Trailers for Alternative 4

VEHICLE TYPE	MODEL YEARS	DIESEL APU PENETRATION
Combination Long-Haul Tractors	2010-2020	9%
	2021-2023	80%
	2024+	90%

Table 11-12 Estimated Reductions in Road Load Factors for Alternative 4

VEHICLE TYPE	MODEL YEARS	REDUCTION IN TIRE ROLLING RESISTANCE COEFFICIENT	REDUCTION IN AERODYNAMIC DRAG COEFFICIENT	WEIGHT REDUCTION (LB)[a]
Combination Long-haul Tractor-Trailers	2018-2020	5.5%	5.1%	-131
	2021-2023	12.6%	19.3%	-246
	2024+	17.9%	26.9%	-304
Combination Short-haul Tractor-Trailers[b]	2018-2020	4.0%	1.6%	-41
	2021-2023	13.0%	11.6%	-100
	2024+	17.6%	15.9%	-127
Intercity Buses	2021-2023	6.5%	0%	0
	2024+	16.5%	0%	0
Transit Buses	2021-2023	0%	0%	0
	2024+	3.0%	0%	0
School Buses	2021-2023	0%	0%	0
	2024+	4.0%	0%	0
Refuse Trucks	2021-2023	0%	0%	20
	2024+	3.0%	0%	25
Single Unit Short-haul Trucks	2021-2023	4.8%	0%	5.8
	2024+	13.0%	0%	7
Single Unit Long-haul Trucks	2021-2023	6.5%	0%	20
	2024+	16.5%	0%	25
Motor Homes	2021-2023	3.0%	0%	0
	2024+	7.4%	0%	0

Notes:
[a] Negative weight reductions reflect an expected weight increase as a byproduct of the other vehicle and engine improvements.
[b] Vocational tractors are included in the short-haul tractor segment.

11.1.5 Alternative 5: More Stringent Standards

Alternative 5 represents even more stringent standards compared to Alternatives 3 and 4, as well as the same implementation timeline as Alternative 4. As discussed in the feasibility discussions in the Preamble, we are not adopting Alternative 5 because we cannot project that manufacturers can develop and introduce in sufficient quantities the technologies that could be used to meet Alternative 5 standards. We believe that for some or all of the categories, the Alternative 5 standards are technically infeasible within the lead time allowed. We have not fully estimated costs for this alternative for tractors and vocational vehicles because we believe that there would be such substantial additional costs related to pulling ahead the development of so many additional technologies that we cannot accurately predict these costs. We also believe this alternative could result in a decrease in the in-use reliability and durability of new heavy-duty vehicles and that we do not have the ability to accurately quantify the costs that would be associated with such problems. Instead we merely note that costs would be significantly greater than the estimated costs for Alternatives 3, assuming (against our view) that such standards would be feasible at all.

The tractor and vocational vehicle standards would be based on higher adoption rates of the projected technologies and higher effectiveness. In addition, it assumes some adoption of all-electric vocational vehicles.

The trailer standards in Alternative 5 are more stringent than Alternatives 3 and 4, but rely on the same technologies. The greater reductions would be projected to be achieved through a combination of slightly higher effectiveness and higher adoption rates.

The Alternative 5 HD pickup truck and van standards in Method B are based on more extensive use of mild and strong hybrid technology and its use by more manufacturers. The result would be that over half of the HD gasoline pickup fleet would need to incorporate some form of strong hybrid technology. If achievable, Alternative 5 would require the average pickup truck or van fuel consumption and GHG emissions to decrease by approximately 4.0 percent per year relative to Phase 1 for model years 2021, 2022, 2023, 2024 and 2025. This is more aggressive than Alternative 3 by 1.50 percent per year over the same model years. The estimated reductions in energy rates used in MOVES and the projected use of auxiliary power units (APUs) during extended idling for Alternative 5 are presented in Table 11-13 and Table 11-14, respectively. The reductions in aerodynamic and tire rolling resistance coefficients, and the absolute changes in average vehicle weight are presented in Table 11-15.

Table 11-13 Estimated Reductions in Energy Rates for Alternative 5 using Analysis Method B [a]

VEHICLE TYPE	FUEL	MODEL YEARS	FUEL/CO_2 REDUCTION
Long-haul Tractor-Trailer and HHD Vocational	Diesel	2018-2020	1.0%
		2021-2023	12.5%
		2024+	17.3%
Short-haul Tractor-Trailer and HHD Vocational	Diesel	2018-2020	0.6%
		2021-2023	12.7%
		2024+	17.2%
Single-Frame Vocational[b]	Diesel and CNG	2021-2023	12.7%
		2024+	18.3%
	Gasoline	2021-2023	10.7%
		2024+	15.3%
Urban Buses	Diesel and CNG	2021-2023	11.8%
		2024+	14.4%
HD pickup trucks and vans	Diesel and Gasoline	2021	4.0%
		2022	7.84%
		2023	11.53%
		2024	15.07%
		2025+	18.46%

Notes:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.
[b] Vocational vehicles modeled in MOVES include heavy heavy-duty, medium heavy-duty, and light heavy-duty vehicles. However, for light heavy-duty vocational vehicles, class 2b and 3 vehicles are not included in the inventories for the vocational sector. Instead, all vehicles with GVWR of less than 14,000 lbs were modeled using the energy rate reductions described below for HD pickup trucks and vans. In practice, many manufacturers of these vehicles choose to average the lightest vocational vehicles into chassis-certified families (i.e., heavy-duty pickups and vans).

Table 11-14 Assumed Diesel APU Use during Extended Idling for Combination Long-haul Tractor-Trailers for Alternative 5

VEHICLE TYPE	MODEL YEARS	DIESEL APU PENETRATION
Combination Long-Haul Tractors	2010-2020	9%
	2021+	100%

Table 11-15 Estimated Reductions in Road Load Factors for Alternative 5

VEHICLE TYPE	MODEL YEARS	REDUCTION IN TIRE ROLLING RESISTANCE COEFFICIENT	REDUCTION IN AERODYNAMIC DRAG COEFFICIENT	WEIGHT REDUCTION (LB)[a]
Combination Long-haul Tractor-Trailers	2018-2020	6.1%	7.2%	-169
	2021-2023	16.2%	25.06%	930
	2024-2026	19.1%	31.7%	843
	2027+	19.1%	33.7%	817
Combination Short-haul Tractor-Trailers[b]	2018-2020	5.5%	0.9%	-23
	2021-2023	16.4%	11.2%	1069
	2024-2026	19.8%	13.9%	1058
	2027+	19.8%	13.9%	1058
Intercity Buses	2021-2023	20.8%	0%	0
	2024+	24.7%	0%	0
Transit Buses	2021-2023	0%	0%	0
	2024+	12.0%	0%	0
School Buses	2021-2023	14.9%	0%	0
	2024+	19.0%	0%	0
Refuse Trucks	2021-2023	0%	0%	0
	2024+	12.0%	0%	0
Single Unit Short-haul Trucks	2021-2023	6.4%	0%	9.4
	2024+	10.2%	0%	15.2
Single Unit Long-haul Trucks	2021-2023	13.3%	0%	31.5
	2024+	13.3%	0%	39.4
Motor Homes	2021-2023	20.8%	0%	0
	2024+	24.7%	0%	0

Notes:
[a] Negative weight reductions reflect an expected weight increase as a byproduct of the other vehicle and engine improvements.
[b] Vocational tractors are included in the short-haul tractor segment.

11.2 How Do These Alternatives Compare in Overall GHG Emissions Reductions and Fuel Efficiency?

As noted earlier, the agencies analyzed the impact of each alternative on both downstream and upstream emissions using two separate methods. The results of NHTSA's Method A are shown in Chapter 11.2.1. The results of EPA's Method B are shown in Chapter 11.2.2.

11.2.1 Comparison of Alternatives Using Method A

The following tables compare the NHTSA estimates of overall fuel consumption and GHG emissions reductions and benefits and costs of each of the regulatory alternatives the agencies considered. Note that for tractors, trailers, pickups and vans the agencies compared overall fuel consumption and GHG emissions reductions and benefits and costs relative to two different baselines, described above in the section on the No Action alternative. Therefore, for tractors, trailers, pickups and vans two results are listed; one relative to each baseline, namely Alternative 1a and Alternative 1b.

For Method A, NHTSA analyzed pickup and van overall fuel consumption and emissions reductions and benefits and costs using the NHTSA CAFE model. In addition, the agencies used EPA's MOVES model to estimate pickup and van fuel consumption and emissions and a cost methodology that applied vehicle costs in different model years. The Method A analysis extended through MY 2032. The agencies concluded that in these instances the choice of baseline and the choice of modeling approach (Method A versus Method B) did not impact the agencies' decision to propose Alternative 3 as the preferred alternative and hence the final standards for HD pickups and vans.

Table 11-16through Table 11-19 summarize the key costs and benefit estimates of the program using Method A. The first two tables show the costs and benefits using a 3 percent discount rate under both the flat and dynamic baselines. The third and fourth tables show the costs and benefits using a 7 percent discount rate for both baselines. Under all possible combinations of discount rate and baseline the net benefits from highest to lowest are as follows: Alternative 5; Alternative 3; Alternative 4; Alternative 2.

Table 11-16 MY 2018-2029 Lifetime Summary of Program Benefits and Cost, Discounted at 3% (relative to Baseline 1a), Method A[a]

Vehicle segment	Alt 2	Alt 3	Alt 4	Alt 5
Discounted pre-tax fuel savings ($billion)				
HD pickups and Vans	12.1	18.7	20.3	22.3
Vocational Vehicles	13.5	25.5	23.6	34.6
Tractors/Trailers	50.2	118.8	115.7	169.1
Total	75.7	163.0	159.6	225.9
Discounted Total technology costs ($billion)				
HD pickups and Vans	3.1	6.8	8.2	9.9
Vocational Vehicles	1.6	6.6	7.1	9.5
Tractors/Trailers	9.0	11.0	11.6	26.8
Total	13.7	24.4	26.9	46.2
Discounted value of emissions reductions ($billon)				
HD pickups and Vans	3.4	5.3	5.7	6.3
Vocational Vehicles	5.2	9.8	9.1	13.3
Tractors/Trailers	21.9	50.9	50.9	73.4
Total	30.5	66.0	65.7	93.0
Total costs($billion)				
HD pickups and Vans	4.4	7.9	8.6	10.3
Vocational Vehicles	2.4	7.3	8.8	11.3
Tractors/Trailers	13.2	14.0	15.7	30.8
Total	20.0	29.2	33.1	52.4
Total benefits($billion)				
HD pickups and Vans	18.1	28.1	30.4	33.3
Vocational Vehicles	20.2	37.8	35.1	51.2
Tractors/Trailers	78.1	179.8	176.5	255.5
Total	114.1	245.7	242.0	340.0
Net benefits($billion)				
HD pickups and Vans	13.7	20.2	21.8	23.0
Vocational Vehicles	17.8	30.5	26.3	39.9
Tractors/Trailers	64.9	165.8	160.9	224.7
Total	94.1	216.5	208.9	287.6

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Section X.A.1.

Table 11-17 MY 2018-2029 Lifetime Summary of Program Benefits and Costs, Discounted at 3% (relative to Baseline 1b), Method A[a]

Vehicle segment	Alt 2	Alt 3	Alt 4	Alt 5
Discounted pre-tax fuel savings ($billion)				
HD pickups and Vans	10.7	17.4	19.5	21.9
Vocational Vehicles	13.5	25.5	23.6	34.6
Tractors/Trailers	37.6	106.2	103.1	156.5
Total	61.8	149.1	146.2	213.0
Discounted Total technology costs ($billion)				
HD pickups and Vans	2.8	6.4	7.5	9.8
Vocational Vehicles	1.6	6.6	7.1	9.5
Tractors/Trailers	8.8	10.7	11.3	26.6
Total	13.2	23.7	25.9	45.9
Discounted value of emissions reductions ($billon)				
HD pickups and Vans	3.0	4.9	5.5	6.2
Vocational Vehicles	5.2	9.8	9.1	13.3
Tractors/Trailers	16.4	45.4	45.4	67.9
Total	24.6	60.1	60.0	87.4
Total costs($billion)				
HD pickups and Vans	4.0	7.4	8.6	10.0
Vocational Vehicles	2.4	7.3	8.8	11.3
Tractors/Trailers	12.9	13.8	15.5	30.6
Total	19.3	28.5	32.9	51.9
Total benefits($billion)				
HD pickups and Vans	16.0	26.0	29.2	32.7
Vocational Vehicles	20.2	37.8	35.1	51.2
Tractors/Trailers	59.2	161.0	157.7	236.7
Total	95.4	224.8	222.0	320.6
Net benefits($billion)				
HD pickups and Vans	12.0	18.6	20.6	22.7
Vocational Vehicles	17.8	30.5	26.3	39.9
Tractors/Trailers	46.3	147.2	142.2	206.1
Total	76.1	196.3	189.1	268.7

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Section X.A.1.

Table 11-18 MY 2018-2029 Lifetime Summary of Program Benefits and Cost, Discounted at 7% (relative to Baseline 1a) Method A[a]

Vehicle segment	Alt 2	Alt 3	Alt 4	Alt 5
Discounted pre-tax fuel savings ($billion)				
HD pickups and Vans	7.1	10.9	11.9	13.0
Vocational Vehicles	7.1	13.4	12.5	18.5
Tractors/Trailers	26.6	62.7	61.8	90.7
Total	40.8	87.0	86.2	122.2
Discounted Total technology costs ($billion)				
HD pickups and Vans	2.2	4.8	5.9	7.0
Vocational Vehicles	1.1	4.4	4.8	6.5
Tractors/Trailers	6.2	7.4	8.0	18.5
Total	9.5	16.6	18.7	32.0
Discounted value of emissions reductions ($billon)				
HD pickups and Vans	3.1	4.8	5.2	5.7
Vocational Vehicles	4.2	7.8	7.3	10.7
Tractors/Trailers	16.9	39.5	39.3	57.1
Total	24.2	52.1	51.8	73.5
Total costs($billion)				
HD pickups and Vans	3.0	5.5	6.1	7.3
Vocational Vehicles	1.5	4.8	5.8	7.5
Tractors/Trailers	8.5	9.2	10.2	20.7
Total	13.0	19.5	22.1	35.5
Total benefits($billion)				
HD pickups and Vans	11.7	18.0	19.6	21.5
Vocational Vehicles	12.1	22.6	21.1	31.0
Tractors/Trailers	47.1	108.0	106.8	155.1
Total	70.9	148.6	147.5	207.6
Net benefits($billion)				
HD pickups and Vans	8.7	12.5	13.5	14.2
Vocational Vehicles	10.6	17.8	15.3	23.5
Tractors/Trailers	38.6	98.8	96.6	134.4
Total	58.0	129.1	125.4	172.1

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Section X.A.1.

Table 11-19 MY 2018-2029 Lifetime Summary of Program Benefits and Costs, Discounted at 7% (relative to Baseline 1b), Method A[a]

Vehicle segment	Alt 2	Alt 3	Alt 4	Alt 5
Discounted pre-tax fuel savings ($billion)				
HD pickups and Vans	6.3	10.1	11.5	12.9
Vocational Vehicles	7.1	13.4	12.5	18.5
Tractors/Trailers	19.9	56.1	55.2	84.1
Total	33.3	79.6	79.2	115.5
Discounted Total technology costs ($billion)				
HD pickups and Vans	2.0	4.4	5.3	7.0
Vocational Vehicles	1.1	4.4	4.8	6.5
Tractors/Trailers	6.1	7.3	7.8	18.4
Total	9.2	16.1	17.9	31.9
Discounted value of emissions reductions ($billon)				
HD pickups and Vans	2.7	4.4	5.0	5.6
Vocational Vehicles	4.2	7.8	7.3	10.7
Tractors/Trailers	12.7	35.3	35.1	52.8
Total	19.6	47.5	47.4	68.2
Total costs($billion)				
HD pickups and Vans	2.7	5.1	6.0	7.1
Vocational Vehicles	1.6	4.8	5.8	7.5
Tractors/Trailers	8.4	9.0	10.1	20.6
Total	12.7	18.9	21.9	35.2
Total benefits($billion)				
HD pickups and Vans	10.4	16.7	19.0	21.3
Vocational Vehicles	12.1	22.7	21.1	31.0
Tractors/Trailers	35.9	96.8	95.6	143.9
Total	58.4	136.2	135.7	195.2
Net benefits($billion)				
HD pickups and Vans	7.7	11.6	13.0	14.2
Vocational Vehicles	10.5	17.9	15.3	23.5
Tractors/Trailers	27.5	87.8	85.5	123.3
Total	45.7	117.3	113.8	161.0

Note:
[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the less dynamic baseline, 1a, and more dynamic baseline, 1b, please see Section X.A.1.

Table 11-20 and Table 11-21show the estimated fuel savings and GHG reductions by considered alternatives and under both baselines. Under both baselines the reductions in both fuel and GHG's are highest under Alternative 5, higher under Alternative 3 than Alternative 4, and lowest under Alternative 2.

Table 11-20 MY 2018-2029 Lifetime Fuel Savings and GHG Emissions Reductions by Vehicle Segment, Relative to Baseline 1a, Method A[a]

MY 2018 - 2029 TOTAL	FUEL REDUCTIONS (billion gallons)	UPSTREAM & DOWNSTREAM GHG REDUCTIONS (MMT)
Alternative 2		
HD Pickup Trucks/Vans	6.2	77
Vocational Vehicles	6.5	86
Tractors and Trailers	23.4	323
Total	36.1	486
Alt. 3 - Preferred Alternative		
HD Pickup Trucks/Vans	9.8	120
Vocational Vehicles	12.3	162
Tractors and Trailers	55.6	767
Total	77.7	1049
Alt. 4		
HD Pickup Trucks/Vans	10.6	130
Vocational Vehicles	11.4	150
Tractors and Trailers	54.0	744
Total	76.0	1024
Alt. 5		
HD Pickup Trucks/Vans	11.6	143
Vocational Vehicles	16.7	219
Tractors and Trailers	78.8	1087
Total	107.1	1449

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1.

Table 11-21 MY 2018-2029 Lifetime Fuel Savings and GHG Emissions Reductions by Vehicle Segment, Relative to Baseline 1b Method A[a]

MY 2018 - 2029 TOTAL	FUEL REDUCTIONS	UPSTREAM & DOWNSTREAM GHG REDUCTIONS
	(billion gallons)	(MMT)
Alternative 2		
HD Pickup Trucks/Vans	5.5	68
Vocational Vehicles	6.5	86
Tractors and Trailers	17.5	242
Total	29.5	396
Alt. 3 - Preferred Alternative		
HD Pickup Trucks/Vans	9.0	111
Vocational Vehicles	12.4	162
Tractors and Trailers	49.7	685
Total	71.1	958
Alt. 4		
HD Pickup Trucks/Vans	10.1	125
Vocational Vehicles	11.4	150
Tractors and Trailers	48.1	663
Total	69.6	938
Alt. 5		
HD Pickup Trucks/Vans	11.3	140
Vocational Vehicles	16.7	219
Tractors and Trailers	72.9	1006
Total	100.9	1365

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1.

In addition to considering lifetime GHG and fuel reductions, we have also considered calendar year level GHG and fuel reductions for calendar years 2040 and 2050 across regulatory alternatives under both baselines. These results are present in Table 11-22 and Table 11-23.

Table 11-22 Annual GHG and Fuel Reductions Relative to the Dynamic Baseline in 2040 and 2050 using Method A[a]

	UPSTREAM & DOWNSTREAM GHG REDUCTIONS (MMT CO_2EQ)		FUEL REDUCTIONS (BILLION GALLONS)	
	2040	2050	2040	2050
Alt. 2 Less Stringent - Total	49.1	57.3	3.6	4.2
Tractors and Trailers	30.9	36.6	2.2	2.7
HD Pickups & Vans	6.7	7.3	0.6	0.6
Vocational Vehicles	11.5	13.4	0.8	0.9
Alt. 3 Preferred – Total	139	166	10.2	12.3
Tractors and Trailers	102	124	7.4	9.0
HD Pickups & Vans	12.6	13.8	1.0	1.2
Vocational Vehicles	24.1	28.2	1.8	2.1
Alt. 4 More Stringent – Total	116	136	8.6	10.1
Tractors and Trailers	83.1	98.7	6.0	7.2
HD Pickups & Vans	12.6	13.8	1.1	1.2
Vocational Vehicles	20.0	23.1	1.5	1.7
Alt. 5 More Stringent – Total	167	194	12.4	14.2
Tractors and Trailers	124	146	9.0	10.6
HD Pickups & Vans	14.8	16.2	1.3	1.3
Vocational Vehicles	27.8	32.0	2.1	2.3

Note:

[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.

Table 11-23 Annual GHG and Fuel Reductions Relative to the Flat Baseline in 2040 and 2050 using Method A[a]

	UPSTREAM & DOWNSTREAM GHG REDUCTIONS (MMT CO_2EQ)		FUEL REDUCTIONS (BILLION GALLONS)	
	2040	2050	2040	2050
Alt. 2 Less Stringent - Total	63.7	75.2	4.7	5.5
Tractors and Trailers	44.2	53.0	3.2	3.8
HD Pickups & Vans	8.0	8.8	0.6	0.7
Vocational Vehicles	11.5	13.4	0.9	1.0
Alt. 3 Preferred – Total	153	184	11.3	13.7
Tractors and Trailers	115	141	8.4	10.2
HD Pickups & Vans	13.8	15.1	1.1	1.3
Vocational Vehicles	24.1	28.2	1.8	2.2
Alt. 4 More Stringent – Total	131	153	9.6	11.4
Tractors and Trailers	96.5	115	7.0	8.3
HD Pickups & Vans	14.0	15.3	1.1	1.3
Vocational Vehicles	20.0	23.1	1.5	1.8
Alt. 5 More Stringent – Total	181	213	13.4	15.6
Tractors and Trailers	137	163	9.9	11.8
HD Pickups & Vans	16.0	17.6	1.4	1.5
Vocational Vehicles	27.8	32.0	2.1	2.3

Note:

[a] For an explanation of analytical Methods A and B, please see Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Section X.A.1.

11.2.2 Comparison of Alternatives Using Method B

EPA's Method B analyzed the impact of each alternative on both downstream and upstream emissions, as shown in Table 11-24. The table contains the annual GHG reductions and fuel savings in 2040 and 2050 for each alternative relative to the flat (Alternative 1a) baseline, presenting both the total impacts across all regulatory categories and for each individual regulatory category.

Table 11-24 Annual GHG and Fuel Reductions in Calendar Years 2040 and 2050, Relative to the Flat Baseline using Analysis Method B [a]

	UPSTREAM +DOWNSTREAM GHG REDUCTIONS (MMT CO_2eq)		FUEL REDUCTIONS (BILLION GALLONS)	
	2040	2050	2040	2050
Alternative 1a (relative to itself)	0	0	0	0
Alt. 2 Less Stringent- Total	71.8	84.0	5.4	6.3
Tractors and Trailers	44.2	53.0	3.2	3.8
HD Pickups & Vans	16.1	17.6	1.4	1.5
Vocational Vehicles	11.5	13.4	0.9	1.0
Alt. 3 Preferred – Total	166.5	198.9	12.5	14.9
Tractors and Trailers	115.5	140.7	8.4	10.2
HD Pickups & Vans	26.9	30.0	2.2	2.6
Vocational Vehicles	24.1	28.2	1.9	2.1
Alt. 4 More Stringent– Total	144.1	168.5	10.9	12.7
Tractors and Trailers	96.5	115.1	7.0	8.3
HD Pickups & Vans	27.7	30.3	2.3	2.6
Vocational Vehicles	20.0	23.1	1.5	1.8
Alt. 5 More Stringent– Total	196.8	230.0	14.8	17.2
Tractors and Trailers	136.9	162.9	9.9	11.8
HD Pickups & Vans	32.2	35.2	2.7	3.0
Vocational Vehicles	27.8	32.0	2.1	2.4

Note:
[a] For an explanation of analytical Methods A and B, please see Preamble Section I.D; for an explanation of the flat baseline, 1a, and dynamic baseline, 1b, please see Preamble Section X.A.1.

References

[1] OMB Circular A-4, September 17, 2003. Available at http://www.whitehouse.gov/omb/circulars_a004_a-4.
[2] NEPA requires agencies to consider a "no action" alternative in their NEPA analyses and to compare the effects of not taking action with the effects of the reasonable action alternatives to demonstrate the different environmental effects of the action alternatives. *See* 40 CFR 1502.2(e), 1502.14(d).CEQ has explained that "[T]he regulations require the analysis of the no action alternative even if the agency is under a court order or legislative command to act. This analysis provides a benchmark, enabling decision makers to compare the magnitude of environmental effects of the action alternatives. [*See* 40 CFR 1502.14(c).] * * * Inclusion of such an analysis in the EIS is necessary to inform Congress, the public, and the President as intended by NEPA. [*See* 40 CFR 1500.1(a).]" Forty Most Asked Questions Concerning CEQ's National Environmental Policy Act Regulations, 46 FR 18026 (1981) (emphasis added).
[3] http://energy.gov/eere/vehicles/vehicle-technologies-office-21st-century-truck.
[4] http://www3.epa.gov/smartway/.
[5] State of California Global Warming Solutions Act of 2006 (Assembly Bill 32, or AB32).
[6] Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles; National Research Council; Transportation Research Board (2010). "Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles," (hereafter, "NAS 2010"). Washington, D.C. The National Academies Press. Available electronically from the National Academies Press Website at http://www.nap.edu/catalog.php?record_id=12845 (last accessed September 10, 2010).

Chapter 12: Final Regulatory Flexibility Analysis

This chapter discusses the agencies' Final Regulatory Flexibility Analysis (FRFA) that evaluates the potential impacts of the final standards on small entities. The Regulatory Flexibility Act, as amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA), generally requires an agency to prepare a regulatory flexibility analysis of any rule subject to notice and comment rulemaking requirements under the Administrative Procedure Act or any other statute unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities. Pursuant to this requirement, we have prepared an FRFA for the final rule.

Throughout the process of developing the FRFA, EPA conducted outreach and held meetings with representatives from the various small entities that could be affected by the rulemaking to gain feedback, including recommendations, on how to reduce the impact of the rule on these entities. The small business recommendations stated here reflect the comments of the small entity representatives (SERs) and members of the Small Business Advocacy Review Panel (SBAR Panel, or 'the Panel'). NHTSA maintains obligations to evaluate small business impacts under the Regulatory Flexibility Act, but is not required to convene a SBAR Panel. As a joint rulemaking, EPA and NHTSA have coordinated formulation of standards, including flexibilities for small businesses.

12.1 Overview of the Regulatory Flexibility Act

In accordance with section 609(b) of the Regulatory Flexibility Act (RFA), EPA convened an SBAR Panel before conducting the FRFA. A summary of the Panel's recommendations is presented in the Preamble of this final rulemaking. Further detailed discussion of the Panel's outreach, advice and recommendations is found in the Final Panel Report contained in the docket for this final rulemaking.[1]

Section 609(b) of the RFA directs the Panel to report on the comments of small entity representatives and make findings on issues related to elements of a FRFA under section 603 of the RFA. Those elements of a FRFA are:

- A description of, and where feasible, an estimate of the number of small entities to which the final rule will apply
- A description of projected reporting, record keeping, and other compliance requirements of the final rule, including an estimate of the classes of small entities which will be subject to the requirement and the type of professional skills necessary for preparation of the report or record
- An identification, to the extent practicable, of all relevant Federal rules which may duplicate, overlap, or conflict with the final rule
- A description of any significant alternatives to the final rule which accomplish the stated objectives of applicable statutes and which minimize any significant economic impact of the final rule on small entities

The RFA was amended by SBREFA to ensure that concerns regarding small entities are adequately considered during the development of new regulations that affect those entities. Although EPA is not required by the Clean Air Act to provide special treatment to small businesses, the RFA requires EPA to carefully consider the economic impact that our rules will have on small entities. The recommendations made by the Panel may serve to help lessen these economic impacts on small entities when consistent with the Clean Air Act requirements.

12.2 Need for Rulemaking and Rulemaking Objectives

Heavy-duty vehicles are classified as those with gross vehicle weight ratings (GVWR) of greater than 8,500 lb. Section 202(a) of the Clean Air Act (CAA) requires EPA to promulgate emission standards for pollutant emissions from new motor vehicles and engines which emissions cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare. In 2009, EPA found that six greenhouse gases (GHGs) were anticipated to endanger public health or welfare, and that new motor vehicles and new motor vehicle engines contribute to that pollution which endangers. As explained in Section I of the Preamble to the final rule, the D.C. Circuit upheld this endangerment finding in its entirety (a judgment the Supreme Court declined to review), and further held that EPA had a mandatory duty to promulgate standards for emissions of the pollutant which contributes to the endangerment: GHGs from new motor vehicles and engines.

The Energy Independence and Security Act of 2007 (EISA) directs NHTSA to develop regulations to increase fuel efficiency for commercial medium- and heavy-duty on-highway vehicles and work trucks. Fundamentally, EISA seeks energy conservation. In 2010, total fuel consumption and GHG emissions from medium- and heavy-duty vehicles accounted for 23 percent of total U.S. transportation-related GHG emissions.

EPA and NHTSA's Phase 1 Heavy-Duty Engines and Vehicles Program, which was finalized in September 2011 (76 FR 57106), marked the first greenhouse gas emissions and fuel efficiency standards for heavy-duty vehicles and engines. The program addressed medium- and heavy-duty GHG emissions and fuel efficiency through the adoption of performance-based standards that allow manufacturers to determine the optimal mix of technologies to achieve the necessary reductions for their vehicle fleets and engines.

Building on the Phase 1 rule, this final Phase 2 rule will reduce GHG emissions and fuel consumption associated with the transportation of goods across the United States post-2017. The final Phase 2 rulemaking considers changes to existing engine, GHG, and fuel efficiency standards, as well as regulatory standards and certification requirements for previously-unregulated new trailers pulled by semi-tractors. Manufacturers of heavy-duty engines, chassis, vehicles and trailers will be required to incorporate GHG-reducing and fuel-saving technologies in order to comply with the agencies' performance-based standards.

12.3 Definition and Description of Small Businesses

The RFA defines small entities as including "small businesses," "small governments," and "small organizations" (5 U.S.C. 601) and references the Small Business Administration for the definition of "small businesses" using size standards based on the North American Industry

Classification System (NAICS) (13 CFR 121.201). The standards being considered by EPA for this rulemaking are expected to affect a variety of small businesses. A listing of the NAICS codes identified as relevant to the potential rulemaking, along with their respective SBA size thresholds, is located in Table 12-1, below. In the period between the convening of the SBAR Panel (and Initial Regulatory Flexibility Analysis) and issuing the final rule, SBA finalized new size standards for small business classification.[2] We have updated our analysis to reflect the new size standards and noted the changes in Table 12-1.

The agencies expect that the same industries affected by the Phase 1 rulemaking will also be affected by the final Phase 2 rulemaking. In addition, small businesses and trailer manufacturers are also included in the final Phase 2 rule. EPA and NHTSA used the criteria for small entities developed by SBA as a guide to identifying Small Entity Representatives (SERs) for this rulemaking. Table 12-1 lists industries potentially directly affected by the regulation. The NAICS code and size thresholds are shown as well.

Table 12-1 Industry Sectors Potentially Affected by the Agencies' Action

INDUSTRY EXPECTED IN RULEMAKING	NAICS CODE	NAICS DESCRIPTION	SBA SIZE THRESHOLD (LESS THAN OR EQUAL TO)	
			IRFA	FRFA
Alternative Fuel Engine Converters	333999	Misc. General Purpose Machinery	500 employees	
	811198	All Other Auto Repair & Maintenance	$7.0M (annual receipts)	$7.5M (annual receipts)
HD Pick-up Trucks & Vans	336111	Automobile Manufacturing	1,000 employees	1,500 employees
Vocational Chassis, Class 7 & 8 Tractors	336120	Heavy-Duty Truck Manufacturing	1,000 employees	1,500 employees
Trailers	336212	Truck Trailer Manufacturing	500 employees	1,000 employees
HD Spark-Ignition Engines	336310	Motor Vehicle Gasoline Engine & Engine Parts	750 employees	1,000 employees
HD Compression-Ignition Engines	333618	Other Engine Equipment Manufacturing	1,000 employees	1,500 employees

12.4 Summary of Small Entities to which the Rulemaking will Apply

Using the information from Table 12-1, with the agencies' certification data and employment information from the Hoover's online business information database, EPA and NHTSA have determined that there are small business in the following affected industries: heavy-duty truck manufacturers (vocational chassis and glider vehicle manufacturers), heavy-duty engine manufacturers, alternative fuel engine converters, and trailer manufacturers. The agencies believe there are about 178 trailer manufacturers of which 147 qualify as small entities with 1,000 employees or less. EPA and NHTSA identified ten heavy-duty engine manufacturers that are currently certifying natural gas engines. The agencies believe nine of these companies are small businesses. About 60 companies have filed paperwork with EPA as alternative fuel converters. Many of these service only light-duty vehicles and light-duty trucks; we estimate that there are 20-30 companies performing aftermarket fuel conversions with heavy-duty vehicles and heavy-duty engines, all of which are likely to qualify as small businesses under the Phase 2 program. Currently, 20 manufacturers that make chassis for vocational vehicles certify with EPA under the Phase 1 program and the agencies have identified an additional 19 small vocational chassis manufacturers that are not currently certifying under Phase 1.

Glider vehicles are a subset of vehicles that will be regulated under the Phase 2 rulemaking (including for regulation of criteria emissions). Glider vehicle manufacturers traditionally manufacture or purchase new vehicle bodies (vocational vehicles or Class 7 and 8 tractors) for use with older powertrains. These engineless vehicle bodies are often referred to as "glider kits" and to the extent glider vehicle manufacturers rely on glider kits, they can be referred to as assemblers and well as manufacturers. The agencies were aware of four glider vehicle manufacturers (for whom glider vehicle production was a primary business) during the SBAR Panel process and we identified three of these manufacturers as small entities. We are not aware of any small businesses that produce glider *kits* for others to assemble.[1] Public comments on the proposed rule indicated that there are more than 1,200 purchasers of glider kits, and we presume they would all meet the Act's definition of "manufacturer," which includes anyone who assembles motor vehicles. See Preamble Section I.E.(1)(c). This large number of businesses that were not accounted for during the SBAR Panel is largely a result of our focus on glider manufacturers for whom glider vehicle production is a primary business. We note that almost every repair shop that is capable of overhauling truck engines is also capable of assembling a glider vehicle. Perhaps most have, at some point, installed a used highway engine in a glider kit. Producing glider vehicles is quite clearly not a major business focus for most of these additional companies. Nevertheless, we believe that a clear majority of the companies assembling glider vehicles, including those that do so as a side business, qualify as small businesses.

12.5 Related Federal Rules

The Phase 1 rulemaking continues to be in effect in the absence of this final rule. The Panel noted that it was aware that the final Phase 2 rule would be a joint action by EPA and the Department of Transportation (DOT), through NHTSA, as in the Phase 1 rulemaking. We are also aware of other state and Federal rules related to heavy-duty vehicles and to the final Phase 2 rule under consideration. NHTSA has safety requirements for medium- and heavy-duty vehicles located at 49 CFR part 571. California adopted its own greenhouse gas initiative, which places aerodynamic requirements on trailers used in long-haul applications. None of these existing regulations were found to conflict with the final rulemaking.

12.6 Projected Reporting, Recordkeeping, and Other Compliance Requirements

For any emission control program, EPA must have assurances that the regulated products will meet the standards. Certification and in use requirements are explicit statutory requirements. See e.g. CAA section 203 (a). The program that EPA and NHTSA are adopting for manufacturers subject to this rule includes testing, reporting, and recordkeeping requirements. Testing requirements for these manufacturers includes use of EPA's Greenhouse gas Emissions Model (GEM) vehicle simulation tool to obtain the overall CO_2 emissions rate for

[1] Although this discussion is written based on the assumption that no small businesses produce glider kits for others to assemble, the conclusions would also be valid with respect to small entities that produce glider kits for sale, should they exist.

certification of vocational chassis and trailers, aerodynamic testing to obtain aerodynamic inputs to GEM for some trailer manufacturers, and engine dynamometer testing for alternative fuel engine converters to ensure their conversions meet the CO_2, CH_4 and N_2O engine standards. Reporting requirements include emissions test data or model inputs and results, technical data related to the vehicles, and end-of-year sales information. Manufacturers will have to keep records of this information.

12.7 Regulatory Flexibilities

The Panel developed a range of regulatory flexibilities intended to mitigate the impacts of the final rulemaking on small businesses, and recommended that EPA propose and seek comment on the flexibilities. The Panel's findings and discussions are based on the information that was available during the term of the Panel and issues that were raised by the SERs during the outreach meetings and in their written comments. It was agreed that EPA should consider the issues raised by the SERs (and issues raised in the course of the Panel) and that EPA should consider the comments on flexibility alternatives that would help to mitigate any negative impacts on small businesses.

Alternatives discussed throughout the Panel process include those offered in the development of the upcoming rule. Though some of the recommended flexibilities may be appropriate to apply to all entities affected by the rulemaking, the Panel's discussions and recommendations are focused mainly on the impacts, and ways to mitigate adverse impacts, on small businesses. A summary of the Panel's recommendations, along with those provisions that we are finalizing in this action, are detailed below. A full discussion of the regulatory alternatives and hardship provisions discussed and recommended by the Panel, all written comments received from SERs, and summaries of the two outreach meetings that were held with the SERs can be found in the SBREFA Final Panel Report, located in the rulemaking docket.[3] In addition, all the flexibilities that are being adopted in the rulemaking for small businesses, as well as those for all entities that may be affected by the rulemaking, are described in the Preamble to the final rule.

12.7.1 Heavy-Duty Highway Engine Manufacturers and Engine Converter Flexibilities

12.7.1.1 SBAR Panel Recommendations

Based on the comments received from SERs, the Panel recommended not having separate standards for small business natural gas engine manufacturers. The Panel believed this would discourage entrance into this emerging market by adding unnecessary costs to a technology that has the potential to reduce CO_2 tailpipe emissions. In addition, the Panel stated that it believes additional leakage requirements beyond a sealed crankcase for small business natural gas-fueled CI engines and requirements to follow industry standards for leakage could be waived for small businesses with minimal impact on overall GHG emissions.

To reduce the compliance burden of small business engine converters who convert engines in previously-certified complete vehicles, the Panel recommended allowing engine compliance to be sufficient for certification. This would mean the converted vehicle would not need to be recertified *as a vehicle.* This flexibility would eliminate the need for these small manufacturers to gather all the additional component-level information (e.g., transmission data, aerodynamic performance, tire rolling resistance) in addition to the engine CO_2 performance necessary to properly certify a vehicle with GEM. In addition, the Panel recommended that small engine converters be able to submit an engineering analysis, in lieu of measurement, to show that their converted engines do not increase N_2O emissions. Many of the small engine converters are converting SI engines, and the catalysts in these engines are not expected to substantially impact N_2O production. Small engine converters that convert CI engines could likely certify by ensuring that their controls require changes to the SCR dosing strategies.

The Panel recommended that small business engine manufacturers receive a one-year delay in implementation at the beginning of Phase 2, which would allow these manufacturers to begin certifying in MY 2019. Additionally, the Panel recommended that small engine manufacturers producing alternative-fuel engines receive a one-year delay in implementation for each increase in stringency throughout the program. This flexibility would provide additional lead time to obtain the necessary equipment and perform calibration testing if needed.

12.7.1.2 What We Proposed

The agencies proposed the Panel's recommended regulatory flexibility provisions for small businesses producing alternative-fuel engines. EPA and NHTSA proposed to offer these entities a one-year delay in implementation at the start, and small manufacturers of alternative fueled-engines were given an additional one-year delay for each increase in stringency throughout the program. The agencies believed a majority of these small businesses would manufacture their engines from standard gasoline or diesel engine architectures and additional lead time was warranted.

The Phase 2 proposal included three new requirements for companies that manufacture heavy-duty engines: measuring N_2O emissions, reporting CO_2 and CH_4 emissions (which are already measured for meeting criteria standards), and generating an engine fuel map for vehicle manufacturers installing the subject engines. These requirements apply to all new engines, including those fueled by gasoline and diesel alternatives such as natural gas. The agencies did not propose separate standards for alternative fuel engines.

Alternative fuel engine converters generally modify engines that are no longer new. Instead, they convert previously certified engines or vehicles to run on alternative fuels. In accordance with Clean Air Act section 203, these converters are required to ensure that they are not tampering with emissions controls. In the Phase 2 proposal, we clarified that companies converting Phase 2-certified vehicles would be subject to CO_2 and CH_4 standards in the same way that they are subject to criteria standards, but the agencies believe an engine conversion is unlikely to increase N_2O generation, and we proposed to allow engine converters to submit an engineering analysis to demonstrate compliance with the N_2O standard. See 80 FR 40551.

12.7.1.3 Public Comments Received on the NPRM and What We're Finalizing

We did not receive comments on the small-business relief provisions as they apply for engine manufacturers and alternative fuel converters. We are accordingly adopting the proposed flexibilities.

12.7.2 Vocational Vehicle Chassis Manufacturer Flexibilities

12.7.2.1 SBAR Panel Recommendations

The Panel recommended proposing less stringent standards for emergency vehicle chassis manufactured by small businesses. The Panel stated that it believes it is feasible for small manufacturers to install a Phase 2-compliant engine, but recommended that the rulemaking request comment on whether the use of LLR tires will provide enough CO_2 benefits to justify requiring small business emergency chassis manufacturers to adopt them. In addition, the Panel recommended a simplified certification approach for small manufacturers who make chassis for emergency vehicles that reduces the number of inputs these manufacturers would need to obtain for GEM.

The Panel recommended proposing a low volume exemption for small business custom chassis manufacturers based on the volume of sales. Similar to the recommendation for emergency vehicle chassis manufacturers, the Panel stated it believes it is feasible to require installation of a Phase 2-compliant engine and recommended that EPA request comment on the benefits of LRR tires in this market segment. The Panel also recommended that the rulemaking request comment on how to design a small business exemption by means of a volume exemption and what sales volume would be an appropriate threshold.

12.7.2.2 What We Proposed

EPA and NHTSA proposed a flexibility for all emergency vehicles that included fewer technology requirements and a simplified certification approach. Consistent with the recommendations of the Panel, the agencies requested comments on how to design a small business vocational vehicle program, including comments on a possible small volume threshold below which some small business exemption may be available.

12.7.2.3 Public Comments Received on the NPRM and What We're Finalizing

Consistent with the recommendations of the Panel, the agencies are adopting less stringent emergency vehicle standards using a simplified GEM. Innovus commented in support of a small volume threshold for small businesses of either 200 vehicles per year or a different threshold set based on the market share of the entity. Autocar requested further consideration of the small business concerns of manufacturers of specialty vehicle applications, specifically recommending a low volume threshold if the agencies are not inclined to use a manufacturer's business size as grounds for an exemption. Examples of specialty vehicles listed by Autocar include street sweepers, asphalt blasters, aircraft deicers, sewer cleaners, and concrete pumpers. Innovus also requested additional flexibility for meeting OBD requirements. Capacity Trucks commented that the terminal tractor industry is primarily comprised of small businesses who produce a total of less than 6,000 terminal tractors per year, 70 percent of which are fully off-road vehicles.

In considering these comments, the agencies are adopting a custom chassis program for which all manufacturers are eligible. The program includes less stringent standards and a simplified GEM process, where the technology packages have been tailored to specific vehicle applications, and each technology has been determined to be feasible and effective for those vehicles. See Section V of the Preamble for more details.

12.7.3 Glider Vehicle Manufacturer Flexibilities

12.7.3.1 SBAR Panel Recommendations

The Panel stated that it believes that the number of vehicles produced by small business glider vehicle manufacturers is too small to have a substantial impact on the total heavy-duty GHG inventory.[2] The Panel also stated that there should be an allowance to produce some number of glider kits for legitimate purposes, such as for newer vehicles badly damaged in crashes. The Panel therefore recommended proposing an explicit allowance for existing small businesses to continue assembling glider vehicles without having to comply with the GHG requirements. The Panel also recommended that any regulations for glider production be flexible enough to allow sales levels as high as the peak levels in the 2010-2012 timeframe.

12.7.3.2 What We Proposed

The exemption that the agencies proposed for glider vehicle manufacturers was expected to encompass small glider manufacturers. Small manufacturers who assemble 300 or fewer gliders per year would be exempt from certification, up to each company's documented production volumes from 2010-2014. Any additional gliders produced would have to meet the vehicle and engine standards for their respective regulatory categories in the current model year. For instance, tractor gliders would have to meet the tractor standards and vocational chassis would meet the vocational standards, and for both, the engines would need to meet all applicable GHG and criteria emission standard for the year the glider vehicle is completed.

We believed the flexibilities offered to custom chassis vocational vehicles would also reduce the requirements of any small businesses that manufacturer vocational gliders, such as cement mixers and emergency vehicles.

12.7.3.3 Public Comments Received on the NPRM and What We're Finalizing

Engine and vehicle manufacturers took opposing positions. Some supported the proposed approach. Others stated that the proposed provisions exceeded EPA's authority to set emission standards for new engines and new vehicles, in addition to objecting to the detailed provisions as a matter of policy. See Preamble Section I.E. and Response to Comments (RTC) Section 14.2. However, the most helpful comments were those that allowed EPA to target

[2] The Panel did not have accurate data on annual glider vehicle production at the time of the report, but it believed the production to be less than 5,000 per year, which is half of the current rate or less. The Panel also addressed only GHG impacts, not impacts of vast increases in criteria pollutant emissions.

flexibility for glider vehicles that serve an arguably legitimate purposes (such as reclaiming relatively new powertrains from vehicles chassis that fail prematurely), without causing substantial adverse environmental impacts.

We are finalizing the proposed glider-related provisions but have made several revisions in recognition of the differences between gliders produced to circumvent the 2010 criteria pollutant emission standards and those manufactured for other more legitimate purposes. The provisions being finalized are intended to allow a transition to a long-term program in which manufacture of glider vehicles from glider kits is permissible consistent with the original reason OEM manufacturers began to offer glider kits – to allow the reuse of relatively new powertrains from damaged vehicles. The long-term program as well as the transitional program are summarized below. See Section XIII.B of the FRM for a complete description of these provisions.

Under the provisions being finalized for the long-term program, all glider vehicles will need to be covered by both vehicle and engine certificates. The vehicle certificate will require compliance with the GHG vehicle standards of 40 CFR part 1037. The engine certificate will require compliance with the GHG engine standards of 40 CFR part 1036, plus the criteria pollutant standards of 40 CFR part 86. Used engines (including rebuilt/remanufactured engines) may be installed in the gliders without meeting engine standards applicable for the year of glider assembly, provided the engines are within their regulatory useful life (or meet similar criteria).

EPA is also finalizing a transitional program that will allow glider kit/vehicle manufacturers additional flexibility. The first step allows significant production of glider vehicles under the Phase 1 approach, but limits each manufacturer's combined production of glider kits and glider vehicles at the manufacturer's highest annual production of glider kits and glider vehicles for any year from 2010 to 2014. All vehicles within this cap will remain subject to the existing Phase 1 requirements (for both engines and vehicles). Any glider kits or glider vehicles produced beyond this cap will be subject to all requirements applicable to new engines and new vehicles for MY 2017. Other than the 2017 production limit, EPA will continue the Phase 1 approach until January 1, 2018. This allows small businesses to produce glider kits up to the production limit without new constraints. Large manufacturers producing complete glider vehicles remain subject to the 40 CFR part 1037 GHG vehicle standards, as they have been since the start of Phase 1. However large manufacturers may provide exempted glider kits to small businesses during this time frame, and they would not be required to obtain a vehicle certificate for them. However, these exempted glider kits would count against the glider *kit* manufacturers' production cap for 2017.

Effective January 1, 2018, the long-term program begins generally, but with certain transitional flexibilities. In other words, except for the following allowances, glider vehicles will need to comply with the long-term program. The exceptions are:

- Small businesses may produce a limited number of glider vehicles without meeting either the engine or vehicle standards of the long-term program. Larger vehicle manufacturers may provide glider kits to these small businesses without the assembled vehicles meeting the applicable vehicle standards. This number is limited to the small vehicle manufacturer's highest annual production volume in 2010 through 2014 or 300, whichever is less.

- Model year 2010 and later engines are not required to meet the Phase 1 GHG engine standards.
- Glider vehicles conforming to the previously certified vehicle configuration of the donor vehicle do not need to be recertified to current vehicle standards.

These 2018 allowances mostly continue after 2020, but effective January 1, 2021, the completed vehicle will need to meet the vehicle standards, even if the engine is exempt under the small manufacturer provisions. In practice, this will likely mean that the large manufacturers providing glider kits to small manufacturers will need to meet the vehicle standards for the completed vehicle by obtaining a certificate and delegating final assembly to the assembler.

This transitional program combined with the additional flexibility in the long-term program will achieve the stated goal of the Panel, which was to have any regulations for glider production be flexible enough to allow sales levels as high as the peak levels in the 2010-2012 timeframe.

12.7.4 Trailer Manufacturer Flexibilities

12.7.4.1 SBAR Panel Recommendations

12.7.4.1.1 Box Trailers

Box trailer manufacturers have the benefit of relying on the aerodynamic technology development initiated through EPA's voluntary SmartWay program. The Panel acknowledged EPA's plan to adopt a simplified compliance program for all manufacturers, in which aerodynamic device manufacturers have the opportunity to test their devices and register their data with EPA as technologies that can be used by trailer manufacturers in their trailer certification. This pre-approved data strategy is intended to provide all trailer manufactures a means of complying with the standards without testing. Upon the completion of the SBREFA Panel process, it was unclear if this strategy would be available indefinitely, or if it would be an interim flexibility to allow manufacturers to ease into a testing-only compliance program. The Panel recommended that, in the event that this strategy is limited to the early years of the trailer program for all manufacturers, small manufacturers should continue to be given the option to use pre-approved devices in lieu of testing.

The Panel stated its belief that, in the event that small trailer manufacturers adopt pre-approved aerodynamic technologies and the appropriate tire technologies for compliance, it would not be necessary to require the use of a vehicle emissions model, such as GEM, for certification. Instead, the Panel stated that it could be possible for manufacturers to simply report to EPA that all of their trailers include approved technologies.

12.7.4.1.2 Non-Box Trailers

The Panel recommended that EPA not base a standard for non-box trailers on performance of aerodynamic devices. Some of the non-box trailer manufacturer SERs have seen prototype-level demonstrations of aerodynamic devices on non-box trailers. However, most non-box trailer SERs identified unique operations in which their trailers are used that preclude the use of those technologies.

Some non-box trailer manufacturers have experience with LRR tires and ATI systems. However, the non-box trailer manufacturer SERs indicated that LRR tires are not currently available for some of their trailer types. The SERs noted that tire manufacturers are currently focused on box trailer applications and that there are only a few LRR tire models that meet the needs of their customers. The Panel stated that it believes EPA should ensure appropriate availability of these tires in order for it to be deemed a feasible means of achieving these standards and recommended a streamlined compliance process based on the availability of technologies. The Panel suggested that the best compliance option from a small business perspective would be for the agencies to pre-approve tires once they are available in sufficient quantities on the market, similar to the approach proposed for aerodynamic technologies, and to maintain a list that could be used to exempt small businesses when no suitable tires are available. However, the Panel stated that it recognizes the difficulties of maintaining an up-to-date list of certified technologies. The Panel recommended that, if the rulemaking does not adopt the list-based approach, the agency consider a simplified letter-based compliance option that allows manufacturers to petition the agencies for an exemption if they are unable to identify tires that meet the LRR performance requirements on a trailer family basis.

12.7.4.1.3 Trailers with Unique Use Patterns

The Panel recommended excluding all trailers that spend a significant amount of time in off-road applications. These trailers may not spend much time at highway speeds and aerodynamic devices may interfere with the vehicle's intended purpose. Additionally, tires with lower rolling resistance may not provide the type of traction needed in off-road applications.

12.7.4.1.4 General Flexibilities for All Small Trailer Manufacturers

The Panel stated that it recognizes that some manufacturers, who have diverse product lines and high sales volumes, may benefit from an emissions averaging, banking and trading (ABT) strategy. However, due to the custom-order nature of the trailer industry, SERs have expressed their concern that ABT may provide an opportunity for historically loyal customers or customers with large fractions of a manufacturer's business to bargain for the portion of a manufacturer's sales that have minimal requirements. Based on the low volume of sales and niche market of many small business trailer manufacturers, small businesses in particular may have little leverage in this situation and risk losing their customers to larger manufacturers who have credits to spare. In addition, the accounting and reporting burdens of ABT may preclude small businesses from utilizing this flexibility.

Due to the potential for reducing a small business's competitiveness compared to the larger manufacturers, as well as the ABT recordkeeping burden, the Panel recommended EPA consider small business flexibilities to allow small entities to opt out of ABT without placing themselves at a competitive disadvantage to larger firms that adopt ABT, such as a low volume exemption or requiring only LRR where appropriate. The Panel recommended that EPA also consider flexibilities for small businesses that would ease and incentivize their participation in ABT, such as streamlined the tracking requirements for small businesses. In addition, the Panel recommended that EPA request comment on the feasibility and consequences of ABT for the trailer program and additional flexibilities that would promote small business participation.

In addition, for all trailer types that will be included in the Phase 2 program, the Panel recommended a 1-year delay in implementation for small trailer manufacturers at the start of the program to allow them additional lead time to make the proper staffing adjustments and process changes, and possibly add new infrastructure to meet these requirements. In the event that the agencies are unable to provide pre-approved technologies for manufacturers to choose for compliance, the Panel recommended that the standards provide small business trailer manufacturers an additional 1-year delay for each subsequent increase in stringency. This additional lead time would allow these small businesses to research and market the technologies required by the new standards.

12.7.4.2 What We Proposed

The agencies proposed many of the Panel's recommendations for small business trailer manufacturers, and sought comment on the possibility of a small volume exemption. While many of the smallest trailer manufactures sell significantly fewer trailers than the largest small manufacturers, many of the smallest trailer manufacturers produce specialty trailers that would have been candidates for exemption under the proposed off-highway or heavy-haul provisions.

Testing requirements for small businesses were largely reduced by proposed provisions for both large and small trailer manufacturers. A majority of the small trailer manufacturers produce non-box trailers, and we did not propose standards predicated on use of aerodynamic controls for these trailers, which reduced the number of technologies to investigate, market, and implement. As is seen in the Phase 1 tractor program, we expect that tire rolling resistance will be measured by tire manufacturers and information needed for compliance would be presented to trailer manufacturers when they purchase their tires, and no additional testing will be needed. See 40 CFR 1037.650 of the Phase 1 regulations and 40 CFR 1037.620 of the final Phase 2 regulations.

The agencies proposed an option for pre-approved aerodynamic device data to be made available to box trailer manufacturers for use in complying with aerodynamic requirements. We did not set an end date for this provision and the pre-approved data would eliminate the requirement for box trailer manufacturers to complete aerodynamic performance testing for certification throughout the program. EPA and NHTSA expect small business box trailer manufacturers will use the pre-approved aerodynamic devices for most of their trailers.

Additionally, the agencies proposed a simplified compliance program with options to demonstrate trailer performance without requiring the trailer manufacturers to perform vehicle modeling using GEM. The design-based standards proposed for non-box trailer manufacturers would have required the use of LRR tires and ATI systems without testing of any type. The agencies developed a GEM-based equation for each box trailer subcategory that reproduces the CO_2 results of the vehicle model and box trailer manufacturers will simply insert the performance data from any technologies installed to calculate their compliance values. As a result, we proposed that trailer manufacturers would not use GEM for compliance in this final rule.

For the small business trailer manufacturers that produce trailers that are regulated in this program, EPA proposed a one-year implementation delay at the beginning of the program to allow small business trailer manufacturers to demonstrate compliance starting in model year 2019, providing small businesses additional lead time to make the proper staffing adjustments and process changes and possibly add new infrastructure to meet their requirements. NHTSA's standards are voluntary until MY 2021. Since small business trailer manufacturers will already be required to comply with EPA standards when NHTSA's fuel efficiency standards will begin, NHTSA does not believe that an additional year of delay to comply with its fuel efficiency standards will provide beneficial flexibility.

The agencies proposed a limited averaging program for box trailer manufacturers. The five largest trailer manufacturers produce over 85 percent of the dry and refrigerated vans in the market. We did not propose an option to bank or trade credits, because the volume of credits that could be generated by large manufacturers has the potential to exceed the total sales of small manufacturers. In such a scenario, a small manufacturer could lose all of its customers to larger manufacturers that could sell the same number of trailers with fewer or no technologies installed. The limited averaging program was restricted to averaging within a single model year, but the agencies proposed to allow deficits to be carried-over for three years.

12.7.4.3 Public Comments Received on the NPRM and What We're Finalizing

EPA and NHTSA are finalizing the option for trailer manufacturers to use pre-approved aerodynamic device data submitted by device manufacturers. We did not set an end date for this provision and the pre-approved data would eliminate the requirement for box trailer manufacturers to complete aerodynamic performance testing for certification throughout the program. The agencies expect small business box trailer manufacturers will take advantage of the pre-approved aerodynamic devices for most of their trailers, which will significantly reduce or eliminate their testing burden.

The agencies did not receive any comments recommending an appropriate sales volume that could qualify manufacturers for low-volume exemption. The Truck Trailer Manufacturers Association (TTMA) and the American Trucking Associations (ATA) provided comments suggesting that additional trailer types should be excluded from the program based on these trailers' typical operational characteristics. We recognize that many trailers in the proposed non-box subcategory have unique physical characteristics for specialized operations that may make use of LRR tires and/or tire pressure systems difficult or infeasible. Instead of focusing on trailer characteristics that indicated off-highway use, the agencies have identified three specific types of non-box trailers that represent the majority of non-box trailers and that we believe are designed and mostly used in on-road applications: tanks, flatbeds, and container chassis.

We believe that manufacturers of tanks, flatbeds, and container chassis can relatively easily install LRR tires and tire pressure systems, and that customers will benefit from using these technologies. We are limiting the final non-box trailer program to tanks, flatbeds, and container chassis. All other non-box trailers are excluded from the Phase 2 trailer program, with no regulatory requirements. This exclusion reduces the number of small businesses in the trailer program from 147 to 74 companies. With no regulatory requirements, these companies are expected to have zero burden.

Additionally, the agencies are adopting provisions that would increase the number of eligible tire pressure systems that can be installed for compliance. We proposed to only allow automatic tire inflation (ATI) systems, but we received comments from manufacturers that were concerned about the cost and availability of ATI systems for the trailer industry. The agencies agree that tire pressure monitoring (TPM) systems have the potential to promote proper tire inflation and that allowing lower cost systems will increase acceptance of the technologies. The agencies recognize that TPM systems have the potential to promote proper tire inflation and that allowing lower cost systems will increase acceptance of the technologies. We are finalizing provisions to allow TPM systems to receive credit. The non-box trailers, which have design-based tire standards, will be deemed to comply if they have a minimum of a TPM system and lower rolling resistance tires. The increased the number of options for tire pressure systems and inclusion of the cheaper TPM systems will improve the availability of technologies and reduce the technology cost.

Comments from the trailer industry were strongly opposed to any averaging at any point in the program, citing the highly competitive nature of the industry combined with a wide range of product diversity among companies likely leading to that it would unfairly benefit the few larger companies and be impossible to implement for many of the companies with limited product diversity. Additionally, compared to other industry sectors, trailer manufacturers noted that they can have little control over what kinds of trailer models their customers demand and thus limited ability to manage the mix and volume of different products. Comments from Strick, a small business box trailer manufacturer and a SER during the Panel process, opposed averaging and noted the unfair advantage that larger manufacturers would have in an averaging program.

The agencies generally agree with these concerns, and the final program limits the option for trailer manufacturers to apply averaging to MYs 2027 and later trailers. We believe this delay will provide the trailer manufacturers sufficient time to develop, evaluate, and market new technologies, and become familiar with the compliance process. As the standards become more stringent, the agencies believe the trailer manufacturers may wish for additional flexibilities in achieving the standards. The final program limits averaging to within a given model year and does not include banking or trading. Similar to the proposal, we are allowing deficits to be carried-over for up to three years.

TTMA commented that all trailer manufacturers are “small businesses” relative to other heavy-duty industries and that the one-year delay would divert sales to small businesses for that model year. Wabash National Corporation (Wabash) argued that providing a flexibility is not *required* by the RFA and not authorized by the Clean Air Act. The agencies believe that small businesses do not have the same resources available to become familiar with the regulations, make process and staffing changings, or evaluate and market new technologies as their larger counterparts. We believe a one-year delay will provide sufficient time for small businesses to address these issues, without a large CO_2 and fuel consumption impact. EPA is required to consider issues of cost and lead time under section 202 (a)(2), and can reasonably differentiate among classes of regulated entities based on these factors, and is doing so here. The cumulative annual production of all of the small business box trailer manufacturers is less than the annual production of the four largest manufacturers. We expect any diverted sales for this one year will be a small fraction of the larger manufacturers' production and we are accordingly finalizing the one-year delay for all small business trailer manufacturers.

12.8 Projected Economic Effects of the Final Rulemaking

This section summarizes the economic impact of the final Phase 2 rulemaking on small businesses. To gauge this impact, the agencies employed a cost-to-sales ratio test to determine if small businesses would be impacted by less than one percent, between one and three percent, and above three percent of their sales. The costs used in this analysis for the final requirements are based on the cost estimates developed for Chapters 2 and 7 of this RIA, and the Information Collection Request (ICR) required by the Paperwork Reduction Act. As noted below, the agencies believe that there will not be a significant economic impact on a substantial number of small entities as a result of the Phase 2 rulemaking.

12.8.1 Heavy-Duty Engine Manufacturer Economic Effects

As described above, the expected incremental burden for engine manufacturers to demonstrate compliance with the new greenhouse gas emission standards is to create a fuel map, measure N_2O emissions, and to report CO_2 and CH_4 emission values (which are already measured for certification related to criteria emissions).

We expect very small engine manufacturers to rely on contract test labs to perform emission testing, and that these labs already have N_2O testing capability. As a result, there should be no necessary capital expenditures to meet this requirement. Rather, we estimate the incremental cost of measuring N_2O for any hired certification testing to be on the order of $500 for each engine family. Manufacturers with greater resources might run their own laboratories, in which case they would need to purchase additional analytical equipment for measuring N_2O; however, this would only be the case if the companies' revenues would support this approach as a more cost-effective way of meeting the regulatory requirements.

The agencies believe it will cost $2,400 to generate a fuel map, which includes an estimated eight hours of dynamometer testing time at a rate of $300 per hour.

The smallest natural gas engine manufacturer certifies two engine families with 10 employees and annual revenue of $2.4 million. Their total cost is expected to be $5,900 to meet new requirements across their product line. These costs would be spread over several years, especially considering the possibility of using carryover data to certify over multiple model years. However, even applying this cost to a single year would represent only 0.2 percent of annual revenue.

The second smallest natural gas engine manufacturer certifies five engine families with 20 employees and annual revenue of $4.7 million. Their total cost is expected to be $14,700 to meet new requirements across their product line. Concentrating these costs again to a single model year represent only 0.3 percent of annual revenue. This worst-case assessment shows that the new requirements will not be a substantial burden for any small engine manufacturers.

12.8.2 Alternative Fuel Engine Converter Economic Effects

Alternative fuel converters continue to be subject to criteria standards. The incremental burden of this program is for reporting CO_2 and CH_4 emissions (where reporting is required), and performing an engineering analysis to demonstrate that modified engines continue to meet the N_2O standard. CO_2 and CH_4 emissions are currently measured to demonstrate compliance with CO and nonmethane hydrocarbon standards. We consider the additional burden for manufacturers to report include these two emissions values in their reports to EPA to be minimal.

Additionally, we believe the engineering analysis required for alternative fuel engine converters will be straightforward. Engines that do not include SCR (i.e., gasoline-fueled engines) have no propensity for increased N_2O formation and the analysis can simply state this. There is some greater concern for engines that rely on SCR; however, the manufacturer would only need to show that the fueling strategy and urea dosing allows for a reasonable expectation that N_2O formation across the catalyst will not increase.

Since aftermarket converters are simply verifying that their conversion did not change previously certified emission levels and we do not require full certification testing, engine converters are not required to generate engine fuel maps. The total estimated burden for aftermarket converters is about 1.5 engineering hours per model (or family).

Aftermarket converters performing fuel conversion on certified vehicles have supplied revenue and volume information as part of their reporting under 40 CFR part 85. The top five converters cover 80 percent of the production volume from this sector. The remaining 12 companies have an average annual revenue of about $1.1 million from an average of about 200 conversions.

To assess the cost burden for these small businesses, we assume the average small-volume engine converter must demonstrate compliance with conversions representing three different models (or families), resulting in an annual cost of about $240, which is 0.02 percent of average annual revenues for the 12 smallest aftermarket converters. These 12 companies also include a range of smaller and larger companies; however, even smaller companies would clearly not exceed 1 percent of annual revenue.

12.8.3 Vocational Vehicle Chassis Manufacturer Economic Effects

For vocational chassis manufacturers, EPA identified 19 companies that met SBA's small business threshold of 1,500 employees or fewer. As mentioned previously, we are adopting provisions that will allow custom chassis manufacturers (many of whom are small businesses) to use a simplified version of our GEM vehicle compliance tool. Part of this simplification includes use of a default driveline, which reduces the amount of data these manufacturers will have to collect and submit. Additionally, we are allowing electric vehicle manufacturers to certify without the use of GEM.

We did not assume the same costs for every year of the program. Instead, the first year is expected to require more capital costs and time from employees. Subsequent years include very few capital costs and less time. We are basing our analysis on an 8-year average cost, which includes the hourly cost of engineers, managers, attorneys, administrative and information technology support. We project that the average cost of compliance to be $47,000 for custom chassis manufacturers and $13,000 for electric vehicle manufacturers.

We compared these costs to the revenue information we collected from Hoovers for the 19 small business vocational chassis manufacturers. With all of the flexibilities adopted in this rulemaking, only two small vocational chassis manufacturers (11 percent) are projected to have an economic impact greater than one percent and no companies are projected to have an impact greater than three percent. Table 12-2 summarizes the small business vocational chassis results.

Table 12-2 Summary of Impacts on Small Business Vocational Chassis Manufacturers

	Number/Fraction of Entities with Economic Impact of…		
	< 1 %	1% to 3%	≥ 3%
Number of Small Businesses	17	2	0
Fraction of Small Businesses	89%	11%	0%

12.8.4 Glider Vehicle Manufacturer Economic Effects

As described in Chapter 12.4, there are large numbers of small businesses that produce vehicles from glider kits. The large majority of these are truck-repair facilities that occasionally find themselves in a situation where a customer wants to install an existing engine or powertrain into a glider kit. Under the final program, such companies that qualify as small businesses and that sold glider vehicles in 2014 may continue to produce vehicles from glider kits up to their historical levels over the 2010-2014 time frame, or up to 300 units, whichever is less. Almost all these companies will therefore not be constrained by the new provisions requiring additional glider vehicles beyond the applicable threshold to meet emission standards based on the date of the vehicle (i.e. the glider kit) into which an engine is installed . These companies will have no change in their business practice other than the requirement to notify EPA initially, submit an annual report with their production volumes, and add a label to their vehicles. These costs are much less than 1 percent of revenue even if production is limited to a single new vehicle.

The remaining assessment is for companies that produced more than 300 annual units. These companies would be subject to emission standards and would need to install newer engines in the glider vehicles they produce beyond the 300 cap. We would expect many customers in these circumstances to purchase a freshly manufactured vehicle instead of opting for a glider vehicle with compliant engines, so it is possible that they may see a drop in sales. However, any loss in sales would only be relative to recent years, and is not likely to drop below pre-2007 levels. Thus, it is not straightforward to determine how to quantify a cost burden for companies in this situation; however, it is apparent that any such companies should be characterized as having a cost burden that exceeds 3 percent of annual revenue. We are aware of one small business that produces more than 300 vehicles from glider kits. Nevertheless, this company has previously acknowledged that they could "make a profit at 300 a year."[4]

There are clearly fewer than 100 companies with sufficient production volumes such that their cost burden from the rule exceeds 1 or 3 percent of annual revenue.

12.8.5 Trailer Manufacturer Economic Effects

For trailers, EPA identified 147 companies that met SBA's small business threshold of 1,000 employees or fewer. As mentioned previously, we are limiting the non-box trailer program to tanks, flatbeds and container chassis, and exempting all other types of non-box trailers. As a result, 73 small business trailer manufacturers have zero burden from this rulemaking. The economic burden for the remaining 74 small business trailer manufacturers depends on which type of trailers they manufacture. Three companies exclusively manufacture box trailers, 69 only manufacture non-box trailers and two manufacturer both non-box and box trailers.

Prior to the start of the regulations, we projected that trailer manufacturers would incur some start-up costs to prepare for compliance. We assumed trailer manufacturers would purchase new computer systems to track sales and store compliance records, and new equipment for emissions labeling. We also assumed box trailer manufacturers would build an additional warehouse to store aerodynamic devices. We based this analysis on the assumption that all small box trailer manufacturers would take advantage of the pre-approved aerodynamic data option and would not perform any testing. We do assume a small engineering cost for engineers and managers to review the test procedures and become familiar with the requirements so they can appropriately evaluate available technologies. We also assume continuous costs associated with review of the regulations and guidance documents, evaluating aerodynamic and tire technologies, creating user manuals, calculating compliance values, generating applications and reports for compliance, and maintaining records.

We did not assume the same costs for every year of the program. Instead, the first year is expected to require more capital costs and time from employees. Subsequent years include very few capital costs and less time. We are basing our analysis on an 11-year average cost (the trailer program begins three years earlier than the other heavy-duty sectors in the Phase 2 rules), which includes the hourly cost of engineers, managers, attorneys, administrative and IT support. We project that the average cost of compliance to be $76,000 for trailer manufacturers that are certifying box and non-box trailers, $67,000 for manufacturers of box trailers only, and $23,000 for non-box trailer manufacturers. We compared these costs to the revenue information we collected from Hoovers for the 147 small business trailer manufacturers. With all of the flexibilities adopted in this rulemaking, only 18 small trailer manufacturers (12 percent) are projected to have an economic impact greater than one percent. Table 12-3 summarizes the small business trailer results.[5]

Table 12-3 Summary of Impacts on Small Business Trailer Manufacturers

	Number/Fraction of Entities with Economic Impact of…		
	< 1 %	**1% to 3%**	**≥ 3%**
Number of Small Businesses	129	15	3
Fraction of Small Businesses	88%	10%	2%

12.9 Summary of Economic Effects

The agencies identified five general heavy-duty industries that would be potentially affected by this rulemaking: alternative fuel engine converters, heavy-duty engine manufacturers, vocational vehicle chassis manufacturers, glider manufacturers, and trailer manufacturers. The agencies proposed and sought comment on the recommendations from the Panel. The flexibilities proposed for the engine manufacturers, engine converters, vocational vehicle manufacturers, and glider manufacturers are adopted in the final rule (with increased flexibility in some cases) and fewer than 20 percent of the small entities in those sectors are estimated to incur a burden greater than one percent of their annual revenue. In addition to the flexibilities proposed for the trailer program, the agencies also reduced the number of small entities regulated by the final rules by limiting the non-box trailer program to three distinct trailer types. As a result, more than half of the small business trailer manufacturers have zero burden from this rulemaking. Of the remaining small business trailer manufacturers, only 12 percent are estimated to have an economic impact greater than one percent of their annual revenue. As a result of these findings, EPA believes it can certify that these rules will not have a significant economic impact on a substantial number of small entities under the RFA.

References

[1] Final Report of the Small Business Advocacy Review Panel on EPA's Planned Proposed Rule: Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles: Phase 2. Signed on January 15, 2015. Available in docket at: EPA–HQ–OAR–2014–0827.

[2] Small Business Size Standards for Manufacturing. Small Business Administration. Docket ID: SBA-2014-0011. Available online at: https://www.regulations.gov/docket?D=SBA-2014-0011.

[3] Final Report of the Small Business Advocacy Review Panel on EPA's Planned Proposed Rule: Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles: Phase 2. Signed on January 15, 2015. Available in docket at: EPA–HQ–OAR–2014–0827.

[4] http://www.truckinginfo.com/article/story/2013/04/the-return-of-the-glider.aspx., accessed July 16, 2016.

[5] Memorandum to Docket EPA-HQ-OAR-2014-0827: "Small Business Economic Burden Calculations for Trailer SISNOSE Analysis." July 2016.

Chapter 13: Natural Gas Vehicles and Engines

13.1 Detailed Lifecycle Analysis

In this section we present our assessment of the lifecycle impacts of natural gas used by the heavy-duty truck sector. We also present the results of an analysis by the Energy Information Administration projecting the future use of natural gas by heavy-duty trucks. Finally, we list a number of potential technologies which could help to reduce the methane emissions from natural gas trucks.

This section was updated and improved in a number of ways since the draft analysis in the proposed rulemaking. First, the estimated upstream methane emissions from the natural gas sector were updated to the 2016 Greenhouse Gas (GHG) Inventory which estimates GHG emissions in 2014. This is important because the GHG Inventory was revised to show much higher upstream methane emissions for natural gas. While the GHG emissions associated with the production of petroleum was also updated in the GHG Inventory, the GHG emissions associated with diesel fuel was not updated in this analysis because GREET, which is the source for diesel fuel GHG emissions, has not yet been updated with the new upstream GHG emission estimates. Using the latest GHG Inventory with higher re-estimated upstream methane emissions from the natural gas sector responds to comments which claim that the previous year's GHG Inventory underestimates GHG emissions from the upstream natural gas sector.

Second, methane tailpipe emissions from 2014 and later natural gas trucks, which must meet a 0.1 g/brake horsepower-hour methane emissions standard, was estimated for this final rule lifecycle emissions analysis based on certification data for trucks complying with the methane emissions standard. For the proposed rule analysis we based the estimate of methane tailpipe emissions from natural gas heavy-duty trucks either on the methane emissions standard or on trucks prior to the methane emissions standard because data was not yet available to estimate what actual emissions would be under the methane emissions standard.

Third, the natural gas heavy-duty truck lifecycle emissions analysis now estimates some additional methane emissions from natural gas heavy-duty trucks. The new methane emission points includes refueling emissions, CNG compressor emissions and methane emissions from LNG liquefaction plants which were not includes in the lifecycle analysis in the proposed rulemaking. Estimating and including these additional methane emissions in our lifecycle analysis responds to comments that our analysis was missing some methane emissions from natural gas trucks.

13.1.1 Upstream Emissions

Upstream methane emissions, occurring in the natural gas production, natural gas processing, transmission, storage and distribution sectors, are estimated and summarized in an annual report "Inventory of U.S. Greenhouse Gas Emissions and Sinks" (GHG Inventory) submitted to the United Nations Framework Convention on Climate Change (UNFCCC).[1] As a basis for estimating the lifecycle impact of natural gas use by heavy-duty trucks, we used the year 2014 methane emission estimates in the most recent GHG Inventory, published in 2016.[A] The GHG Inventory also includes the quantity of carbon dioxide which is co-produced with methane throughout the natural gas system and emitted to the atmosphere through venting, flaring, and as fugitive emissions.

The GHG Inventory is updated annually to account for new emission sources (e.g., new natural gas wells), updated data, emission factors and/or methodologies, and to account for changes in emissions due to changes in policy, regulations and industry practices. The GHG Inventory reflects emission reductions due to existing state regulations, National Emission Standards for Hazardous Air Pollutants (NESHAP) promulgated by EPA in 1999,[2] the New Source Performance Standards (NSPS OOOO) promulgated by EPA in 2012,[3] and Natural Gas Star (a flexible, voluntary partnership that encourages oil and natural gas companies to adopt proven, cost-effective technologies and practices that improve operational efficiency and reduce methane emissions).[4]

Emission estimates in the GHG Inventory are generally bottom-up estimates which are per-unit (compressor, pneumatic valve, etc.) emission estimates based on measured or calculated emission rates from such emission sources.

In addition to the national-level data available through the GHG Inventory, facility-level petroleum and natural gas systems data is also available through EPA's Greenhouse Gas Reporting Program (GHGRP). These data represent a significant step forward in understanding GHG emissions from this sector and EPA expects that this data will be an important tool for the Agency and the public to analyze emissions, and understand emission trends. EPA is already using GHGRP data to update emission estimates in the GHG inventory, and EPA plans to continue to leverage GHGRP data to update future GHG Inventories.

Before discussing the lifecycle emissions of CNG and LNG, it is important to understand the logistics of providing natural gas for CNG and LNG. The natural gas which comprises CNG is expected to be off-loaded from the natural gas system where the vehicles using CNG are refueled. This is because the natural gas used as CNG is compressed at the retail stations and fleet facilities which fuel the CNG vehicles. To get the natural gas to the CNG retail facilities, the natural gas must be shipped through the distribution system downstream of the natural gas transmission system. When the natural gas is transmitted through the distribution system, the methane emissions are higher because the methane emissions from the distribution system are added to the rest of the upstream methane emissions.

Because LNG plants are located separate from the retail facilities, they can be located to access the lowest cost feedstock. This means the natural gas for LNG can be sourced from the larger natural gas transmission pipelines which are upstream of the distribution pipelines. This provides two advantages for LNG: 1) by avoiding the natural gas distribution system, the natural gas is priced lower, and 2) avoiding the natural gas distribution system avoids the methane emissions which occur from the distribution system. Table 13-1 contains the 2014 methane emissions estimate based on the GHG Inventory. About 10 percent of the natural gas consumed

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[A] Compared to the 2015 U.S. GHG Inventory, the 2016 U.S. GHG Inventory natural gas methane emission estimates are much higher for natural gas production, about the same level of methane emissions for natural gas processing, and much lower from natural gas transmission, storage and distribution.

in the US is sourced from Canada, and the GHG Inventory does not include the methane emissions from the Canadian natural gas. Table 13-1 contains a second column of values which adjusts the field production and the natural gas processing upwards by 10 percent to estimate and account for those methane emissions.

Table 13-1 Methane Emissions from the Natural Gas System in 2014

EMISSION POINT FROM NG FACILITIES	METHANE EMISSIONS (GIGAGRAMS)	METHANE EMISSIONS ADJUSTED FOR CANADIAN NATURAL GAS (GIGAGRAMS)
Field Production	4359	4843
NG Processing	960	1067
Transmission and Storage	1282	1282
Subtotal without Distribution	6601	7192
Distribution	444	444
Total with Distribution	7045	7636

The methane emissions attributed to the production of natural gas does not account for the methane emissions caused when producing the natural gas associated with the production of crude oil. According to the Energy Information Administration, natural gas produced along with (associated with) crude oil production comprises 18 percent of the total quantity of natural gas produced in the U.S. To estimate the methane emissions from associated natural gas wells, we accessed the estimated methane emissions from the petroleum sector in the GHG Inventory, which is 2694 gigagrams (kilotons) of methane in 2014. To estimate what fraction of these methane emissions is being emitted by associated wells versus petroleum only wells, we applied a fraction of associated wells to total crude oil wells. There are 503,873 associated wells out of a total of 898,268 crude oil wells, or 56 percent.

EPA is taking additional steps to reduce the emissions of methane from the natural gas and oil production facilities. On May 12, 2016, EPA finalized regulations (2016 NSPS OOOOa) which, among other things, include methane standards for new, modified, and reconstructed oil and gas equipment used across the oil and gas source category (before this amendment, these rules only covered VOC, not methane directly), and require the use of reduced emissions completions (RECs) at hydraulically fractured oil wells.[B] [5] In March of 2016, the Obama Administration and the Environmental Protection Agency announced plans to regulate emissions from existing oil and gas sources.[6] [7] The goal of these various actions is to achieve an aggregated 40 to 45 percent reduction in methane emissions relative to methane emissions in 2012. The lifecycle analysis in this Chapter 13 does not take into account the 2016 NSPS, or any future action that would address existing sources of methane emissions. As such, this analysis

[B] Reduced emission completions is a technology for capturing natural gas emissions during the time that the well is being completed and the production from the well is inconsistent and includes a lot of water.

likely overestimates future methane emissions from natural gas facilities for this lifecycle analysis which attempts to model emissions in the year 2025.

The GHG Inventory also includes the quantity of carbon dioxide which is co-produced with methane throughout the natural gas system and emitted to the atmosphere through venting, flaring, and as fugitive emissions. Similar to how we adjusted the methane emissions to account for Canadian-produced natural gas, we made a similar adjustment here to estimate the quantity of carbon dioxide being emitted from Canadian natural gas wells. The quantity of carbon dioxide being emitted from natural gas wells is summarized in Table 13-2.

Table 13-2 Carbon Dioxide Emissions from the Natural Gas System in 2014

EMISSION POINT FROM NG FACILITIES	CARBON DIOXIDE EMISSIONS (GIGAGRAMS)	CARBON DIOXIDE EMISSIONS ADJUSTED FOR CANADIAN NATURAL GAS (GIGAGRAMS)
Production	18,585	20,650
NG Processing	23,713	26,348
Transportation and Storage	39	39
Distribution	14	14
Total	42,351	47,050

In the GHG Inventory, EPA assessed the amount of uncertainty with its emission estimates and provided a lower and upper bound estimate for its emission estimates. The lower bound emission estimate is 19 percent lower than the best case estimate in Table 13-1 and the upper bound estimate is 30 percent higher than the best case estimate.

In the 2016 Second Biannual Report of the United States of America, EPA projects that total methane emissions will increase in the future due to increases in natural gas production.[8] Table 13-3 summarizes the projected increase in US methane emissions from the Climate Action Plan and the projected increase in natural gas production referenced from Energy Information Administration's 2015 Annual Energy Outlook.

Table 13-3 Projected Natural Gas Production Volume and Methane Emissions (g/million BTU)

YEAR	2014	2025
Methane Emissions Teregram CO_2eq.	641	674
Natural Gas Production (dry) trillion cubic feet	25.57	30.51

As Table 13-3 shows, methane emissions from natural gas facilities are expected to increase from 641 teregram CO_2eq in 2014 to 674 teregram CO_2 eq. in 2025, about a 5 percent increase. At the same time, natural gas production of dry natural gas is expected to increase from 25.6 trillion cubic feet in 2014 to 30.5 trillion cubic feet in 2025, about a 19 percent increase. When estimating the methane emissions on the same natural gas production basis, the methane emissions are projected to be 12 percent lower in 2025 than 2014.[C]

In the GHG Inventory, emissions associated with powering the units or equipment (i.e., compressors, pumps) used in natural gas production, processing, transmission and distribution are aggregated with all the other fossil fuel combustion activities. Rather than attempt to disaggregate those specific GHG emissions from the rest of the process emissions in the GHG Inventory, we instead used the estimated emissions for these sources provided by GREET.[9] Table 13-4 summarizes the process energy consumed to produce and process natural gas.

Table 13-4 Process Energy Demand by the Natural Gas System (BTU/million BTU)

FUEL TYPE	PRODUCTION			NATURAL GAS PROCESSING	TRANSMISSION/ DISTRIBUTION	TOTAL	TOTAL – INCLUDES PROCESS ENERGY FOR CANADIAN GAS
	Conv Wells	Shale Wells	Weighted Average				
Natural Gas	22,016	20,955	21,307	26,123	0	47,687	52,986
Diesel	2816	2680	2725	272	0	3030	3367
Electricity	256	244	248	816	0	1067	1185
Gasoline	256	244	248	0	0	251	279
Residual Fuel	256	244	248	0	0	251	279
Totals	25,600	24,367	24,777	27,211	0	52,286	58,096

Table 13-5 contains the factors we used to convert the GREET process energy demands used to operate the equipment used to produce, process and distribute natural gas to carbon dioxide emissions for those process fuels.[10]

[C] The 12% reduction figure is calculated by multiplying the methane emissions estimate in 2025 by the ratio of 2014 natural gas production over the 2025 natural gas production (674x25.6/30.5) and the resulting value is 115, which is 88% of 641, or 18% less.

Table 13-5 Carbon Dioxide Emission Factors for Process Fuel Consumption

PROCESS FUEL	GCO2/BTU
Natural Gas	0.0398
Diesel	0.0555
Electricity	0.1549
Gasoline	0.0535
Residual Fuel	0.0563

Table 13-6 summarizes the total estimated methane and carbon dioxide emissions emitted by the upstream natural gas system. Two estimates are provided, one of which includes the emissions from the distribution system representing the upstream emissions for CNG. The second estimate summarizes the emissions excluding the emissions from the distribution system representing the upstream emissions for LNG, since it is expected to access the natural gas from the transmission portion of the natural gas system.

Table 13-6 Projection of Year 2025 Emissions from the Natural Gas System (grams/million BTU)

	METHANE EMISSIONS	CARBON DIOXIDE
CNG Analysis (includes CH_4 emissions from the distribution system)	320	3885
LNG Analysis (does not include CH_4 emissions from the distribution system)	305	3885

13.1.2 Downstream Emissions

The GHG Inventory does not estimate the methane emissions for natural gas once the natural gas is diverted for use by the transportation sector, thus, we obtained information from other sources. Natural gas can be used by vehicles either as a compressed gas (CNG) or as liquefied natural gas (LNG). We discuss the emissions of both.

13.1.2.1 Compressed Natural Gas (CNG)

To make CNG available to trucks, the natural gas must be compressed from the pressure that it is available from the distribution pipelines to a pressure over 3600 psi to enable filling the truck CNG storage tanks which are either 3,000 pound per square inch gauge (psig) or 3,600 psig. We used the GHG emissions from GREET for compression for this step which reflects national-average emissions for electricity generation for the electricity required to compress CNG.[11] We also estimated that fugitive emissions from compressors are 34 grams of methane per million BTU of natural gas compressed. The estimate is based on an EPA report which estimated methane emissions from reciprocal compressors at a storage facility to be 300,000 standard cubic feet of methane per year.[12] This value is supported by a more recent review of compressor emissions.[13] The packing seal emissions are assumed to be emitted from a typical sized reciprocating compressor that are used in retail CNG stations which compresses 20,000 standard cubic feet of natural gas per hour.[14] We assumed that these compressors operate 24 hours per day. The GHG emissions associated with electricity generation for compressing natural gas and the fugitive emissions associated with natural gas compression for CNG are summarized in Table 13-7.

Table 13-7 Estimated Emissions for Electricity Generated to Power CNG Compressors (g/million BTU)

FUGITIVE EMISSIONS	ELECTRICITY GENERATION		
Methane	Methane	Carbon Dioxide	Nitrous Oxide
34	6.9	3988	0.06

An important advantage that CNG has over LNG is that only a single facility, the retail outlet, is required for distributing CNG, while LNG requires both a liquefaction plant and a retail outlet. The simplified logistics of providing CNG also provides fewer opportunities for emissions and leakage to the environment.

The act of refueling CNG trucks can contribute to methane emissions. When the truck driver connects the refueling hose to the refueling port on the truck and begins refueling, there may be refueling emissions from the station equipment and also the truck's refueling nozzle. We estimate a quantity of refueling emissions based on the emission limits of several pieces of equipment involved in the refueling process. As summarized in Table 13-8, United Nations regulation number 110 Revision 3 specifies emissions limits for flexible piping, refueling fittings and pressure relief valves.[15] In deriving an emissions estimate, we assume that these various refueling hardware devices emit half of these emissions limits over the respective hardware's lifetime. For example, flexible fuel lines are limited to emitting 95 cubic centimeters per day per meter of flexible fuel line of methane or natural gas per day. We assumed that 3.5 meters of flexible piping would be required and that the emissions levels would be 95/2 or 47.5 cubic centimeter per day per meter of piping. To estimate the emissions associated with decoupling the refueling fittings we used emissions data from an emissions study.[16] The methane emissions associated with decoupling the CNG refueling nozzles is based on actual measurements of decoupling CNG refueling nozzles. Table 13-8 summarizes the emissions standard from which we estimate the quantity of methane emissions, and summarizes the resulting emission value per million BTU of natural gas consumed.

Table 13-8 Summary of CNG Refueling Emissions

	Emissions Standard	Other Assumptions	g/MMbtu
Flexible Piping	95 cm^3/meter-day (assume 3.5 meters)	Refueling 60 gallons equivalent over 12 minutes	0.0001
Refueling Fittings	15 cm^3/hour	Refueling 60 gallons equivalent over 12 minutes	0.0001
Pressure Relief disk	15 cm^3/hour	Refueling 60 gallons equivalent over 12 minutes	0.0001
CNG Decoupling Fueling Hose Emissions	5 cm^3/refueling event	Refueling 60 gallons	0.449

Another potential source of fugitive emissions is from small leaks in the CNG fuel storage system. While CNG has an advantage over LNG because it is contained in a sealed system, the very high pressure at which CNG is stored dramatically increases fugitive emissions if a fitting pipe were to develop a leak. The level of fugitive emissions for a certain sized hole is directly proportional to the pressure. We do not have any data on the fugitive emissions from CNG trucks, therefore, in our lifecycle analysis, we assume that CNG fugitive emissions are zero which likely underestimates the methane emissions from CNG trucks.

13.1.2.2 Liquefied Natural Gas (LNG)

The first step in making LNG available to trucks is the liquefaction step. As discussed above, the liquefaction plant is likely to be constructed near natural gas transmission pipelines to access the natural gas at the lowest price point. The liquefaction step involves the removal of heat from the natural gas until it undergoes a phase change from a gas to a liquid at a low pressure. Once the natural gas is liquefied, it is stored in an insulated storage tank to keep the LNG liquefied.

LNG plants are configured depending on their ultimate capacity. Large LNG export facilities produce 5 million metric tons, or more, per year of LNG and the economy of scale of these large plants support the significant addition of capital to reduce their operating costs. An LNG plant solely producing LNG for truck fuel is expected to be significantly smaller than the large LNG export facilities and so the capital invested is expected to be much lower, thus, their operating costs would be expected to be much higher, and their energy efficiency much lower on a percentage basis. The California Air Resources Board estimated that the liquefaction plants used for producing truck LNG fuel are 80 percent efficient, compared to 90 percent efficient for large LNG export facility.[17] Recently, CARB estimated the lifecycle impacts of LNG using both 90 and 80 percent efficient LNG liquefaction plants (this assessment by CARB is solely for illustrative purposes – to qualify for credit under the Low Carbon Fuel Standard (LCFS), the actual LNG plant performance would need to be the basis for requesting credit under the Low Carbon Fuel Standard). In our lifecycle analysis of LNG as a truck fuel, we assumed that LNG plants are 80 percent efficient based on the earlier CARB paper along with additional review of LNG plant types most likely to be used for providing LNG fuel for truck stops.[18] [19] Methane emissions from LNG plants are estimated to be 14 grams per million BTU based on a National Energy Technology Laboratory report.[20] For our GHG analysis, we estimate the carbon dioxide emitted when 20 percent of the natural gas is combusted to provide the energy required to liquefy the natural gas to LNG. The upstream emissions associated with the natural gas consumed in the liquefaction process must be accounted for and added onto the LNG produced by the plant. These emissions are included as indirect emissions. Table 13-9 summarizes the GHG emissions attributed to the liquefaction plant.

Table 13-9 LNG Liquefaction Plant Emissions (g/million BTU)

	METHANE	CARBON DIOXIDE
Direct Emissions	14	15,175
Indirect Emissions	61	971
Total Emissions	76	16,146

To transport the LNG to the retail station, the LNG is loaded into an insulated horizontal trailer designed specifically for transporting LNG. If the LNG in the trailer were to warm sufficiently to cause the LNG to reach the pressure relief valve venting pressure, there would be boil-off emissions from the trailer. However, since the LNG is super cooled, boil off events are likely to be rare. We used a CARB estimate of boil-off emissions for LNG transportation between the LNG plant and retail outlets.[21] Table 13-10 contains the estimate of boil off emissions and the emissions from the vehicle transporting the LNG to retail.

Table 13-10 Boil-Off Emissions Estimate for LNG Transportation to Retail (g/million BTU)

	METHANE	CARBON DIOXIDE	NITROUS OXIDE
Fuel Use (Diesel Fuel)	0.45	378	0.009
Methane Boil Off Emissions	0.43	0	0
Total	0.88	378	0.009

LNG is stored in the insulated storage tank at the retail facility. Heat gain in the storage tank could eventually lead to boil-off emissions. Service stations with little LNG demand are at a higher risk of boil-off emissions compared to service stations which have a significant throughput volume. LNG stations could be configured to avoid boil-off events to the atmosphere, such as venting to a co-located CNG facility, or venting to a nearby natural gas pipeline re-liquefying the boil off vapor and flaring the boil off gas.[22] We used a GREET emission estimate to provide an estimate of the boil-off emissions from LNG retail facilities.[23] Table 13-11 summarizes the estimated boil off emissions for LNG retail facilities.

Table 13-11 Boil-Off Emissions Estimate for LNG Retail Facilities (g/million BTU)

LNG RETAIL BOIL-OFF EMISSIONS	35

The act of refueling LNG trucks can contribute to methane emissions. We used the same method described above for estimating the emissions from refueling CNG trucks to estimate refueling emissions from LNG trucks. Table 13-12 below summarizes our estimate for the emissions from LNG trucks.

13-12 Summary of LNG Refueling Emissions

	Emissions Standard	Other Assumptions	g/MMbtu
Flexible Piping	95 cm3/meter-day (assume 3.5 meters)	Refueling 60 gallons equivalent over 12 minutes	0.0001
Refueling Fittings	15 cm3/hour	Refueling 60 gallons equivalent over 12 minutes	0.0001
Pressure Relief Valves	15 cm3/hour	Refueling 60 gallons equivalent over 12 minutes	0.0001
LNG Decoupling Fueling Hose	2.4 cm3/refueling event	Refueling 60 gallons	0.435

The total well to tank emissions for CNG and LNG are summarized in Table 13-14. These emissions represent the total of upstream and downstream emissions which includes delivering the fuel to the truck fuel storage tank.

Table 13-13 Total Well to Tank Emissions Estimate for CNG and LNG (g/million BTU)

	METHANE	CARBON DIOXIDE	NITROUS OXIDE
CNG	361	7598	0.06
LNG	432	20,409	0.009

13.1.3 Vehicle Emissions

13.1.3.1 Vehicle Configurations

There are several different ways that diesel heavy duty engines can be configured to use natural gas as a fuel. The first is a spark ignition natural gas (SING), Otto cycle SING heavy duty engine burns the fuel stoichiometrically and uses a three-way catalyst. Some also add an oxidation catalyst to provide the greatest emissions reduction. Stoichiometric combustion is used in most light-duty SING engines and is used in heavy-duty service as well, but is particularly popular for natural gas trucks. Problems with thermal stress and low power density have favored the use of the lean-burn combustion system in some heavy duty engine applications. The use of cooled EGR provides further potential to increase the engine output and, at the same time, decreases NO_X emissions. In this case the engine compression ratio is reduced similar to that of a gasoline engine, about 12 to 1 or more, and thus its thermal efficiency is lower than a diesel-like engine by about 10 - 15 percent, depending on the driver.

The second is a direct injection natural gas (DING), diesel cycle. The DING engine uses a small quantity of diesel fuel (pilot injection) or a glow plug as ignition sources. As the injection system for the diesel fuel does not have the capability of greater injection quantities, this option has no dual-fuel properties, but allows for about 95 percent of the fuel to be provided by natural gas. Additionally, the optimization of the pilot injection can be made to achieve lower emissions. An advanced high pressure direct injection (HPDI) fuel system combining the injection of both diesel fuel and natural gas can be used for lean burn combustion. This enables the engine to maintain the efficiency advantage of a compression ignition engine while running mainly CNG/LNG.

The third is a mixed-fuel natural gas (MFNG), diesel cycle. In a mixed-fuel engine, natural gas is mixed with intake air before induction to the cylinder and diesel fuel is used as ignition source. Mixed-fuel vehicle/engine means any vehicle/engine engineered and designed to be operated on the original fuel(s), or a mixture of two or more fuels that are combusted together. Mixed-fuel system means that a diesel engine works with two types of fuels together. In fact the engine is a diesel thermodynamic cycle and the energy is given by the diesel and the natural gas fuel. In mixed-fuel conversion the original engine is not modified in any way, a conversion system is installed in order to permit the engine to run on both fuels. The conversion of the engine is totally reversible, in fact it is possible to choose the mode how to run the engine (diesel / mixed-fuel). When the engine runs in diesel mode, the engine runs in the same way as per the original configuration. Engine results showed that the efficiency of the engine could decrease by about 2-5 percent in mixed-fuel mode compared to diesel mode and that the diesel replacement was approximately 40-60 percent efficient.

Each of these natural gas engine types has its merits. The SING engine is less costly, but is less fuel efficient and because of the lower compression ratio it has less torque than the two diesel cycle engines. The DING engine is likely the most expensive because of the special natural gas/diesel fuel injection system and large required amount of natural gas (LNG or CNG) storage since the truck must run on natural gas. However, because the truck can run almost completely on natural gas, the DING engine has the potential to more quickly pay down the higher investment cost of the natural gas truck. The MFNG engine provides the truck owner the flexibility to operate on natural gas or diesel fuel, but at the expense of a slower natural gas investment pay down rate because it can operate at most 50 percent of the time on natural gas.

An important advantage of LNG is the increased energy density compared to CNG. At present, CNG stored at its maximum storage pressure is only 25 percent of the energy density of diesel fuel, while LNG contains about 60 percent of the energy density of diesel fuel. Because of its higher energy density, LNG is favored over CNG for long-haul trucking.

An adsorbent for natural gas (ANG) material technology[D] called metal organic framework (MOF) for storing CNG has been invented and is being tested for large scale use. The technology involves filling the CNG tank with a specially designed substance which looks similar to a pelletized catalyst. The substance establishes a matrix which causes the methane molecules in natural gas to become better organized and store the same quantity of natural gas in a smaller volume at the same pressure, or store the same density of natural gas at a lower pressure. This MOF could improve the energy density of CNG which would make it a better candidate for natural gas storage for long range combination trucks, while avoiding the boil-off events that are a risk with using LNG.

13.1.3.2 Tailpipe Emissions

When assessing the methane emissions from both CNG and LNG trucks, it is important to separate those trucks built or converted before 2014 to those built or converted in 2014 and later. The trucks built before 2014 are only required to meet a nonmethane hydrocarbon (NMHC) standard, which means that the methane emissions from these trucks are unregulated. Our certification data shows that the methane tailpipe emissions from these trucks/buses ranges from 2 – 5 g/bhp-hr for both spark ignition (gasoline type) and compression ignition (diesel type) engines.

For 2014 and later OEM compression ignition natural gas trucks or natural gas conversions of 2014 and later diesel trucks, the trucks must meet a 0.1 g/bhp-hr methane emission standard in the case of a larger truck engine tested with an engine dynamometer, and a 0.05 g/mile methane emission standard in the case of smaller trucks tested on a chassis dynamometer.[E] For spark ignition (gasoline style) engines, the standards take effect in 2016.[24] The natural gas truck manufacturers are allowed to offset methane emissions over the standard by converting the methane emission exceedances into CO_2 equivalent emissions and using CO_2 credits. For the initial natural gas engine certifications that EPA has received for 2014, 2015 and 2016 model years, the truck manufactures chose to continue to emit high levels of methane (ranges from 0.7 to 2 g/bhp-hr) and use carbon dioxide credits to offset those emissions. We don't know if this practice of using CO_2 credits to offset high methane emissions will continue in the future; however, for evaluating the lifecycle impacts of natural gas heavy-duty vehicles, the 2014 and later natural gas heavy-duty trucks may in fact have an emissions profile in-between the pre-2014 trucks and the 2014 and later trucks. Our emissions analysis assumes that these

[D] Menon, V.C., Komarneni, S. 1998 "Porous Adsorbents for Vehicular Natural Gas Storage: A Review," Journal of Porous Materials 5, 43-58 (1998); Burchell, T "Carbon Fiber Composite Adsorbent Media for Low Pressure Natural Gas Storage" Oak Ridge National Laboratory.
[E] An exception is that small volume, heavy-duty natural gas truck manufacturers are exempt from EPA's GHG regulations.

trucks are emitting 1 gram per brake horsepower-hour methane emissions. In cases when these trucks experience an increase in emissions due to deterioration or malfunction of the engines, fuel supplies or associated emission control devices on these trucks, the methane emissions could be higher than estimated. Table 13-14 summarizes the emission standards and the estimated methane emissions from heavy-duty trucks assumed in the analysis.

Table 13-14 Methane Emission Standards and Estimated Emissions from Heavy-Duty Trucks

		PRE-2014	2014 AND LATER
Methane Standard		None	0.1 g/bhp-hr
Estimated Emissions	g/bhp-hr	2 – 5	1
	g/million BTU	214 – 534	107

13.1.3.3 Boil-off, Venting and other Fugitive Emissions

Truck drivers requiring LNG fuel drive up to an LNG retail outlet or fleet refueling facility and fill up with LNG fuel. Prior to refueling it may be advantageous or necessary, due to high pressure in the truck's LNG tank, to reduce the pressure in the truck's LNG tank to speed up the refueling process. In some cases the retail station is equipped with another hose and associated piping to vent the excess gas to the retail stations' storage tank, or perhaps to a natural gas pipeline. However, for those retail outlets without such vent lines to the storage tank, the truck driver may simply vent the truck's storage tank to atmosphere. As part of a sensitivity analysis for our lifecycle analysis, we estimate the emissions for venting an LNG tank prior to refueling. A major issue with respect to GHG emissions associated with LNG trucks is boil-off emissions from the trucks themselves. When the liquefied natural gas is pumped into the truck LNG tanks, it is "supercooled," meaning that the temperature of the LNG is well below the boil-off pressure and temperature. A typical refueling temperature of LNG is -190F, which corresponds to 164 pounds per square inch absolute, or 149 pounds per square inch gauge. If the truck is driven extensively the drawdown of liquid level will cause some of the fuel to boil off and thus cool the rest of the liquid in the LNG storage tank. It is possible that the fuel would maintain its supercooled temperature, or possibly even cool further below its supercooled temperature until the LNG is completely consumed.

If the truck is not driven or is driven very little, the very low temperature LNG warms through ambient temperature gradient through the tank wall causing the temperature and pressure of the LNG to rise. When the pressure reaches a maximum of 230 psi ta safety release valve on the LNG storage tank releases methane gas directly to the atmosphere until the pressure drops to the reset pressure of the safety release valve. There are two industry standards used to design tanks to reduce the temperature increase, one for a 3 day hold time[F] and one for a 5 day hold time.[G] Hold time is the minimum time elapsed between when the truck's LNG tank is refueled and when it begins to vent.

[F] National Fire Protection Association 52, Compressed Natural Gas (CNG) Vehicular Fuel System Code, 2002 Edition.
[G] SAE International (2008) SAE J2343: Recommended Practice for LNG Medium and Heavy-Duty Powered Vehicles. Warrendale, Pennsylvania.

If there is a boil-off event, a large amount of methane would be released. If aware of the impending boil-off such as when the truck is being maintained, the truck driver could hook up the LNG tank to a hose which would vent the natural gas emissions to a CNG system which would reuse the boil-off natural gas as CNG, or combust the LNG to carbon dioxide, or vent the natural gas emission to a natural gas pipeline. Otherwise the boil-off emission would simply vent to the atmosphere.

When an LNG fuel tank venting (refueling venting or boil-off) incident occurs, there are two separate processes which occur that contribute to methane emissions during the venting. The most obvious process is the pressure drop, from 230 to 170 psi, in the gaseous space above the liquid. The volume of gas vented is proportional to the reduction in absolute pressure in the tank. Since the drop in absolute pressure is 244 to 184 psi (14.7 psi is added to the 230 and 170 psi gauge pressure), about 25 percent of the gas in the tank is vented (184 psi is 25 percent of the way from 244 psi to zero pressure). The second process is the vaporization of liquid during the pressure reduction in the LNG tank. The boiling point of any liquid decreases as the pressure decreases. Thus, when the LNG undergoes the pressure reduction during a venting/boil-off, the boiling point of the methane decreases and to balance the system, some of the liquid methane must boil off to cause the liquid to be cooled. The quantity of liquid methane which must boil off from the liquid is calculated from methane's heat of vaporization over the boiling point temperature change, which drops from -178 F to -189 F as the pressure drops from 230 to 170 psi.

The amount of natural gas which boils off during a venting event varies based on the quantity of liquid in the LNG storage tank. The greatest amount of natural gas which is lost during a venting/boil off event occurs when the tank is closest to being full. For a 200 gallon tank system, each boil off event has the potential to release on the order of 3-9 gallons or 5,300 – 15,800 grams of CH_4 which translates to 132 – 400K grams of CO_2-equivalent emissions, assuming methane has global warming potential (GWP) of 25 over a 100 year lifetime.[25] If the vehicle continues to sit after boil-off events begin to occur with boil-off events each day and up to several boil-offs per day, as much as million grams of CO_2-equivalent emissions may be emitted over the twenty or so days at which point the vehicle LNG tank would be completely empty.

Table 13-15 summarizes the starting and ending conditions and the loss from the tank for venting incidents (200 gallon LNG tank decreases in pressure from 230 to 170 psi) when the LNG tank is 90 percent, 50 percent and 10 percent full. A refueling venting event is more likely to occur when the tank is mostly empty, so the 50 and 10 percent cases are the most likely cases to consider.

Table 13-15 Estimated Quantity of Boil-Off from a 200 Gallon LNG Fuel Tank for a Single Boil-Off Event

	PERCENT FULL (INITIAL)	PERCENT FULL (FINAL)	LIQUID LOSS (GALS)	TOTAL MASS LOSS (LBS)
Boil-off Scenarios	90	83.2	13.6	38.7
	50	46.2	7.6	24.8
	10	9.3	1.5	11.0

Table 13-15 shows that if a truck had 200 gallon of LNG storage capacity, the estimated quantity of liquid boil-off volume would range from 2 to 14 liquid gallons of LNG depending on the fill level of the LNG tank. When the quantity of LNG gas loss is included, the total loss ranges from 11 to 39 lbs.

The quantity of LNG tank boil-off or venting per distance driven by the truck depends on the frequency of boil-off or venting incidents. As described above, a truck's driving profile plays a key role in determining the boil-off risk from LNG trucks. Fleets which purchase LNG trucks do so with the intent of driving the LNG truck extensively to pay off the much higher purchase price of the LNG truck. For this reason, there are likely to be few boil-off incidents, except for cases when the truck is forced out of its routine. Examples of when the truck might be sidelined include times when the truck is being maintained, the immediate period after the truck is involved in an accident, or perhaps when the owning company experiences a loss of workload or files for bankruptcy. We have no data which would allow us to estimate the frequency when these sorts of incidents would occur, and even if we did, we still could not estimate the frequency of boil-offs that occur in these cases.

As the truck ages, it likely would be sold by the company which originally purchased it to avoid having to deal with the increased maintenance that occurs with older trucks. Figure 13-1 shows the estimated vehicle miles traveled by class 8 trucks as they age (the data is from the MOVES Model.

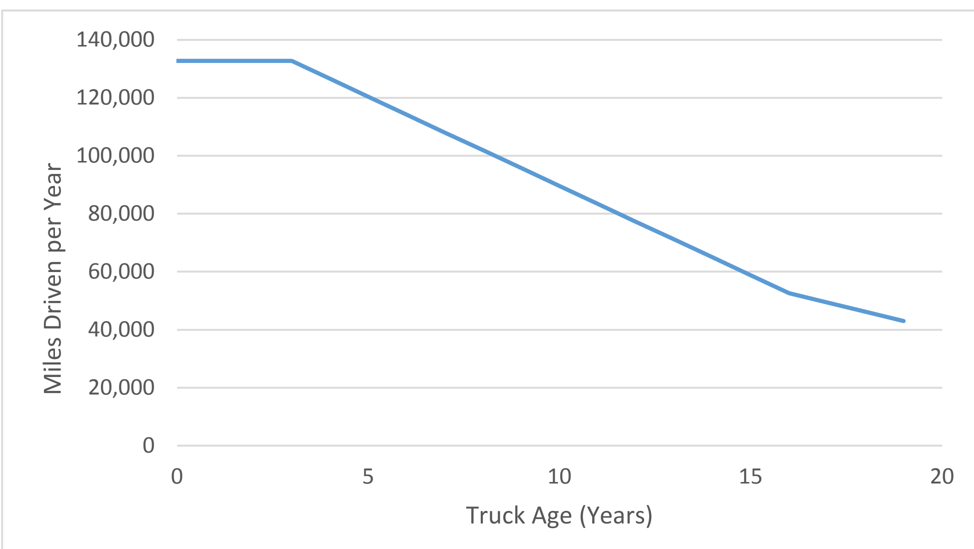

Figure 13-1 Vehicle Miles Traveled by Combination Trucks in 2014

Figure 13-1 shows that the mileage driven by combination trucks decreases as they age. By the time that a combination truck is about 17 years old, it is driven about half the number of miles per year as a new truck. It would seem that the risk of boil-off incidents increases with these older trucks.

Venting incidents during refueling can occur at any time, and there is an incentive to do so when it is time to refuel. The decision to vent an LNG tank in most cases is solely up to the truck driver who is often under pressure to complete his work in less time to maximize profits.

There is a lot of uncertainty in estimating the quantity of boil-off and venting from an LNG truck. To reflect this uncertainty, we assume two different boil-off/venting emission estimates. The low estimate assumes that 35 grams per million BTU of fuel consumed is emitted, which is from GREET.[26] The high estimate assumes a boil-off event and a venting event each time the truck is refueled and before that tank full of LNG is used up, and this quantity is estimated to be 835 g per million BTU of fuel consumed.

The crankcase of these engines receives leakage from the combustion chamber across the piston rings, which can contain methane. The crankcase of the spark ignition engines is normally vented into the intake of the engines; thus, any methane emissions from the crankcase which is not combusted in the engine would be accounted for in both the engine-out and tailpipe emissions. For compression ignition engines, however, the crankcase emissions are typically vented into the exhaust pipe downstream of the aftertreatment devices, although they are accounted for in addition to the engine-out emissions during certification. Engine-out emissions are subjected to deterioration factors based on well-established procedure, which may make estimating engine-out emissions more robust than deterioration factors for vented crankcase emissions. Moreover, deterioration of crankcase emissions may be more variable as the engines accumulate more miles. Thus, sealed crankcases would achieve more robust control of methane emissions.

Another potential source of methane emissions from CNG and LNG trucks is fugitive emissions in the form of leaks from the fuel piping to the engine. Thus, either while parked or operated, the vehicle fuel and engine systems could leak methane to the environment. We do not have, nor did we attempt to estimate this type of methane fugitive emissions from CNG or LNG trucks.

Table 13-16 summarize the estimated tailpipe emissions for CNG trucks, and Table 13-17 summarizes the estimated tailpipe and boil-off and venting emissions for LNG trucks.

Table 13-16 Estimated Tailpipe Emissions for CNG Trucks (g/MMbtu)

		METHANE	CARBON DIOXIDE	NITROUS OXIDE
2014 and Later	Direct	107	60,702	2
	Indirect	2		0
	Total	109	60,702	2

Table 13-17 Estimated Tailpipe and Boil-Off Emissions for LNG Trucks (g/MMbtu)

		METHANE	CARBON DIOXIDE	NITROUS OXIDE
2014 and Later assuming low Venting and Boil-Off Emissions	Direct	141.8	60,702	2
	Indirect	2.7		0
	Total	144.5	60,702	2
2014 and Later Assuming High Venting and Boil-Off Emissions	Direct	942	60,702	2
	Indirect	18.2		0
	Total	960	60,702	2

13.1.3.4 Thermal Efficiency

While not an emission source per se, the thermal efficiency of the natural gas engine also plays a role in the lifecycle emissions of the truck. Thermal efficiency is defined by the amount of energy that is obtained to propel the truck compared to the energy consumed by the engine. If a fuel-engine is less thermally efficient, then it consumes more fuel, or more BTUs, to travel the same distance, thus emitting more carbon dioxide per distance traveled, or work performed.

We estimate that SING engines can be as much as 15 percent less efficient than compressed ignition engines which operate on diesel fuel. Conversely, DING and MFNG engines which operate at a higher compression ratio, are estimated to be 5 percent less energy efficient compared to a diesel engine. In our lifecycle analysis, we provide two different sensitivities for natural gas vehicles assuming that they are 5 percent (thermal high) and 15 percent (thermal low) less efficient.

13.1.4 Results of Lifecycle Analysis

To estimate the lifecycle impact of natural gas used by heavy-duty trucks, we totaled the carbon dioxide, methane and the nitrous oxide emissions for the upstream and downstream portions of the natural gas system. The methane and nitrous oxide emissions are converted to carbon dioxide-equivalent emissions using global warming potentials ((GWPs); these are a measure of the relative contribution of global warming of emissions of a given gas in comparison to that of carbon dioxide over a given time period). The GWPs EPA is currently using is from the AR4 (2007) IPCC report for 100 year timeframe, which is 25 and 298 for methane and N_2O, respectively.

To establish the impacts of natural gas use in the heavy-duty fleet, it was necessary to compare the lifecycle impacts of natural gas against its replacement, which is a diesel fueled heavy-duty truck. The lifecycle greenhouse gas emissions of a diesel fuel truck is from the 2015 version of the GREET lifecycle model for the current production and use of diesel fuel.[27] We used this GREET diesel fuel lifecycle estimate for the baseline for comparison with the natural gas lifecycle assessment. The GHG Inventory that was updated in 2016 shows much higher methane emissions from crude oil production wells in the U.S. However, the recently finalized methane emission regulations requires that oil wells utilize reduced emission completion technology to reduce methane emissions from oil wells. Thus, while methane emissions are likely higher than shown by the GREET model in 2015, it is unclear what the methane emissions will be in 2025 which is the analysis year for this lifecycle analysis. We use the 2015 GREET lifecycle values for our lifecycle analysis in 2025. Table 13-18 summarizes the lifecycle emissions for diesel fuel estimated by GREET.

Table 13-18 Estimated Diesel Fuel Lifecycle Greenhouse Gas Emissions (g/million BTU)

	CARBON DIOXIDE	METHANE	NITROUS OXIDE	TOTALS CO_2EQ
Well to Tank	13,792	81	0.27	15,896[a]
Tank to Wheels	78,993	29	0.18	79,772
Well to Wheels	92,785	110	0.45	95,668

Note:
[a] The totals are calculated using 25 and 298 for the GWPs for methane and nitrous oxide, respectively.

The National Energy Technology Laboratory (NETL) has also estimated the lifecycle impact of diesel trucks and recently updated its previous analysis that was conducted for a diesel fuel truck in 2005 to the year 2014.[28] The NETL lifecycle analysis shows much higher well to tank emissions than GREET, much lower tank to wheels emissions than GREET, but overall somewhat lower GHG emission than GREET. In the discussion below about the relative lifecycle analysis of natural gas versus diesel, we discuss the impact if the NETL diesel fuel truck lifecycle analysis was used instead of GREET.

To illustrate the relative full lifecycle impact of natural gas-fueled heavy-duty vehicles versus diesel fueled heavy-duty vehicles, we assessed two different scenarios. The first is a conversion of a diesel engine to use CNG. Of the tens of thousands of heavy-duty natural gas trucks currently in use, over 90 percent are of this type. While these can be conversions of older trucks, we assume that they would still be subjected to the 0.1 gram per brake horsepower- hour methane standard. However, based on certification data, these trucks emit much higher methane emissions than the methane standard allows and we assume that this truck emits 1.0 gram of methane per brake horsepower-hour. We provide two estimates for the lower thermal efficiencies of CNG and LNG trucks. One assumes that the truck is 5 percent less thermally efficient (thermal high) and the second assumes that the truck is 15 percent less thermally efficient (thermal low - 10 percent less efficient than the 5 percent less thermally efficient case).

The second scenario is a combination truck fueled on LNG which is assumed to be in compliance with the 2014 methane standard. Because it is high mileage truck, the most realistic assumption is that the truck must use LNG as a fuel to provide the necessary range for the dedicated natural gas engine. We make two different assumptions with respect to refueling and boil off emissions. In the natural gas average case, we assume a modest quantity of refueling and boil-off methane emissions estimated by GREET. The second boil-off emission estimate is based on venting the LNG storage tank to the atmosphere each time the driver refills his tank, or one LNG boil-off event between each time the driver must refuel his tank. As we discussed in the discussion about refueling and truck boil-off emissions, we don't expect this to be a common practice for newer trucks that are operated regularly. However, as the use of these trucks decreases as they age and are sold into the secondary market, the risk for refueling and boil-off emission events increases – this estimate provides a simple sensitivity emission estimate.

The estimated lifecycle emissions of CNG and LNG trucks, assuming projected upstream emissions in 2025, is summarized in Table 13-19.

Table 13-19 Full Lifecycle Analysis of a Natural Gas Truck (g/million BTU)

TRUCK TYPE	EMISSION CATEGORY	CARBON DIOXIDE	METHANE	NITROUS OXIDE	TOTAL CO_2 EQ. [a]	THERMAL EFFICIENCY 5% AND 15% CO_2EQ.[a]	TOTALS INCLUDING THERMAL EFFICIENCY IMPACT CO_2EQ. [a]
2014 or later CNG Truck	Well to Tank	7598	361	0.06	16,643	832 2496	17,475 19,139
	Tank to Wheels	60,702	109	2.	64,022	3035 9105	67,057 73,127
	Well to Wheels	68,299	470	2.06	80,664	3867 11,602	84,531 92,266
2014 or Later LNG Truck Avg. Boil-Off	Well to Tank	20,409	432	0.009	31,214	1561 4682	32,775 35,890
	Tank to Wheels	60,702	145	2	64,911	3035 9105	67,946 74,749
	Well to Wheels	81,111	574	2.01	96,057	4596 13,787	100,652 109,844
2014 or Later LNG Truck High Boil-Off	Well to Tank	20,409	432	0.009	31,214	1561 4682	32,775 35,890
	Tank to Wheels	60,702	960	2	85,303	3035 9105	88,388 94,408
	Well to Wheels	81,111	1392	2.01	116,517	4913 14,739	121,430 131,256

Note:
[a] The CO_2eq totals are calculated using 25 and 298 for the GWPs for methane and nitrous oxide, respectively.

The CNG and LNG lifecycle assessment relative to a diesel truck lifecycle analysis is shown in Figure13-2. Another comparison made in Figure 13.2 is the relative tailpipe-only emissions for diesel and natural gas trucks. The quantity of carbon dioxide, methane and nitrous oxide emissions from a diesel truck is from GREET. The carbon dioxide emissions from natural gas-fueled truck is calculated and is based on the carbon-hydrogen content of methane. The methane emissions from a natural gas-fueled truck is based on natural gas truck certification data (does not include any methane emissions from the natural gas storage tanks onboard the truck nor other fugitive emissions).

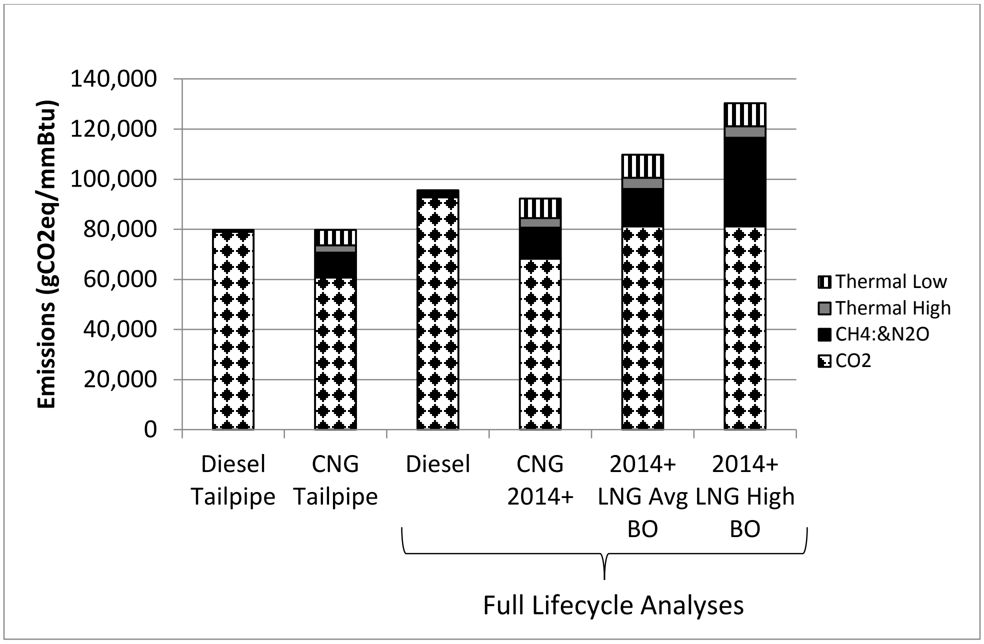

Figure 13-2 Tailpipe Emissions Comparison and Full Lifecycle Analysis of Diesel, CNG and LNG Trucks (Projected Upstream Methane Emissions in 2025, Methane GWP of 25)

In the first two bars of Figure 13-2, it shows that based solely on tailpipe emissions (with thermal efficiency adjustments and assuming 1 gram per brake horsepower-hour methane emissions at the truck), natural gas trucks are estimated to emit about 10 percent less GHG emissions than diesel engines if the engine is only 5 percent less efficient than the diesel engine, and about the same GHG emissions if the engine is 15 percent less efficient than the diesel engine. The three full lifecycle analyses represented by the right three bars in the figure shows that post-2014 CNG trucks are estimated to emit about 12 percent less GHG emissions as diesel trucks if the CNG trucks are 5 percent less efficient, although if their thermal efficiency is 15 percent less efficient, their GHG advantage would decrease to about 5 percent.

Figure 13-2 shows that LNG trucks which are only 5 percent less efficient and which emit an average amount of boil-off emissions, emit about 3 percent more GHG emissions than diesel trucks when we assume an average of refueling and boil-off emissions. Conversely, if the LNG trucks are 15 percent less efficient, then LNG trucks emit about 13 percent more GHG emissions than diesel trucks. In the case of the LNG trucks which emit a high amount of boil-off emissions, the LNG trucks emit 25 percent and 34 percent more GHG emissions than diesels for the 5 percent and 15 percent less efficient natural gas engines, respectively. In comparing CNG to LNG, the LNG trucks appear higher emitting than CNG trucks mostly because of the low thermal efficiency of small liquefaction facilities. If the LNG plant were to be 95 percent efficient instead of the 80 percent efficiency we assume, the difference between the average boil-off emitting LNG trucks and CNG trucks disappears. The 2014 lifecycle analysis of diesel trucks by NETL shows diesel trucks emitting about 3 percent lower GHG emissions (CO_2 eq.) than the diesel GHG emissions we used from GREET, thus, our analysis would show that natural gas fueled trucks would be about 3 percent higher emitting in GHG emissions if we used the NETL as the basis for diesel fueled trucks

It is important to point out the uncertainties associated with the lifecycle estimates provided in Figure 13-2. As discussed above, there is uncertainty in both the upstream and downstream methane emission estimates for natural gas facilities and equipment, and the trucks that consume natural gas. In the GHG Inventory, EPA estimates a range of natural gas emissions from the upstream natural gas production sector. The range varies from -19 percent to +30 percent relative to the principal estimate. To illustrate the impact the range has on the relative life cycle impacts of natural gas versus diesel trucks, Figure 13-3 shows the impact on the relative lifecycle emissions for CNG trucks when the low and high methane emissions are compared to the best estimate case we used in the above analyses for a CNG truck emitting 1 gram of methane per brake horsepower-hour.

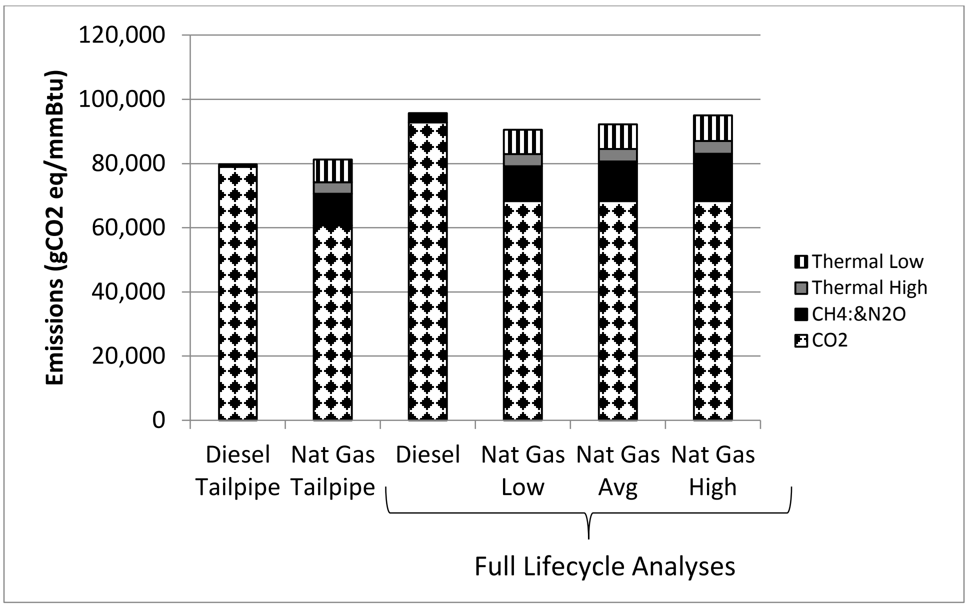

Figure 13-3 Tailpipe Emissions Comparison and Full Lifecycle Analysis of a Diesel and CNG Truck - Low, Average and High Upstream Natural Gas Methane Emissions (Projected Upstream Methane Emissions in 2025, Methane GWP of 25)

Figure 13-4 shows that higher and lower upstream emissions, based on the uncertainty factors provided in the GHG Inventory, does impact the relative GHG lifecycle impact of CNG trucks, but the effect is quite modest.

The GWPs used to assess the relative climate impacts of methane and nitrous oxide can also effect the relative lifecycle impacts natural gas trucks compared to diesel trucks. The GWPs of methane and nitrous oxide vary based on the timescale assumed. To illustrate this point, we added two more sets of figures as sensitivities for comparing the lifecycle impacts of CNG and LNG natural gas trucks to diesel trucks if the greenhouse gas emissions are evaluated over a different lifetime. The GWPs that we use are the two alterative GWPs reported by IPCC in its 4^{th} Assessment Report evaluated at 20 year and 500 year GHG lifetimes. Table 13-20 summarizes the GWPs at the different lifetimes along with the GWPs used in the primary analysis summarized above.

Table 13-20 Summary of GWPs

	PRIMARY ANALYSIS	SENSITIVITY ANALYSES	
	100 Year	20 Year	500 Year
Methane (CH_4)	25	72	7.6
Nitrous Oxide (N_2O)	298	289	153

It is important to point out that while there are fairly significant differences in methane emissions between the various natural gas cases being studied and compared to diesel trucks, the nitrous oxide emissions vary very little across all the cases. Therefore, when comparing the relative lifecycle impacts using different GWPs, the impact on relative lifecycle emissions is almost exclusively due to changes in the methane GWP. Figures 13-4 and 13-5 show the relative lifecycle effects of natural gas trucks compared to diesel trucks when the GWPs used are based on 20 year and 500 year lifetimes.

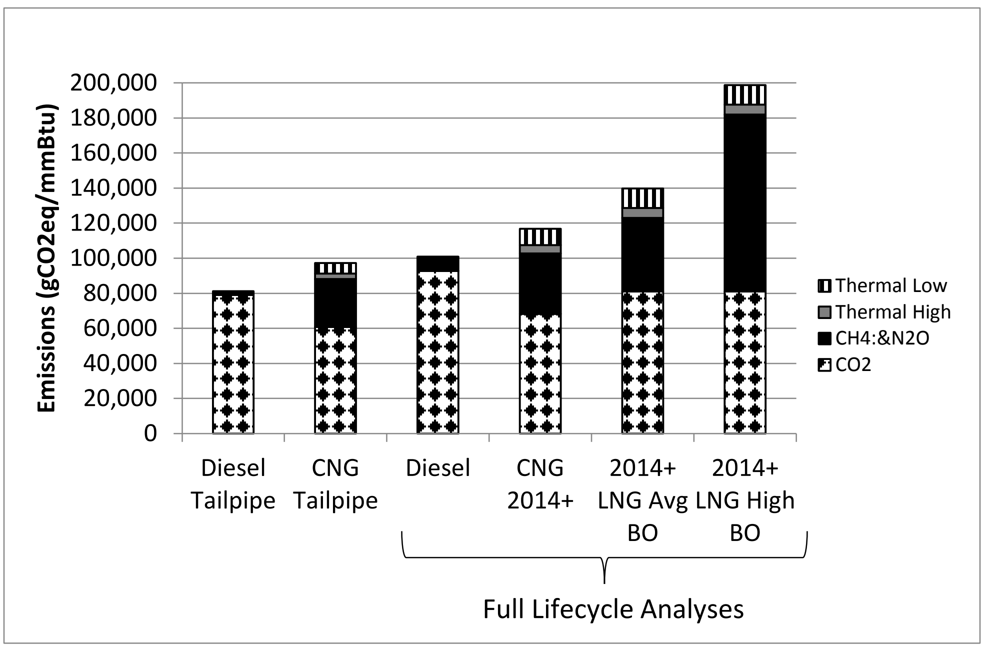

Figure 13-4 Comparison of Tailpipe Emissions and Full Lifecycle Analyses of Diesel, CNG and LNG Trucks (Projected Upstream Methane Emissions in 2025, Methane GWP of 72)

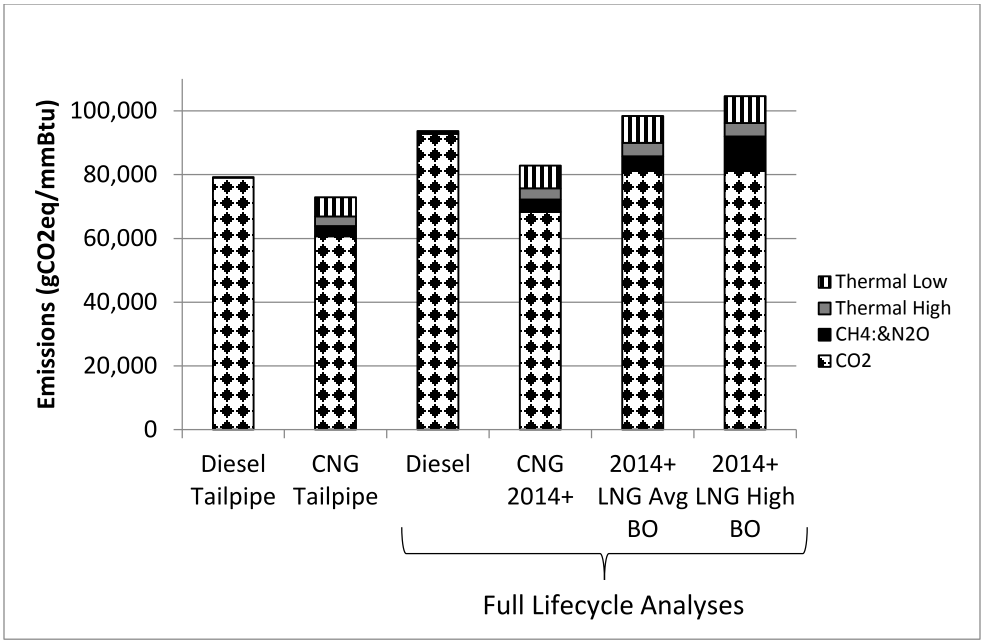

Figure 13-5 Comparison of Tailpipe Emissions and Full Lifecycle Analyses of Diesel, CNG and LNG Trucks (Projected Upstream Methane Emissions in 2025, Methane GWP of 7.6)

Figures 13-4 and 13-5 show that when evaluated over a shorter timescale, the higher GWP for methane increases the relative lifecycle impact of natural gas trucks compared to diesel trucks. Conversely, when evaluated over a longer timescale, the lower GWP for methane decreases the relative lifecycle impact of natural gas trucks compared to diesel trucks.

We compared our lifecycle emission estimates for natural gas, relative to diesel fuel, with the estimates provided by the California Air Resources Board (CARB) for its Low Carbon Fuel Standard (LCFS). For our emissions estimate used in the comparison we used the carbon dioxide-equivalent (CO_2eq) emissions estimated for 2014 and later engines, which must comply with a methane tailpipe emissions standard, and assumed that the engine was 5 percent less thermally efficient than a comparable diesel engine. Both analyses used GWPs based on 100 year timescale (i.e., a GWP of 25 for methane and 298 for nitrous oxide). For the CARB emissions estimates, we used the estimates made for what CARB terms "illustrative purposes" using the values printed in the April 3, 2015 workshop handouts.[29] CARB estimates that CNG engines emit 86 percent of the CO_2eq emissions as a diesel truck using the EER-adjusted values which reflect a 11 percent lower energy efficiency than a diesel truck. When we adjust our analysis to reflect a truck which is 11 percent less efficient than a diesel truck, our analysis estimates that CNG engines emit 89 percent of the CO_2eq emissions as a diesel truck. An important reason why CARB estimates lower CNG truck GHG emissions than our analysis is that a much larger portion of the electricity used to compress natural gas is renewable in California than the rest of the country. Also, our analysis accounts for the recent more accurate GHG Inventory estimates which show higher natural gas upstream emissions. Using the same assumption that natural gas trucks are 11 percent less efficient CARB estimates LNG engines emit about 94 percent of the CO_2eq emissions. After adjusting our analysis to also assume that trucks are 11 percent less efficient, our natural gas lifecycle analysis estimates that LNG trucks emit 106 percent of the CO_2eq emissions as a diesel truck. The reasons why LNG truck emission estimates are so much higher than CARB's is because we assume that LNG liquefaction plants are only 80 percent efficient as opposed to CARB' assumption that LNG liquefaction plants are 90 percent efficient. Also, CARB assumes no boil-off or venting emissions from LNG trucks and for this comparison, we used our more modest boil-off and venting assumption, as described above. Overall, our estimates seem to be consistent to those estimated by CARB when we account for the different assumptions used in the respective analyses. Both our heavy-duty truck lifecycle analyses are expected to improve for natural gas compared to diesel fuel as we consider the effects of the 2016 NSPS and later methane emissions standards.

13.2 Projecting Natural Gas use in HD Trucks

We reviewed several information sources and projections to estimate how much natural gas is currently being used and is projected to be used by heavy-duty trucks.

In the Energy Information Administration's Annual Energy Outlook (AEO) 2015, EIA shows natural gas use comprising about only 0.35 percent of total heavy duty fuel consumption in 2013, and natural gas use by Class 8 trucks is about 0.2 percent.[30] In 2014, AEO 2014 shows natural gas comprising about 0.4 percent of total heavy-duty fuel demand and about the same for Class 8 heavy-duty truck demand.

An estimate by the Natural Gas Vehicle for America (NGVA) of the number of natural gas trucks operating today supports this level of fuel demand made by EIA. In a meeting with NGVA, NGVA presented their estimate that 62,000 heavy-duty trucks are fueled by natural gas in 2014. The MOVES database estimates that there are 12.4 million heavy-duty trucks in 2014. Combined, the NGVA and MOVES numbers estimate that natural gas heavy-duty trucks comprise 0.5 percent of the heavy-duty truck population.

Most projections show increasing natural gas consumption by the heavy duty truck fleet. An obvious set of projections to review was the set of projections provided in the National Academy of Sciences (NAS) report.[31] The NAS report attached a figure, sourced from Citi Research, which provided projections by ACT, PACCAR, Frost and Sullivan and the National Petroleum Council.[32] This figure is reproduced below as Figure 13-6.

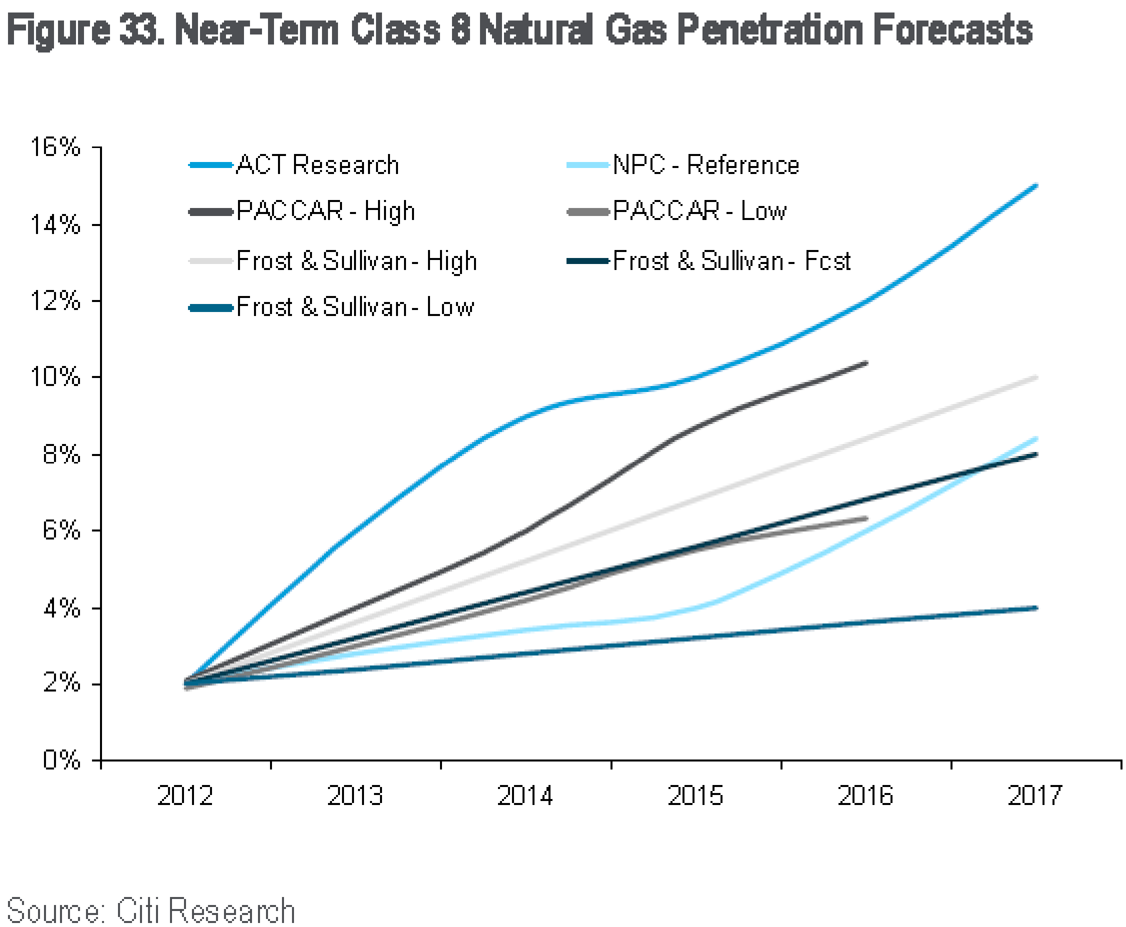

Figure 13-6 Near-Term Class 8 Natural Gas Penetration Forecasts

All these studies referenced by the NAS start out on the basis that sales of natural gas trucks comprise 2 percent of the Class 8 heavy duty truck fleet sales in 2012, and then project different growth rates from that point forward. However, it is unlikely that any of these projections considered the possibility that crude oil prices would collapse during the timeframe of the projections. Starting during the summer of 2014, crude oil prices started to decline until they reached a low price of under 30 dollars per barrel. Recently (early 2016), crude oil has been selling in the range of 30 to 45 dollars per barrel. Natural gas vehicle truck sales declined in 2014 due to the lower diesel fuel prices, although most of the decline is attributed to lower light-duty natural gas vehicle sales.[33] There appear to be other drivers of natural gas truck sales, such as air quality concerns and state subsidies that can offset the underlying economic factors. While natural gas truck sales have been higher than 1 percent of total heavy-duty truck sales in recent years, it is likely that they will fall below 1 percent if crude oil prices stay low for some time.

We tried to gain some insight in how each study referenced in the NAS report was conducted. The ACT Research study shows the most aggressive growth rate for natural gas heavy-duty trucks. The ACT Research projection did not seem to consider the economics of natural gas versus diesel fuel. Instead, the ACT projection seemed to be based on a consumer acceptance profile of a new technology, presumably assuming that the technology is already economically competitive. In a recent ACT press release for a more recent report, it was acknowledged that the growth rates ACT projected earlier were too aggressive and a more modest growth rate is more likely.[34] The NPC projection shows a similar growth rate as that estimated by ACT Research, but NPC's projection for increased uptake of the natural gas technology begins in 2015 instead of 2012. In its study, NPC assumed that the increased capital cost for a natural gas truck compared to a diesel truck study decreases from $60,000 to $20,000 by 2040.[35] This cost decrease seems excessive, and it is likely an important part of the explanation of why the NPC study shows such a large increase in natural gas use by heavy-duty trucks. We did not have access to core assumptions used in the PACCAR and Frost and Sullivan projections to assess their viability.

We searched for the Citigroup report on the Web and in addition to the figure provided in the NAS report, we found Citi Group's projection shown in the context of the other projections referenced by NAS from the Citi bank report in Figure 13-7.[36] Citi Group's projection is less optimistic than the ACT projection, but is more optimistic than the NPC reference case projection.

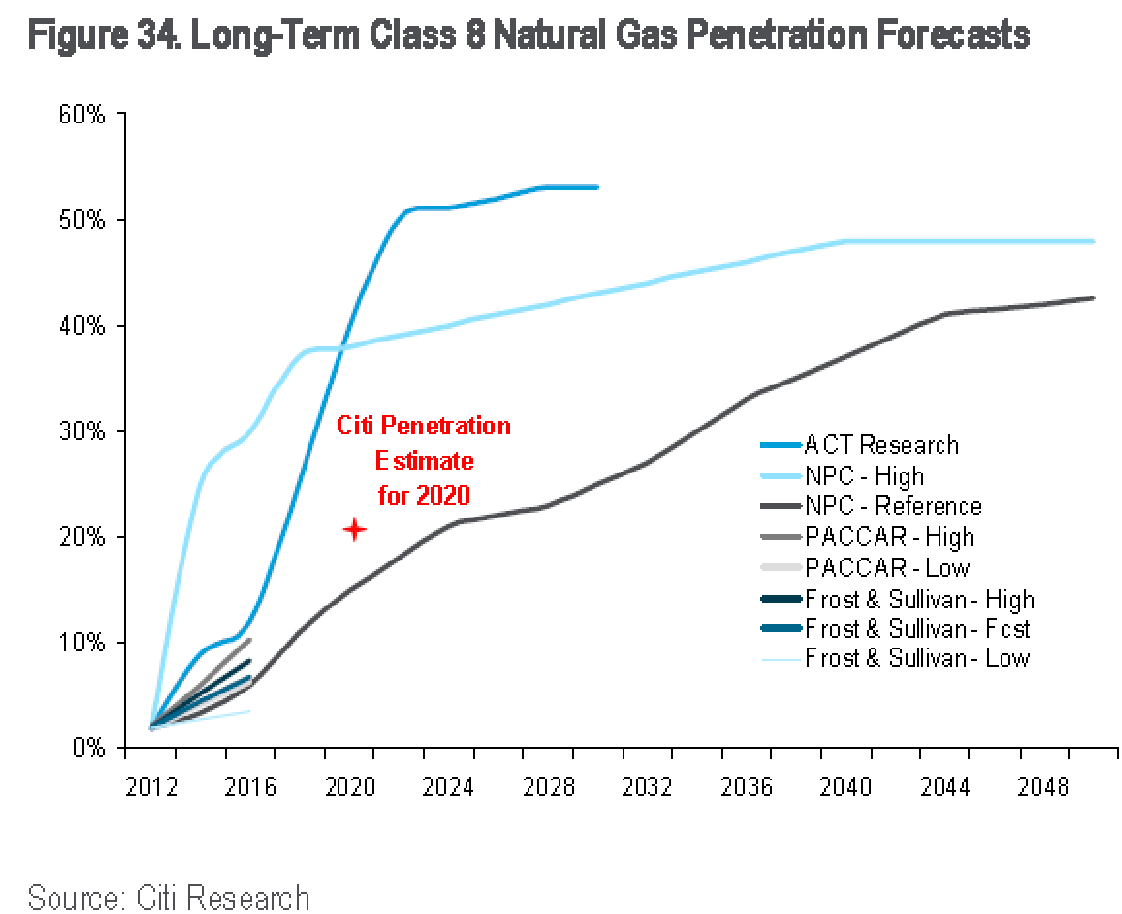

Figure 13-7 Long-Term Class 8 Natural Gas Penetration Forecasts

In its Annual Energy Outlook, EIA projects the use of different fuels by the transportation sector. [37] This projection was not referenced in the NAS report, but our review found it to be especially credible. We routinely use EIA projections for much of our analysis work and thus, using it here would be consistent with other analyses we conducted for this rulemaking. However, we also specifically reviewed the methodology EIA used to project use of natural gas by trucks to assess its viability.

First, EIA estimates that natural gas fueled 0.4 percent of the energy use of heavy-duty trucks in 2014 and this estimate is consistent with the fraction of the heavy-duty fleet which is fueled by natural gas.

Second, the EIA projection is based on an economic analysis which considers the increased cost of manufacturing a natural gas truck over a diesel truck, the fuel savings for using natural gas instead of diesel fuel, and whether the payback time of the fuel savings against the increased truck cost would trigger purchases of natural gas trucks. As part of this analysis, EIA assumes that lighter heavy-duty trucks would use CNG which is a lower cost technology suited for the shorter driving distances for these trucks. The long haul trucks, however, require larger stores of fuel to extend the driving range which is satisfied by storing the natural gas as a liquid. LNG has about 60 percent of the energy density of diesel fuel, compared to CNG which has only 25 percent of the energy density of diesel fuel. To satisfy the long driving range of the long haul trucks, EIA assumed that they would use LNG as a fuel. All the assumptions used by EIA for conducting its economic analysis seem reasonable.

Third, EIA is one of the several well-respected organizations in the world for collecting and analyzing today's fuel prices and projecting future fuel prices. According to the Alternative Fuels Data Center, one of the most important assumptions in projecting the future use of natural gas in the transportation sector is the relative price of natural gas to the price of diesel fuel. Figure 13-8 summarizes the total retail prices and the cost components that make up the final average year 2014 retail prices of diesel fuel, CNG and LNG, whose prices are expressed on a diesel gallon-equivalent basis.

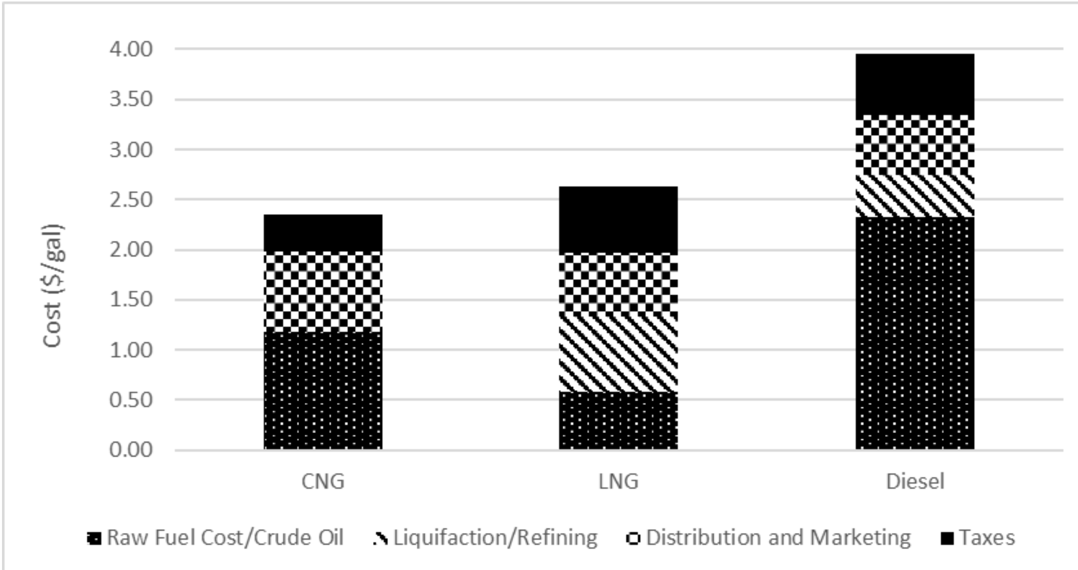

Figure 13-8 Relative Retail Cost of CNG and LNG to Diesel Fuel ($/gal DGE 2014 crude oil prices)

In 2014, the natural gas price purchased by industrial users was about $6 per million BTU, which corresponds to $0.60 per diesel gallon equivalent. The price of crude oil has been volatile during 2014 as the Brent crude oil price started at about $110 per barrel ($2.38/gallon), but decreased to under $50 per barrel towards the end of 2014. Of course, in 2015, the price of crude oil dropped to under $40 per barrel, and even dropped to under $30 per barrel in 2016. From EIA's website, the average retail diesel fuel price in the first part of 2014 was about $3.80 cents per gallon. When comparing the natural gas spot market price on a diesel equivalent basis to the diesel fuel price, it appears that natural gas is priced about one quarter of the diesel fuel price. However, if used as compressed natural gas, the natural gas must be distributed through smaller distribution pipeline system that exists in cities, which dramatically increases the price of the natural gas to $1.15 per DGE. Then the natural gas must be compressed and stored at a retail outlet which adds another $1.30 per DGE. The estimated retail price of CNG is $2.35 on a diesel gallon equivalent basis (DGE), or about $1.45 DGE less than diesel fuel.

Similarly, if natural gas is converted to LNG, the resulting retail LNG price is much higher than the raw natural gas price. LNG liquefaction plants are assumed to be located close to large transmission pipelines away from cities, thus, they would likely pay the same low price as industrial users. However, for producing LNG, the natural gas must be liquefied which adds about $0.75 DGE. When the LNG is transported to retail outlets and marked up, the LNG is priced $0.60 per DGE higher. The tax applied to LNG is on a per gallon basis, thus, is much more than on a DGE basis because of LNG's lower energy density. All these steps add substantially to the price of the LNG and the estimated retail price of LNG is $2.65 DGE, or $1.15 DGE less than diesel fuel.

The relative prices of CNG and LNG versus diesel fuel are quite different in 2015. Figure 13-9 shows what impact the much lower crude oil price in 2015 has had on the relative economics of using CNG and LNG.

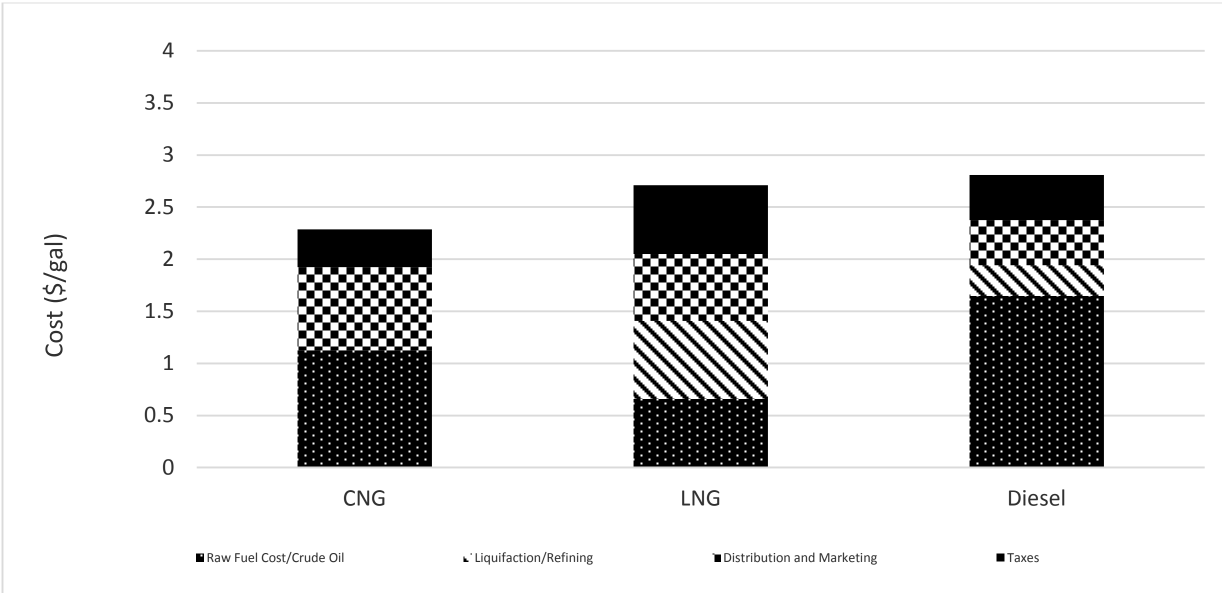

Figure 13-9 Relative Retail Cost of CNG and LNG to Diesel Fuel ($/gal DGE 2015 crude oil prices)

As shown in Figure 13-9, LNG is priced nearly the same as diesel fuel, and CNG is priced about $0.50 less than diesel fuel. If these relative fuel prices are accurate, there would be no opportunity for paying down the higher capital costs of LNG trucks. While CNG tends to be priced somewhat lower than diesel fuel, the breakeven point is certainly much longer than desired by fleet owners. Also, given the volatility in crude oil prices, potential fleet owners may be reluctant to move towards CNG and LNG because fleet owners will want a predictable payback of their higher priced natural gas truck (and perhaps natural gas refueling facilities) purchases.

In its projections, EIA estimates that crude oil prices will range from $70 to $80 per barrel until 2021 and then increase to $100 per barrel in 2030 and increase to $140/BBL in 2040. Natural gas prices are expected to only slightly increase over this period.

The fifth reason why the EIA projections seem reasonable is because the payback hurdle assumptions assumed for truck fleet owners seem reasonable. EIA projects that natural gas trucks begin to be purchased when the payback times are 4 years or less based on a survey conducted by the American Trucking Associations. The ATA survey found that 24 percent of respondents would choose natural gas trucks over diesel trucks if the payoff is 4 years, another 57 percent would choose natural gas if the payoff is 3 years, the next 15 percent would choose natural gas if the payoff is 2 years and the last 5 percent would choose natural gas if the payoff is 1 year or less.[38] This is consistent with some conversations we have had with some fleet owners. The NAS cites the pay back for the extra cost of natural gas trucks as 2 years, but other sources report a longer return closer to 4 years.[H]

[H] Early LNG Adopters Experience Mixed Results; Truck News, October 1, 2013.

The results of EIA's economic analysis and projected natural gas use in heavy duty trucks presented in the 2015 Annual Energy Outlook is presented in Figure 13-10.[39]

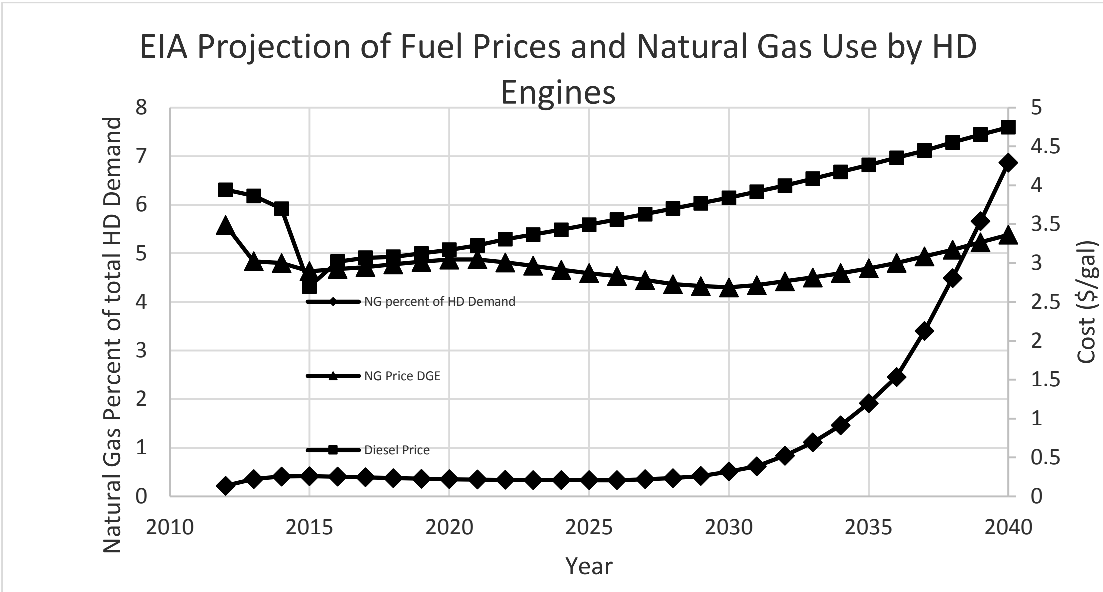

Figure 13-10 EIA Projection of Fuel Prices and Natural Gas Use by HD Engines

Figure 13-10 shows, as we discussed above, that natural gas currently supplies only about 0.5 percent of total heavy-duty truck fuel demand and is expected to continue to do so until about 2030. Starting in 2033, EIA estimates that the price of diesel fuel will increase above $4 per gallon which will create the economic incentive to purchase natural gas trucks. As expected, the EIA projection that the price differential between natural gas and diesel fuel continues to increase results in the effect that the uptake of natural gas use in the heavy-duty truck fleet accelerates as the price differential increases.

A very interesting conclusion of the EIA projection is the natural gas penetration differences between the different heavy-duty truck classes. Figure 13-11 summarizes the projected use of natural gas by the AEO for different truck classes.

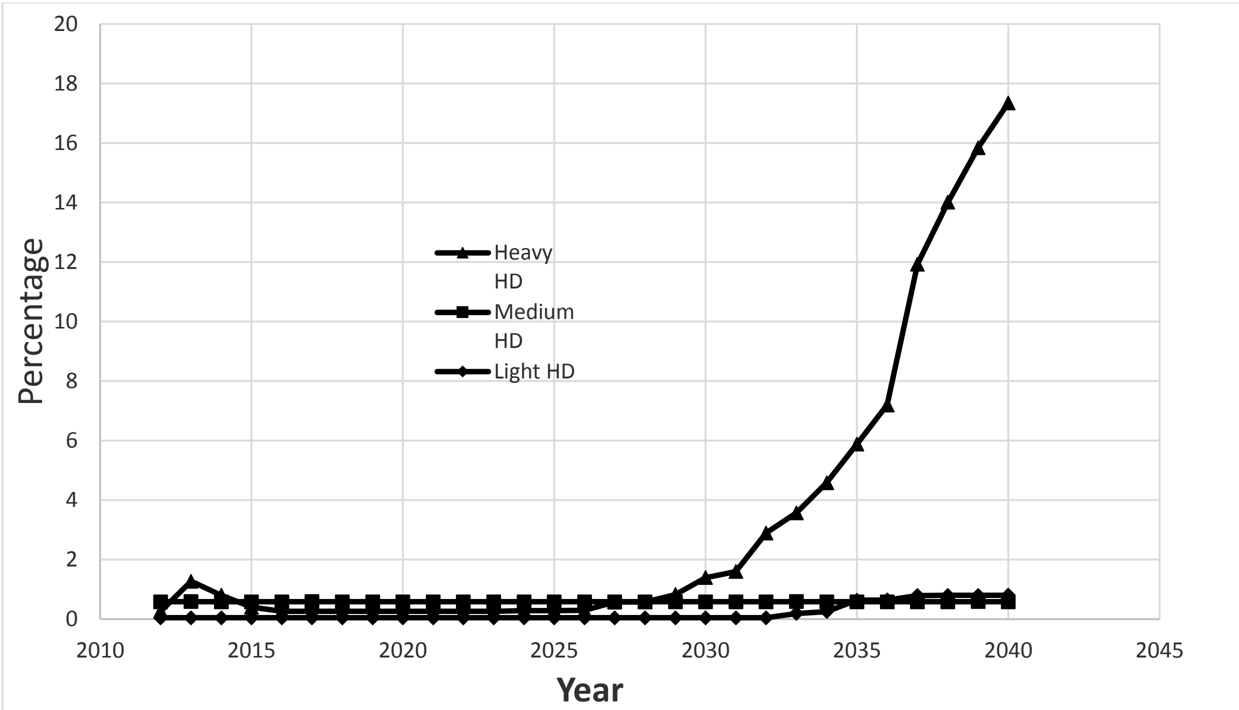

Figure 13-11 EIA Projection of NG use by Truck Weight Class

Figure 13-11 shows that the only heavy-duty sector which is projected to see a large penetration of natural gas is the heavy, heavy-duty sector which increases to 17 percent by 2040. The light and medium classes of the heavy-duty truck fleet do not show increases in natural gas use. The likely reason EIA's analysis shows little CNG or LNG use by light and medium heavy-duty trucks is because they are driven far less and their use does not justify the higher purchase price. According to the Vehicle Inventory and Use Survey, light and medium heavy duty trucks average less than 1/3rd the annual mileage of the heaviest trucks.[40] EIA is using a distribution of VMT for new class 7 and 8 trucks as shown in Figure 13-12.

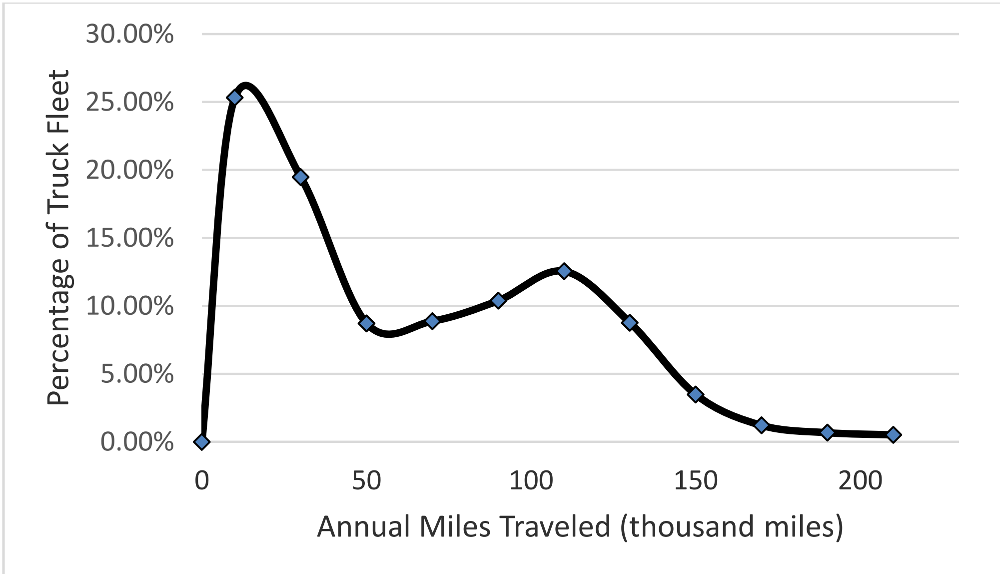

Figure 13-12 Percent of Class 7 and 8 Truck Fleet by Annual Miles Traveled

Figure 13-12 shows that although about half of class 7 and 8 trucks are driven less than 60 thousand miles per year, the other half is driven from 60 thousand to over 200 thousand miles per year. It is these high mileage long haul trucks which are prime candidates for using LNG because of their ability to pay down the high marginal natural gas truck cost.

Since EIA does not report the payback times as an output of its projections, we conducted our own analysis of sample payback times solely for illustrative purposes. We assessed the time required for the lower fuel cost of LNG to payback the incremental truck cost of using LNG assuming that a truck averages 120,000 miles per year. There were several important aspects of the payoff analysis that we conducted. First, based on the EIA analysis which found that the heavy, heavy-duty trucks sector is the only one which will see natural gas use increase dramatically, we studied the payback of natural gas use with combination trucks. Second, as concluded by EIA, we also assume that the higher energy density of LNG will make it the most likely natural gas fuel type used by the heavy, heavy-duty trucks. Third, the higher natural gas truck cost was approximated from the analysis EIA conducted for its Annual Energy Outlook. Fourth, the analysis presents a simple payback as well as a discounted payback using a 7 percent discount factor. Fifth, we evaluated the payback in 2015, and we also assessed what the payback might be in 2020, 2030 and 2040 and assume some changes in the future years as discussed in some example evaluation cases below. Table 13-21 presents the results of our payback analysis for natural gas combination trucks.

Table 13-21 Combination Truck Payback Analysis

	CASE 1 2015 DUEL FUELED	CASE 2 2015 HPDI	CASE 3 2030 HPDI	CASE 4 2040 HPDI
Miles per Year	120,000	120,000	120,000	120,000
Miles per Gallon	6.0	6.0	8.2	9.0
Incremental NG Truck Cost ($)	55,000	70,000	60,000	55,000
Incremental NG Maintenance Cost per year ($)	970	1613	1935	1935
Diesel Fuel Price ($/gal)	2.70	2.70	3.84	4.38
Natural Gas Price ($/gal DGE)	2.90	2.90	2.69	3.36
Diesel Fuel Cost per Year	54,000	54,000	56,200	58,400
Natural Gas Fuel Cost Per Year (LNG)	58,400	62,500	44,080	49,710
Lower NG Efficiency (%)	5%	5%	5%	5%
Vehicle NG Use (%)	50%	95%	95%	95%
Simple Payback (years)	Negative	Negative	4.96	6.30
Discounted Payback (years)	Negative	Negative	6.1	8.3

We evaluated two different cases for 2015. Case 1 assumes a mixed fuel (MFNG) LNG fueled, heavy-duty combination truck which exceeds 26,000 gross vehicle weight rating and averages 120,000 miles per year. But because this truck can operate on diesel only, the truck can manage with a more modest storage quantity of LNG, thus reducing the cost of LNG storage. When this truck is fueled by LNG, it is estimated to be 5 percent less thermally efficient than a similar diesel truck. The fuel costs are the average prices during 2015. The second case we evaluated for 2015 is a direct injection natural gas (DING) truck. Because this truck must fuel on LNG or be parked (the diesel fuel is simply used to enhance the combustion process), there must be more LNG storage capacity and the truck purchase price is estimated to be $70,000 more than a diesel truck. This case also assumes 120,000 miles accumulated per year. In both 2015 cases, neither of the trucks achieve any degree of payback as the LNG fuel price is higher than the diesel fuel price. This illustrates the difficulty fleet owners' face when considering the purchase of natural gas trucks in this low crude oil price environment.

For Case 3, we assessed a 2030 case using EIA fuel price projections. Like the second case, the truck is a DING truck, but because it is fifteen years later, we assumed a modest cost reduction due to a learning curve. Due to the large price spread between diesel and natural gas, this truck's discounted payback time is 6.1 years.

For Case 4, we assessed a 2040 case using EIA fuel price projections. Like the previous two cases, the truck is a DING truck, and we assumed a further modest cost reduction due to a learning curve. This truck is also assumed to accumulate 120,000 annual miles fueled on LNG. While diesel fuel prices are expected to increase between 2030 and 2040, EIA projects that natural gas will increase faster than diesel fuel prices during this time and this truck's discounted payback time actually increases to 8.3 years.

Since the EIA analysis was pessimistic with respect to truck types other than Class 8 combination trucks, we assessed the payback of refuse trucks. This is particularly interesting because refuse trucks have been one of the bright spots for use of natural gas as a transportation fuel source (from the standpoint of the natural gas industry). Refuse trucks have a couple of advantages over combination trucks. One is that the constant stop-start characteristics of its driving cycle result in very poor fuel economy, which increases natural gas use and shortens the payback times for the higher engine and fuel system costs. Another advantage of refuse trucks is that because they drive relatively short distances between refueling, they can rely on a smaller quantity of CNG storage which reduces the CNG fuel system cost. Refuse trucks usually use compression ignition-based engines which are converted to SING engines by adding a spark plug and lowering the compression ratio. SING engines solely use natural gas and do not require (and cannot operate on) any other fuel, which increases natural gas use and enhances payback compared to duel fueled natural gas engines (DING).

Refuse trucks also have some disadvantages for using natural gas use. Since the refuse trucks stop and start up so frequently, they cannot achieve a high annual mileage compared to over-the-road trucks, and this offsets the advantages of the lower fuel economy. Since the engines are usually converted to SING engine types (spark ignited), the engines are retrofitted to use a lower compression ratio, which reduces its fuel economy by about 15 percent compared to diesel fueled compression engines.

Figure 13-22 summarizes the payback analysis that we conducted for refuse trucks.

Table 13-22 Refuse Truck Payback Analysis

	CASE 1 2015 CNG REFUSE TRUCK	CASE 2 2020 CNG REFUSE TRUCK	CASE 3 2030 CNG REFUSE TRUCK	CASE 4 2040 CNG REFUSE TRUCK
Miles per Year	25,000	25,000	25,000	25,000
Miles per Gallon	2.8	2.9	3.8	4.2
Incremental NG Truck Cost ($)	35,000	35,000	30,000	27,500
Incremental NG Maintenance Cost per year	403	403	403	403
Diesel Fuel Price ($/gal)	2.90	3.17	3.84	4.38
Natural Gas Price ($/gal DGE)	2.60	2.75	2.39	3.06
Diesel Fuel Cost per Year	25,850	27,395	25,080	26,086
Natural Gas Fuel Cost Per Year (CNG)	27,664	28,310	18,760	21,860
Lower NG Efficiency (%)	15	15	15	15
Vehicle NG Use (%)	100	100	100	100
Simple Payback (years)	Negative	Negative	4.7	6.5
Discounted Payback (years)	Negative	Negative	5.8	8.7

Figure 13-22 shows, as for the combination trucks, that the collapse in crude oil prices does not allow for a payback of the refuse truck's higher purchase price in 2015. However, even when crude oil prices increase in 2030 and 2040, refuse trucks still experience a fairly long payback period of 6 years or more on a discounted basis. Refuse trucks may actually show a reasonable or even favorable payback if the waste management company which operates the trucks is able to use waste methane gas from landfills at a much lower natural gas price point.

Given the negative payback for natural gas vehicles in 2015, it suggests that existing subsidies for natural gas likely play an important role in encouraging its use. According to EIA, half the natural gas consumption by cars and trucks is in California and this may be partially due to subsidies and other incentives California offers. California subsidies the purchase price of natural gas vehicles, and also offsets the cost of natural gas dispensing stations. The Low Carbon Fuel Standard (LCFS) in place in California also incentivizes natural gas use because natural gas is considered to cause less of an impact on the climate than petroleum-based gasoline and diesel fuel. The majority of the other half of the NG fleet is also in states which subsidize the natural gas truck purchase price or service station construction costs.

Based on the EIA projections for crude oil and natural gas prices, the payback time of LNG trucks is expected remain long (more than 4 years) until sometime after 2030 when diesel fuel prices are projected to increase above 4 dollars per gallon. Thus, natural gas use by heavy-duty trucks is not projected to increase above 1 percent of the heavy-duty fuel demand until after 2030. Even if the economics improve for using CNG and LNG in the heavy-duty fleet, another hurdle is fuel availability since these fuels are not already widely available. Figure 13-13 shows the number of CNG and LNG public and private service stations relative to the number of gasoline and diesel fuel service stations and truck stops, respectively.

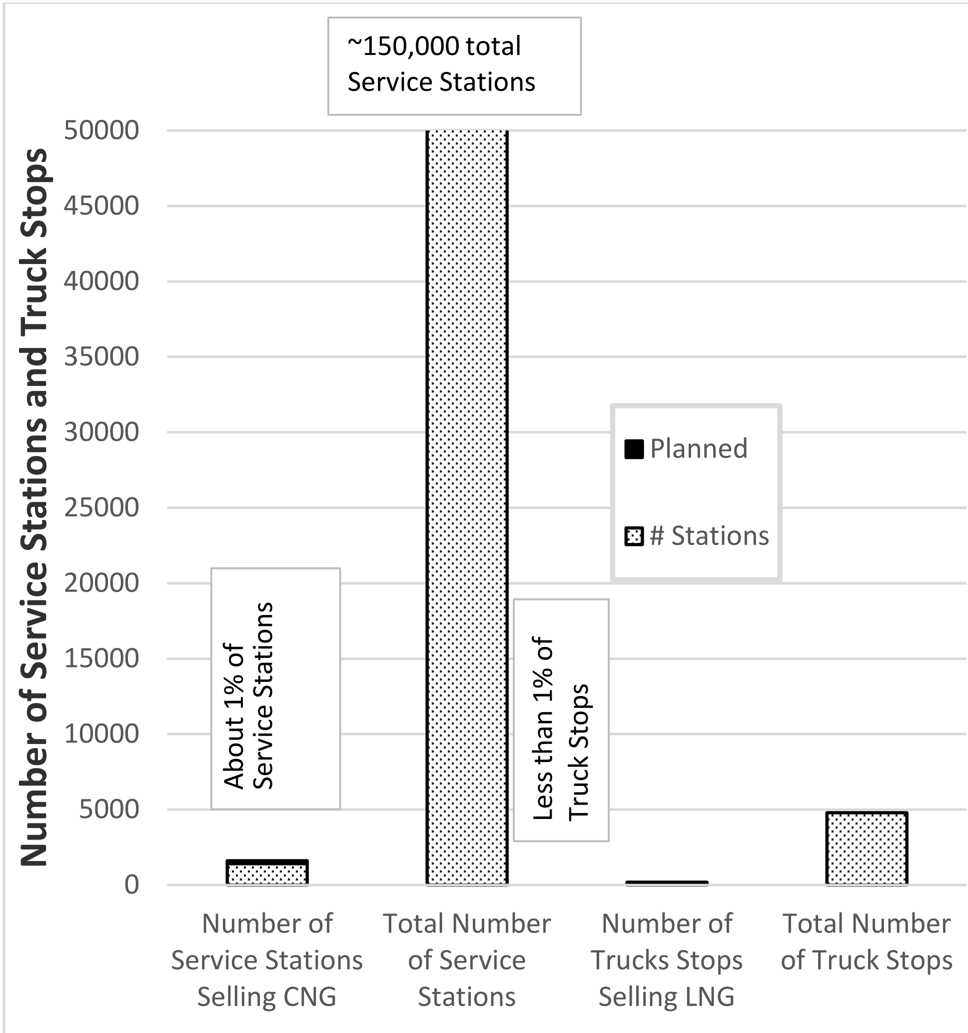

Figure 13-13 CNG and LNG Availability at Service Stations

As Figure 13-13 shows, CNG and LNG fuel availability at service stations is 1 percent or less of the availability of gasoline and diesel fuel. Even if a business owner finds the purchase of one or more new natural gas trucks an attractive investment, if the fuel is not available in the area, the business owner may have to forgo purchasing the natural gas trucks. A fleet owner might be in the position to also install a natural gas service station or establish a contract with a third party fuel provider to provide the fuel, but that may require making a large purchase of trucks to justify the installation of the service station or the establishment of the contract. If the fleet owner would need to build a CNG or LNG refueling station to enable purchasing the natural gas trucks, then the combined cost of the service station installation and the natural gas truck purchase could make the prospect uneconomic even if the natural gas truck purchase by itself would be justified. LNG availability is particularly challenging because in addition to an LNG service station, a LNG liquefaction plant would be needed as well. If the economics turn favorable for using natural gas in the truck fleet, the conversion to natural gas is likely to be slow due to the need to build out the fuel availability.

13.2.1 Dimethyl Ether

Although NAS focused its recommendations on natural gas, it also discussed dimethyl ether (DME), which is a potential heavy-duty truck fuel sourced from natural gas. Dimethyl ether has a high cetane number (more than 55), although its energy density is about 60 percent of that of diesel fuel. Dimethyl ether is a volatile fuel, like liquid petroleum gas, that can be stored as a liquid at normal ambient temperatures under moderate pressure. Typical DME fuel tanks would be designed to prevent any significant evaporative emissions.

A DME fueled truck is only modestly more expensive than a diesel fuel truck. The fuel tank is more expensive than a diesel fuel tank, but much less expensive than an LNG tank since it does not need to be heavily insulated. The engine modifications to enable using DME are also modest. Because DME does not have carbon-carbon bonds that form particulate particles during combustion, the particulate filter, which is normally installed on recent year diesel trucks, can be eliminated. This offsets some of the increased DME engine and fuel tank costs.

Although DME is sourced from cheap natural gas, the conversion of natural gas to DME and moving the fuel to retail outlets greatly increases the cost of the fuel. As Figure 13-14 shows, DME is more expensive than LNG, but still lower in cost than diesel fuel. Similar to Figure 13-8, the diesel fuel price used in Figure 13-14 is based on crude oil prices in early 2014.

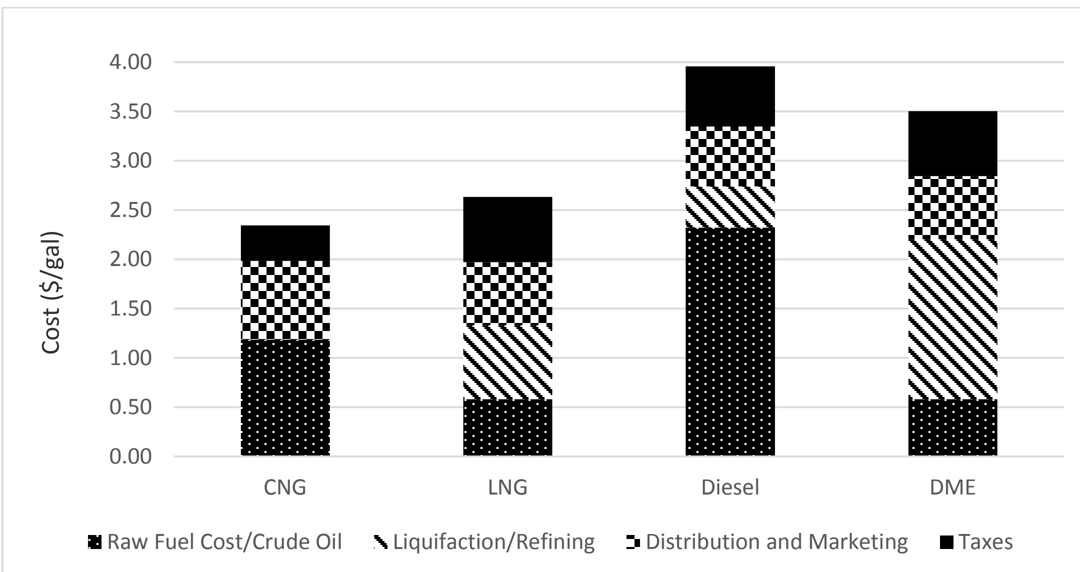

Figure 13-14 Relative Retail Cost of DME to CNG, LNG and Diesel Fuel ($/gal DGE)

DME is estimated to cost $3.50/ DGE, or $0.30 DGE less than diesel fuel. Using the much lower crude oil prices in early 2016 would show that DME is more expensive than diesel fuel.

Because there is very little DME use in the US (there is only a very small fleet of DME trucks being contemplated in California), we did not conduct a lifecycle assessment of DME.

We will, however, discuss a few aspects of a lifecycle analysis for DME. First, since DME is sourced from natural gas, the upstream methane emissions from the natural gas industry would still be allocated to DME. Second, there are not venting issues associated with DME as with LNG or CNG refueling. Third, because DME has a lifetime of less than one week, it is not a long-lived well-mixed gas, and therefore has little direct climate impacts.[41]

References

[1] US Greenhouse Gas Emissions and Sinks: 1990 -2014, US Environmental Protection Agency, April 15, 2016 (EPA 430-R-16-002).

[2] National Emission Standards for Hazardous Air Pollutants (NESHAP): for the Oil and Natural Gas Production and Natural Gas Transmission and Storage, Final Rule, 40CFR part 63, subpart HH; June 17, 1999.

[3] Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews; Final Rule, 40 CFR parts 60 and 63, Environmental Protection Agency, August 16, 2012.

[4] www3.epa.gov/gasstar/.

[5] Oil and Natural Gas Sector: Emission Standards for New and Modified Sources; 40CFR 60, May 12, 2016.

[6] https://www.whitehouse.gov/the-press-office/2016/03/10/us-canada-joint-statement-climate-energy-and-arctic-leadership.

[7] https://blog.epa.gov/blog/2016/03/epa-taking-steps-to-cut-methane-emissions-from-existing-oil-and-gas-sources

[8] 2016 Second Biennial Report of the United States of America, Under the United Nations Framework Convention on Climate Change. Table 4.

[9] GREET1 Model, Argonne National Laboratory, 2015.

[10] Inventory of US Greenhouse Gas Emissions and Sinks: 1990 – 2014, Annex 2, Tables A-38 and A-39, April 15, 2016.

[11] GREET1 Model, Argonne National Laboratory, 2015.

[12] Methane Emissions from the Natural Gas Industry – Volume 2: Technical Report; Prepared by the Natural Risk Management Research Laboratory, EPA – 600/R-96-080b, June 1996.

[13] Harrison, Matthew R., Allen, David, et al; Natural Gas Industry Methane Emission Factor Improvement Study Final Report, Cooperative Agreement XA-83376101, Prepared for the Environmental Protection Agency, December 2011.

[14] Dan Hanson of Ariel Compressors, November 2015.

[15] E/ECE/324/Rev.2/Add.109/Rev.3 – E/ECE/TRANS/505/Rev.2/Add.109/Rev.3; United Nations; June 25, 2014.

[16] Jenks, Christopher; Technology Assessment of Refueling-Connection Devices for CNG, LNG and Propane; Transit Cooperative Research Program, Conducted by the Science Applications International Corporation (SAIC) for the Federal Transit Administration, April 1998, Number 25.

[17] Detailed California-Modified GREET Pathway for Liquefied Natural Gas (LNG) from North American and Remote Natural Gas Sources, Version 1.0, July 20, 2009.

[18] Bronfenbrenner, James C. et al, Selecting a Suitable Process; LNGIndustry.com; summer 2009.

[19] Kunert, Sebastian et al, Small is Beautiful – Mini LNG Concept; Hamworthy Gas Systems; June 2008.

[20] National Energy Technology Laboratory, Lifecycle Inventory Data – Process Documentation File; DF_Stage1_O_2010.1.doc.

[21] Detailed California-Modified GREET Pathway for Liquefied Natural Gas (LNG) from North American and Remote Natural Gas Sources, Version 1.0, July 20, 2009.

[22] Powers, Charles A., Best Practices to Avoid LNG Fueling Station Venting Losses; Prepared for the Brookhaven National Laboratory, Contract 157688, June 25, 2010.

[23] GREET1 Model, Argonne National Laboratory, 2015.

[24] The emission standards were required by the rulemaking named "Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles" published September 15, 2011.

[25] LNG ANG Venting Calculations Spreadsheet, LNG ANG Venting Calcs.xlsx.

[26] GREET1 Model, Argonne National Laboratory, 2015.

[27] GREET1 Model, Argonne National Laboratory, 2015.

[28] Cooney, Greg of Booze Allen Hamilton; Approaches to Developing a Cradle-to-Grave Lifecycle Analysis of Conventional Petroleum Fuels Produced in the U.S. with an Outlook to 2040; for the National Energy Technology Laboratory (NETL), October 6, 2015.

[29] CA-GREET 1.8b versus 2.0 CI Comparison Table, LCFS Workshop Handout, California Air Resources Board, April 3, 2015.

[30] Annual Energy Outlook 2015 with projections to 2040, US Energy Information Administration, April 2015. (www.eia.gov/forecasts/aeo).
[31] Reducing the Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two: First Report, National Research Council, National Academy of Sciences, 2014.
[32] Energy 2020: Trucks, Trains and Automobiles, Citi GPS: Global Perspectives and Solutions, June 2013.
[33] FC Gas Intelligence, http://analysis.fc-gi.com/natural-gas -vehicles/us-heavy-duty-ngv-sales-robust-despite-oil-price-impact-payback; July 8, 2015.
[34] Natural Gas Adoption Increases Slowly, ACT Reports, HDT Truckinginfo, www.truckinginfo.com, September 17, 2014.
[35] Advancing Technology for America's Transportation Future, Summary Report, National Petroleum Council, August 1, 2012.
[36] Energy 2020: Trucks, Trains and Automobiles, Citi GPS: Global Perspectives and Solutions, June 2013.
[37] Issues in Focus: Section 6¨ Heavy-Duty Natural Gas Vehicles, Energy Information Administration, Annual Energy Outlook 2012, June 25, 2012.
[38] Conversation with Nicholas Chase, Energy Information Administration, October 2014.
[39] Annual Energy Outlook 2015 with projections to 2040, US Energy Information Administration, April 2015. (www.eia.gov/forecasts/aeo).
[40] U.S. Department of Commerce, Bureau of the Census, 2002 Vehicle Inventory and Use Survey, Microdata, CD, 2005. (Additional resources: www.census.gov/svsd/www/tiusview.html).
[41] Good, D.A et al, Lifetimes and global warming potentials for dimethyl ether and for fluorinated ethers: CH3OCF3, CHF2OCHF2, CHF2OCF3, Journal of Geophysical Res, Vol 103, Pages 28,181 – 28,186, November 20, 1998.