EPA

National Vehicle and Fuel Emissions Laboratory
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

EPA-420-R-10-901

NHTSA
www.nhtsa.gov

Office of International Policy, Fuel Economy,
and Consumer Programs
National Highway Traffic Safety Administration
U.S. Department of Transportation

Joint Technical Support Document:

Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards

April 2010

TABLE OF CONTENTS

Executive Summary

The Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) are issuing a joint final rulemaking which establishes new standards for light-duty highway vehicles that will reduce greenhouse gas emissions and improve fuel economy. The joint final rulemaking is consistent with the National Fuel Efficiency Policy announced by President Obama on May 19, 2009, responding to the country's critical need to address global climate change and to reduce oil consumption. EPA is finalizing greenhouse gas emissions standards under the Clean Air Act, and NHTSA is finalizing Corporate Average Fuel Economy standards under the Energy Policy and Conservation Act, as amended. These standards apply to passenger cars, light-duty trucks, and medium-duty passenger vehicles, covering model years 2012 through 2016. They require these vehicles to meet an estimated combined average emissions level of 250 grams of CO_2 per mile in MY 2016 under EPA's GHG program, and 34.1 mpg in MY 2016 under NHTSA's CAFE program and represent a harmonized and consistent national program (National Program). These standards are designed such that compliance can be achieved with a single national vehicle fleet whose emissions and fuel economy performance improves each year from MY2012 to 2016. This document describes the supporting technical analysis for areas of these jointly finalized rules which are consistent between the two agencies.

NHTSA and EPA have coordinated closely to create a nationwide joint fuel economy and GHG program based on consistent compliance structures and technical assumptions. To the extent permitted under each Agency's statutes, NHTSA and EPA have incorporated the same compliance flexibilities, such as averaging, banking, and trading of credits, and the same testing protocol for determining the agencies' respective fleet-wide average standards. In addition, the agencies have worked together to create a common baseline fleet and to harmonize most of the costs and benefit inputs used in the agencies' respective modeling processes for this joint finalized rule.

Chapter 1 of this document provides an explanation of the agencies' new methodology used to develop the baseline and reference case vehicle fleets, including the technology composition of these fleets, and how the agencies projected vehicle sales into the future. One of the fundamental features of this technical analysis is the development of these fleets, which are used by both agencies in their respective models. In order to determine technology costs associated with this joint rulemaking, it is necessary to consider the vehicle fleet absent a rulemaking as a "business as usual" comparison. In past CAFE rulemakings, NHTSA has used confidential product plans submitted by vehicle manufacturers to develop the reference case fleet. In responding to comments from these previous rulemakings that the agencies make these fleets available for public review, the agencies created a new methodology for creating baseline and reference fleets using data, the vast majority of which is publicly available.

Chapter 2 of this document discusses how NHTSA and EPA developed the mathematical functions which provide the bases for manufacturers' car and truck

standards. NHTSA and EPA worked together closely to develop regulatory approaches that are fundamentally the same, and have chosen to use an attribute-based program structure based on the footprint attribute, like NHTSA's current Reformed CAFE program. The agencies revisited other attributes as candidates for the standard functions, but concluded that footprint remains the best option for balancing the numerous technical and social factors. However, the agencies did adjust the shape of the footprint curve, in contrast to the 2011 CAFE rule, the CO2 or fuel consumption curve is a piecewise linear or constrained linear function, rather than a constrained logistic function. In determining the shape of the footprint curve, the agencies considered factors such as the magnitudes of CO2 reduction and fuel savings, how much that shape may entice manufacturers to comply in a manner which circumvents the overall goals of the joint program, whether the standards' stringencies are technically attainable, and the mathematical flexibilities inherent to such a function

Chapter 3 contains a detailed analysis of NHTSA and EPA's technology assumptions on which the finalized regulations were based. Because the majority of technologies that reduce GHG emissions and improve fuel economy are identical, it was crucial that NHTSA and EPA use common assumptions for values pertaining to technology availability, cost, and effectiveness. The agencies collaborated closely in determining which technologies would be considered in the rulemaking, how much these technologies would cost the manufacturers (directly) in the time frame of the rules, how these costs will be adjusted for learning as well as for indirect cost multipliers, and how effective the technologies are at accomplishing the goals of improving fuel efficiency and GHG emissions.

Chapter 4 of this TSD provides a full description and analysis of the economic factors considered in this joint final rulemaking. EPA and NHTSA harmonized many of the economic and social factors, such as the discount rates, fuel prices, the magnitude of the rebound effect, the value of refueling time, and the social cost of importing oil and fuel.

CHAPTER 1: The Baseline and Reference Vehicle Fleet

The passenger cars and light trucks sold currently in the United States, and those which are anticipated to be sold in the MY 2012-2016 timeframe, are highly varied and satisfy a wide range of consumer needs. From two-seater miniature cars to 11-seater passenger vans to large extended cab pickup trucks, American consumers have a great number of vehicle options to accommodate their utility needs and preferences. Recent volatility in oil prices and the state of the economy have demonstrated that consumer demand and choice of vehicles within this wide range can be sensitive to these factors. Although it is impossible for anyone or any organization to precisely predict the future, a characterization and quantification of the future fleet are required to assess the impacts of rules which would affect that future fleet. In order to do this, the various leading publicly-available sources are examined, and a series of models are relied upon that help us to project the composition of a reference fleet. This chapter describes the process for accomplishing this.

Most of the public comments to the NPRM supported this methodology for developing the inputs to the rule's analysis. Because the input sheets can be made public, stakeholders can verify and check EPA's and NHTSA's modeling, and perform their own analyses with these datasets. Many commenters stated that creating a transparent fleet from public sources was a significant improvement over previous rulemakings, although other commenters raised accuracy issues with regard to the continuation in the agencies' analysis of MY 2008 vehicles into the future model years covered by the rulemaking. There were no comments on methodology, but GM did comment that they believe the agencies had projected more full size trucks and full size vans than they believe would be produced. EPA had already noticed, after the NPRM had been published, that the standard CSM forecast included heavy duty class 2b and class 3 vehicles. EPA requested that CSM make a custom forecast with these vehicles removed for the final rulemaking.

1.1 Why do the agencies establish a baseline and reference vehicle fleet?

In order to calculate the impacts of the EPA and NHTSA final rule, it is necessary to estimate the composition of the future vehicle fleet absent the final CAFE/GHG standards in order to conduct comparisons. EPA in consultation with NHTSA has developed a comparison fleet in two parts. The first step was to develop a baseline fleet based on model year 2008 data. EPA and NHTSA create a baseline fleet in order to track the volumes and types of fuel economy-improving and CO_2-reducing technologies which are already present in today's fleet. Creating a baseline fleet helps to keep, to some extent, the agencies' models from adding technologies to vehicles that already have these technologies, which would result in "double counting" of technologies' costs and benefits. The second step was to project the baseline fleet sales into MYs 2011-2016. This is called the reference fleet, and it represents the fleet that would exist in MYs 2011-2016 absent any change from current regulations. The third step was to add technologies to that fleet such that each manufacturer's average car and truck CO_2 levels are in

compliance with their MY 2011 CAFE standards. This final "reference fleet" is the light duty fleet estimated to exist in MYs 2012-2016 without the final CAFE/GHG standards. All of the agencies' estimates of emission reductions/fuel economy improvements, costs, and societal impacts are developed in relation to the respective reference fleets. The chapter describes the first two steps of the development of the baseline and reference fleets. The third step of technology addition is developed separately by each agency as the outputs of the OMEGA and Volpe models. The process is described in section II of the preamble and in each agency's respective RIAs.

1.2 The 2008 baseline vehicle fleet

1.2.1 Why did the agencies choose 2008 as the baseline model year?

The baseline vehicle fleet developed by EPA in consultation with NHTSA and is comprised of model year 2008 data. MY 2008 was used as the basis for the baseline vehicle fleet, because it is the most recent model year for which a complete set of data is publicly available. Vehicle manufacturers have 90 days after their last vehicle is produced to submit their CAFE data to EPA.[1] Most manufacturers interpret this to mean 90 days after the end of the calendar year. For example, in calendar year 2007, model year 2008 vehicles were tested and certified by the EPA. These MY 2008 vehicles were then sold in the latter part (often fall) of 2007 until the following fall of 2008. In early 2009 (calendar year), the manufacturers then submit their total sales of MY 2008 vehicles. After these sales figures were submitted, EPA and NHTSA combined the sales with the previously measured and reported fuel economies to calculate the sales-weighted average fleet fuel economy. Even though the fuel economies (and some other specifications) of the MY 2009 vehicles were known, since they were tested earlier, the sales were not yet known for each company exactly. Full MY 2009 sales data is not available until April 2010, due to the fact that manufacturers have 90 days after the end of the model year to submit their data.[a] Therefore, the agencies chose to use MY 2008 as the baseline since it was the latest complete transparent data set available.

1.2.1.1 On what data is the baseline vehicle fleet based?

As part of the CAFE program, EPA measures vehicle CO_2 emissions and converts them to mpg and generates and maintains the federal fuel economy database. Most of the information about the 2008 vehicle fleet was gathered from EPA's emission certification and fuel economy database, most of which is available to the public. The data obtained from this source included vehicle production volume, fuel economy, carbon dioxide emissions, fuel type, number of engine cylinders, displacement, valves per cylinder, engine cycle, transmission type, drive, hybrid type, and aspiration. However, EPA's certification database does not include a detailed description of the types of fuel economy-improving/CO_2-reducing technologies considered in this final rule, because this level of information is not necessary for emission certification or fuel economy testing. Thus, the agency augmented this description with publicly-available data which includes

---

[a] § 600.512-08 Model Year Report

more complete technology descriptions from Ward's Automotive Group.[2,b] In a few instances when required vehicle information was not available from these two sources (such as vehicle footprint), this information was obtained from publicly-accessible internet sites such as Motortrend.com, Edmunds.com and other sources to a lesser extent (such as articles about specific vehicles revealed from internet search engine research.[3,c]

The baseline vehicle fleet for the analysis in this rule is comprised of publicly-available data to the largest extent possible. However, a few relatively low-impact technologies were added based on confidential information provided from some manufacturers (within their product plan submissions to NHTSA and EPA). This was done because the data were not available from any other source. These technologies include low friction lubricants, electric power steering, improved accessories, and low rolling resistance tires. This confidential information has been excised from the baseline data submitted to the docket, though the summary results are still used, so that any specific information cannot be traced back to any specific manufacturer. This discrepancy between the public baseline and the one used by the agencies is relatively minor and results in only result small differences in the outputs of the Volpe and OMEGA models for certain manufacturers.

Creating the 2008 baseline fleet Excel file was an extremely labor intensive process. EPA in consultation with NHTSA first considered using EPA's CAFE certification data, which contains most of the required information. However, since the deadline for manufacturers to report this data did not allow enough time for early modeling review, it was necessary to start this process using an alternative data source.

The agencies next considered using EPA's vehicle emissions certification data, which contains much of the required information, however it lacked the production volumes that are necessary for the OMEGA and Volpe models. The data set also contains some vehicle models manufacturers have certified, but not produced. A second data source which would supply production volumes and eliminate extraneous vehicles was needed. Data from a paid subscription to Ward's Automotive Group was used as the second source for data, which contains production volumes and vehicle specifications.

The vehicle emissions certification dataset came in two parts, an engine file and a vehicle file. Since there was a common index in the two files, the engine and vehicle data were easily combined into one spreadsheet. The agencies had hoped to supplement this dataset with production volume data from Ward's Automotive Group but the Ward's data does not have production volumes for individual vehicles down to the resolution of the specific engine and transmission level. Although production volumes from Ward's Automotive Group could not be used, the subscription did provide specific details on individual vehicles and engines. The Ward's data used came in two parts (engine file and vehicle file), and also required mapping. In this case, mapping was more difficult since there was no common index between the two files. A new index was implanted in the engine file and a search equation in the vehicle file, which identified most of the vehicle

---

[b] Note that WardsAuto.com is a fee-based service, but all information is public to subscribers.
[c] Motortrend.com and Edmunds.com are free, no-fee internet sites.

and engine combinations. Each vehicle and engine combination was reviewed and corrections were made manually when the search routine failed to give the correct engine and vehicle combination. The combined Ward's data was then mapped to the vehicle emissions certification data by creating a new index in the combined Ward's data and using the same process that was used to combine the Ward's engine and vehicle files. In the next step, CAFE certification data had to be merged in order to fill out the needed production volumes.

NHTSA and EPA reviewed the CAFE certification data for model year 2008 as it became available. The CAFE certification dataset could have been used with the Ward's data without the vehicle emission certification dataset, but was instead appended to the combined Ward's and vehicle certification dataset. The two former datasets were then mapped into the CAFE dataset using the same Excel mapping technique described above. Finally, EPA and NHTSA obtained the remaining attribute and technology data, such as footprint, curb weight, and others (for a complete list of data with sources see Table 1-1 below) from other sources (such as the internet and the confidential product plan data), thus completing the baseline dataset.

This was the first time a baseline fleet was created using this method. Given the long delay before the CAFE certification data became available, EPA explored creating the alternative dataset. It is possible to create the same baseline with CAFE certification data, the Ward's engine data, a limited amount of product plan data, and some internet searches.

Table 1-1 below shows the columns of the complete fleet file, which includes the 2008 MY baseline data that was compiled. Each column has its name, definition (description) and source. The EV and Aero columns were added to the fleet file to more accurately describe vehicles for the final rule. The data that is marked "not available" is data NHTSA would normally get from product plans. As mentioned above, some of the desired model inputs, such as the presence of low rolling resistance tires, reduced engine friction, improved accessories, etc., are not available from public sources and the agencies had to rely on manufacturers' confidential product plans. The Technology Effectiveness Basis and the Cost Effectiveness Basis values reflect the percent of a technology package's effectiveness and cost present in the baseline fleet, and they are described in further detail in chapters 3.1 and 3.5, respectively. Those technologies that are not accounted for in the baseline—that is, the ones marked "not available"—run the risk of getting double counted by the agencies' models, but those effects are expected to be small.

Table 1-1 Data, Definitions, and Sources

Data Item	Definition	Where The Data is From
Manufacturer	Common name of company that manufactured vehicle. May include more name plates than Cert Manufacturer Name.	Certification data
CERT Manufacturer Name	Certification name of company that manufactured vehicle	Certification data
Name Plate	Name of Division	Certification data
Model	Name of Vehicle	Certification data
Reg Class	EPA Fuel Economy Class Name	Certification data
Class	If a car's Footprint<43 then "SubCmpctAuto" If a car's 43<=Footprint<46 then "CompactAuto" If a car's 46<=Footprint<53 then "MidSizeAuto" If a car's Footprint >=53 then "LargeAuto" If a S.U.V.'s Footprint < 43 then "SmallSuv" If a S.U.V.'s 43<=Footprint<46 then "MidSizeSuv" If a S.U.V's Footprint >=46 then "LargeSuv" If a Truck's Footprint < 50 then "SmallPickup" If a Truck's Footprint>=50 then "LargPickup" If a Van's Structure is Ladder then "CargoVan" If a Van's Structure is Unibody then "Minivan"	Derived From Certification data and Footprint
CSM Class	CSM Worldwides class for the vehicle. Used to weight vehicles based on CSM data.	CSM Worldwide
Traditional Car/Truck	C= Car, T=Truck. As defined in the certification database. **Not used in calculations.**	Certification data
Total Production Volume	Total number of vehicles produced for that model.	Certification data
Fuel Econ. (mpg)	EPA Unadjusted Fuel Economy	Certification data
Curb Weight (lb)	Vehicles Curb Weight	Some from Edmonds.com or Motortrend.com, Others from product plans with a subset verified with Edmonds.com or Motortrend.com for accuracy.
Area (sf)	Average Track x Wheelbase	Calculated from track width and wheel base
Fuel	Gas or Diesel	Wards
Disp (lit.)	Engine Cylinder Displacement Size in Liters	Wards/Certification data
Effective Cyl	Number of Cylinder + 2 if the engine has a turbo or super charger.	Derived From Certification data.
Actual Cylinders	Actual Number of Engine Cylinders	Certification data
Valves Per Cylinder	Number of Valves Per Actual Cylinder	Certification data
Valve Type	Type of valve actuation.	Wards (Note:Type E is from Cert Data)
Engine Cycle	As Defined by EPA Cert. Definition	Wards
Horsepower	Max. Horsepower of the Engine	Wards
Torque	Max. Torque of the Engine	Wards
Trans Type	A=Auto AMT=Automated Manual M=Manual CVT= Continuously Variable Transmission	Certification data
Trans	Type Code with number of Gears	Certification data
Num of Gears	Number of Gears	Certification data
Structure	Ladder or Unibody	General Internet Searches using Google.com
Drive	Fwd, Rwd, Awd, 4wd	Certification data
Wheelbase	Length of Wheelbase	Some from Edmonds.com or Motortrend.com, Others from product plans with a subset

		verified with Edmonds.com or Motortrend.com for accuracy.
Track Width (front)	Length of Track Width in inches	Some from Edmonds.com or Motortrend.com, Others from product plans with a subset verified with Edmonds.com or Motortrend.com for accuracy.
Track Width (rear)	Length of Track Width in inches	Some from Edmonds.com or Motortrend.com, Others from product plans with a subset verified with Edmonds.com or Motortrend.com for accuracy.
Footprint	Average Track x Wheelbase	Calculated from track width and wheel base
Curb Weight	Curb Weight of the Vehicle	Some from Edmonds.com or Motortrend.com, Others from product plans with a subset verified with Edmonds.com or Motortrend.com for accuracy.
GVWR	Gross Vehicle Weight Rating of the Vehicle	Some from Edmonds.com or Motortrend.com, Others from product plans with a subset verified with Edmonds.com or Motortrend.com for accuracy.
HYBRID	Is the Vehicle a Hybrid?	Certification data
HYBRID TYPE	Type of Hybrid	Certification data
Turbo	Turbo Charged Engine	Certification data
Super Charged	Super Charged	Certification data
Turbo and/or Super Charged	Either or both Turbo charged / Super Charged	Certification data
SOHC	Single Overhead Cam Engine	Wards
DOHC	Dual Overhead Cam Engine	Wards
OHV	Overhead Valve Engine	Wards
1 LUB	Low friction lubricants—incremental to base engine	Obtained from product plans from manufacturers that report this information.[2]
2 EFR	Engine friction reduction—incremental to base engine	Obtained from product plans from manufacturers that report this information.[2]
3 CCPS	VVT - Coupled Cam Phasing (CCP) on SOHC	Wards[1]
4 DVVLS	Discrete Variable Valve Lift (DVVL) on SOHC	Wards[1]
5 DEACS	Cylinder Deactivation on SOHC	Wards[1]
6 ICP	VVT - Intake Cam Phasing (ICP)	Wards[1]
7 DCP	VVT - Dual Cam Phasing (DCP) (independent)	Wards[1]
8 DVVLD	Discrete Variable Valve Lift (DVVL) on DOHC	Wards[1]
9 CVVL	Continuously Variable Valve Lift (CVVL)	Wards[1]
10 DEACD	Cylinder Deactivation on DOHC	Wards[1]
11 DEACO	Cylinder Deactivation on OHV	Wards[1]
12 CCPO	VVT - Coupled Cam Phasing (CCP) on OHV	Wards[1]
13 DVVLO	Discrete Variable Valve Lift (DVVL) on OHV	Wards[1]

14 **CDOHC**	Conversion to DOHC with DCP	Not available
15 **SGDI**	Stoichiometric Gasoline Direct Injection (GDI)	Wards[1]
16 **CBRST**	Combustion Restart	Not available
18 **EGRB**	Exhaust Gas Recirculation (EGR) Boost	Not available
19 **DSLT**	Conversion to Diesel (from TRBDS)	Not available
20 **DSLC**	Conversion to Diesel (from CBRST)	Not available
21 **6MAN**	6-Speed Manual/Improved Internals	Certification data
22 **IATC**	Improved Auto. Trans. Controls/Externals	Not available
23 **CVT**	Continuously Variable Transmission	Certification data
24 **NAUTO**	6/7/8-Speed Auto. Trans with Improved Internals	Certification data
25 **DCTAM**	Dual Clutch or Automated Manual Transmission	Certification data
26 **EPS**	Electric Power Steering	Obtained from product plans from manufacturers that report this information.[2]
27 **IACC**	Improved Accessories	Obtained from product plans from manufacturers that report this information.[2]
28 **MHEV**	12V Micro-Hybrid	Not available
29 **HVIA**	Higher Voltage/Improved Alternator	Not available
30 **BISG**	Belt Mounted Integrated Starter Generator	Certification data
31 **CISG**	Crank Mounted Integrated Starter Generator	Certification data
32 **PSHEV**	Power Split Hybrid	Certification data
33 **2MHEV**	2-Mode Hybrid	Certification data
34 **PHEV**	Plug-in Hybrid	Not available
35 **MS1**	Material Substitution (1%)	Not available
36 **MS2**	Material Substitution (2%)	Not available
37 **MS5**	Material Substitution (5%)	Not available
38 **ROLL**	Low Rolling Resistance Tires	Obtained from product plans from manufacturers that report this information.[2]
39 **LDB**	Low Drag Brakes	Not available
EV	Electric Vehicle	Not available
Aero	Aerodynamics Optimised	Not available

Import Car	Cars Imported	Certification data
Index	Index Used to link EPA and NHTSA baselines	Created
Volume 2011	Projected Production Volume for 2011	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2012	Projected Production Volume for 2012	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2013	Projected Production Volume for 2013	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2014	Projected Production Volume for 2014	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2015	Projected Production Volume for 2015	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2016	Projected Production Volume for 2016	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Vehicle Type Number	Vehicle Type Number assigned to a vehicle based on its number of cylinders, valves per cylinder, and valve actuation technology.	Mapping done by Agencies
Footprint: PU Average	Car Foot Print is normal. Truck footprint is the production weighted average for each vehicle.	Derived from data from Edmunds.com or Motortrend.com. Production volumes or specific footprints from product plans.
Footprint: PU Cutoff	Same as above, but footprint valve for trucks limited to 66 before weighting. Meaning valves greater than 66 equal 66.	Derived from data from Edmunds.com or Motortrend.com. Production volumes or specific footprints from product plans.
NHTSA Defined New NHTSA Car/Truck	New NHTSA Car Truck value as determined by NHTSA. Used in calculations.	NHTSA
CO_2	CO_2 calculated from MPG. CO_2 weighted 1.15 times higher for diesel vehicles.	Certification data
Thresholded FootPrint	Footprint valve that will be set to 41 for values less than 41, Will be set to 56 for car values > 56, and will be set to 66 for truck values >66 Used in Summary Calculations	Derived from data from Edmunds.com or Motortrend.com. Production volumes or specific footprints from product plans.
TEB Tech 1	Percentage of Tech Package 1	Calculated using a macro in another spread sheet. Calculated based on the technology in the "Data" sheet.
TEB Tech 2	Percentage of Tech Package 2	Calculated using a macro in another spread sheet. Calculated based on the technology in the "Data" sheet.
TEB Tech 3	Percentage of Tech Package 3	Calculated using a macro in another spread sheet. Calculated based on the technology in the "Data" sheet.
TEB Tech 4	Percentage of Tech Package 4	Calculated using a macro in another spread sheet. Calculated based on the technology in the "Data" sheet.
TEB Tech 5	Percentage of Tech Package 5	Calculated using a macro in another spread sheet.

		Calculated based on the technology in the "Data" sheet.
TEB Tech 6		Calculated using a macro in another spread sheet.
	Percentage of Tech Package 6	Calculated based on the technology in the "Data" sheet.
CEB Tech 1		Calculated using a macro in another spread sheet.
	Percentage of Cost of Tech Package 1	Calculated based on the technology in the "Data" sheet.
CEB Tech 2		Calculated using a macro in another spread sheet.
	Percentage of Cost of Tech Package 2	Calculated based on the technology in the "Data" sheet.
CEB Tech 3		Calculated using a macro in another spread sheet.
	Percentage of Cost of Tech Package 3	Calculated based on the technology in the "Data" sheet.
CEB Tech 4		Calculated using a macro in another spread sheet.
	Percentage of Cost of Tech Package 4	Calculated based on the technology in the "Data" sheet.
CEB Tech 5		Calculated using a macro in another spread sheet.
	Percentage of Cost of Tech Package 5	Calculated based on the technology in the "Data" sheet.
CEB Tech 6		Calculated using a macro in another spread sheet.
	Percentage of Cost of Tech Package 6	Calculated based on the technology in the "Data" sheet.

Notes:
1. For engines not available in the WardsAuto.com engine file, an internet search was done to find this information.
2. These data were obtained from manufacturer's product plans. They were used to block (where possible) the model from adding technology that was already on a vehicle.
3. Ward's Automotive Group data obtained from "2008 Light Vehicle Engines."

The sales volumes for the MY 2008 baseline fleet are included in the section below on reference fleet under the MY 2008 columns. Table 1-2 displays the technologies present in the baseline fleet.

Table 1-2 2008 Technology Percentages

	Turbo	Super Charged	SOHC	DOHC	OHV	LUB	CCPS	DVVLS	DEACS	ICP	DCP	DVVLD
All Trucks	1.0%	0.2%	23.7%	47.6%	28.7%	61.4%	4.1%	5.8%	0.0%	5.3%	36.6%	1.5%
All Cars	3.4%	0.2%	17.4%	73.3%	9.2%	48.5%	1.4%	7.4%	1.3%	3.2%	47.9%	0.2%
BMW Trucks	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	94.7%	0.0%
BMW Cars	6.3%	1.1%	13.9%	86.0%	0.0%	0.0%	11.9%	11.9%	0.0%	0.0%	85.8%	1.5%
Chrysler Trucks	0.2%	0.0%	38.9%	4.1%	56.9%	76.9%	0.0%	0.0%	0.0%	0.0%	3.9%	0.0%
Chrysler Cars	0.9%	0.0%	20.8%	71.5%	7.7%	28.5%	0.0%	0.0%	0.0%	0.0%	41.7%	0.0%
Ford Trucks	0.0%	0.1%	62.9%	34.3%	2.8%	3.9%	26.5%	0.0%	0.0%	0.0%	9.3%	0.0%
Ford Cars	3.1%	0.9%	14.2%	85.8%	0.0%	6.4%	4.0%	0.0%	0.0%	0.0%	5.2%	0.0%
Subaru Trucks	3.2%	0.0%	70.5%	29.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	29.5%	27.4%
Subaru Cars	14.5%	0.0%	69.2%	30.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	30.8%	0.9%
GM Trucks	0.0%	0.0%	0.0%	30.8%	69.2%	92.7%	0.0%	0.0%	0.0%	14.7%	30.8%	0.0%
GM Cars	2.6%	0.0%	0.0%	56.2%	43.8%	92.0%	0.0%	0.0%	0.0%	11.5%	28.8%	0.0%
Honda Trucks	4.2%	0.0%	64.3%	35.7%	0.0%	0.0%	0.0%	64.3%	0.0%	0.0%	31.5%	4.2%
Honda Cars	0.0%	0.0%	57.2%	42.8%	0.0%	0.0%	0.0%	57.2%	10.7%	0.0%	42.6%	0.3%
Hyundai Trucks	0.0%	0.0%	0.0%	100.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	29.6%	0.0%
Hyundai Cars	0.0%	0.0%	0.0%	100.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	32.2%	0.0%
Tata Trucks	0.0%	20.3%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%
Tata Cars	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%
Kia Trucks	0.0%	0.0%	0.0%	100.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	17.2%	0.0%
Kia Cars	0.0%	0.0%	0.0%	100.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	10.2%	0.0%
Mazda Trucks	23.5%	0.0%	0.6%	99.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	99.3%	0.0%
Mazda Cars	11.4%	0.0%	0.0%	100.0%	0.0%	0.0%	0.9%	0.9%	0.9%	0.9%	99.9%	0.9%
Daimler Trucks	15.9%	0.7%	36.2%	63.8%	0.0%	0.0%	0.0%	0.0%	0.0%	46.7%	0.0%	0.0%
Daimler Cars	2.4%	0.3%	54.6%	45.4%	0.0%	0.0%	0.0%	0.0%	0.0%	30.3%	0.0%	0.0%
Mitsubishi Trucks	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%	37.7%	0.0%	0.0%	0.0%	0.0%	0.0%
Mitsubishi Cars	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%	42.9%	0.0%	0.0%	0.0%	0.0%	0.0%
Nissan Trucks	0.0%	0.0%	0.0%	100.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%
Nissan Cars	0.0%	0.0%	0.0%	100.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%
Porsche Trucks	12.4%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%
Porsche Cars	17.4%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	28.7%	82.6%	0.0%
Suzuki Trucks	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Suzuki Cars	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Toyota Trucks	0.0%	0.2%	0.0%	100.0%	0.0%	89.1%	0.0%	0.0%	0.0%	0.0%	78.3%	0.0%
Toyota Cars	0.0%	0.0%	0.0%	100.0%	0.0%	69.9%	0.0%	0.0%	0.0%	0.2%	99.4%	0.0%
VW Trucks	0.6%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	78.9%	99.4%	78.9%
VW Cars	43.1%	0.0%	85.0%	15.0%	0.1%	0.0%	0.0%	0.0%	0.0%	1.9%	14.1%	0.8%

Table 1-2 2008 Technology Percentages

	CVVL	DEACD	DEACO	CCPO	DVVLO	SGDI	6MAN	CVT	NAUTO	DCTAM	EPS	BISG	CISG
All Trucks	2.8%	0.0%	10.5%	1.4%	0.0%	2.9%	1.0%	2.6%	19.9%	0.0%	0.9%	0.0%	0.0%
All Cars	5.2%	0.0%	1.2%	5.7%	0.0%	4.7%	2.3%	11.5%	18.5%	0.8%	12.6%	0.0%	0.4%
BMW Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	6.3%	0.7%	0.0%	99.3%	0.0%	0.0%	0.0%	0.0%
BMW Cars	0.0%	0.0%	0.0%	0.0%	0.0%	7.7%	14.6%	0.5%	83.3%	1.1%	0.0%	0.0%	0.0%
Chrysler Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	4.3%	3.6%	21.4%	0.0%	0.0%	0.0%	0.0%
Chrysler Cars	0.0%	0.0%	5.2%	0.0%	0.0%	0.0%	0.9%	18.5%	3.9%	0.0%	0.0%	0.0%	0.0%
Ford Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	0.0%	1.8%	18.8%	0.0%	0.0%	0.0%	0.0%
Ford Cars	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	1.9%	36.8%	0.0%	0.0%	0.0%	0.0%
Subaru Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Subaru Cars	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
GM Trucks	0.0%	0.0%	39.1%	5.0%	0.0%	0.0%	0.0%	0.0%	18.6%	0.0%	0.0%	0.0%	0.0%
GM Cars	0.0%	0.0%	4.0%	28.8%	0.0%	6.0%	1.1%	0.0%	12.3%	0.0%	0.0%	0.1%	0.0%
Honda Trucks	31.5%	0.0%	0.0%	0.0%	0.0%	4.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Honda Cars	42.6%	0.0%	0.0%	0.0%	0.0%	0.0%	3.1%	3.2%	0.0%	0.0%	0.0%	0.0%	3.2%
Hyundai Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	25.0%	0.0%	0.0%	0.0%	0.0%
Hyundai Cars	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Tata Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
Tata Cars	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	91.6%	0.0%	0.0%	0.0%	0.0%
Kia Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Kia Cars	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mazda Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	23.5%	0.0%	0.1%	57.2%	0.0%	0.0%	0.0%	0.0%
Mazda Cars	0.9%	0.9%	0.9%	0.9%	0.9%	11.4%	3.8%	0.1%	19.2%	0.0%	0.0%	0.0%	0.0%
Daimler Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	15.9%	0.0%	0.0%	99.3%	0.0%	0.0%	0.0%	0.0%
Daimler Cars	0.0%	0.0%	0.0%	0.0%	0.0%	1.7%	0.3%	0.0%	67.4%	10.4%	0.0%	0.0%	0.0%
Mitsubishi Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	14.4%	23.3%	0.0%	0.0%	0.0%	0.0%
Mitsubishi Cars	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	44.2%	7.6%	0.0%	0.0%	0.0%	0.0%
Nissan Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	16.5%	0.0%	0.0%	16.5%	0.0%	0.0%
Nissan Cars	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.5%	69.4%	0.0%	0.0%	32.3%	0.0%	0.0%
Porsche Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	1.4%	0.0%	98.6%	0.0%	0.0%	0.0%	0.0%
Porsche Cars	0.0%	0.0%	0.0%	0.0%	0.0%	17.4%	51.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Suzuki Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Suzuki Cars	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Toyota Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	5.7%	1.4%	4.7%	19.2%	0.0%	0.0%	0.0%	0.0%
Toyota Cars	0.0%	0.0%	0.0%	0.0%	0.0%	7.6%	0.1%	16.7%	22.5%	0.0%	64.0%	0.0%	0.0%
VW Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
VW Cars	0.0%	0.0%	0.0%	0.0%	0.0%	46.0%	6.4%	5.4%	65.7%	14.3%	0.0%	0.0%	0.0%

Table 1-2 2008 Technology Percentages

	PSHEV	2MHEV	PHEV	Auto 4 Speed	Auto 5 Speed	Auto 6 Speed	Auto 7 Speed	Auto 8 Speed	Manual 5 Speed	Manual 6 Speed	CVT	Automated Manual 5 Speed	Automated Manual 6 Speed	Automated Manual 7 Speed
All Trucks	0.8%	0.1%	0.0%	37.9%	37.3%	18.6%	1.4%	0.0%	1.1%	1.0%	2.6%	0.0%	0.0%	0.0%
All Cars	2.7%	0.0%	0.0%	39.1%	22.9%	16.4%	1.7%	0.4%	4.9%	2.3%	11.5%	0.3%	0.5%	0.0%
BMW Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	99.3%	0.0%	0.0%	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%
BMW Cars	0.2%	0.0%	0.2%	0.0%	0.0%	82.6%	0.8%	0.0%	0.3%	14.6%	0.5%	0.0%	0.0%	1.1%
Chrysler Trucks	0.0%	0.0%	0.0%	34.9%	35.5%	21.4%	0.0%	0.0%	0.3%	4.3%	3.6%	0.0%	0.0%	0.0%
Chrysler Cars	0.0%	0.0%	0.0%	67.0%	8.2%	3.9%	0.0%	0.0%	1.4%	0.9%	18.5%	0.0%	0.0%	0.0%
Ford Trucks	0.0%	0.0%	0.0%	55.9%	20.9%	18.8%	0.0%	0.0%	2.7%	0.0%	1.8%	0.0%	0.0%	0.0%
Ford Cars	0.0%	0.0%	0.0%	36.3%	18.2%	36.8%	0.0%	0.0%	5.6%	1.2%	1.9%	0.0%	0.0%	0.0%
Subaru Trucks	0.0%	0.0%	0.0%	62.1%	29.5%	0.0%	0.0%	0.0%	8.4%	0.0%	0.0%	0.0%	0.0%	0.0%
Subaru Cars	0.0%	0.0%	0.0%	69.6%	2.4%	0.0%	0.0%	0.0%	23.9%	4.1%	0.0%	0.0%	0.0%	0.0%
GM Trucks	0.0%	0.5%	0.0%	75.5%	5.0%	19.0%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%
GM Cars	0.0%	0.1%	0.0%	77.9%	5.4%	12.3%	0.0%	0.0%	3.2%	1.1%	0.0%	0.0%	0.0%	0.0%
Honda Trucks	0.0%	0.0%	0.0%	0.0%	99.7%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%
Honda Cars	0.0%	0.0%	0.0%	0.0%	87.3%	0.0%	0.0%	0.0%	6.4%	3.1%	3.2%	0.0%	0.0%	0.0%
Hyundai Trucks	0.0%	0.0%	0.0%	29.8%	45.0%	25.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Hyundai Cars	0.0%	0.0%	0.0%	76.4%	16.7%	0.0%	0.0%	0.0%	6.7%	0.2%	0.0%	0.0%	0.0%	0.0%
Tata Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Tata Cars	0.0%	0.0%	0.0%	0.0%	8.4%	91.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Kia Trucks	0.0%	0.0%	0.0%	23.1%	75.7%	0.0%	0.0%	0.0%	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%
Kia Cars	0.0%	0.0%	0.0%	51.5%	41.0%	0.0%	0.0%	0.0%	7.5%	0.0%	0.0%	0.0%	0.0%	0.0%
Mazda Trucks	0.0%	0.0%	0.0%	10.1%	29.6%	57.2%	0.0%	0.0%	3.0%	0.0%	0.1%	0.0%	0.0%	0.0%
Mazda Cars	0.0%	0.0%	0.0%	33.3%	29.7%	19.2%	0.0%	0.0%	13.9%	3.8%	0.1%	0.0%	0.0%	0.0%
Daimler Trucks	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	99.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Daimler Cars	0.0%	0.0%	0.0%	0.0%	22.0%	0.0%	67.4%	0.0%	0.0%	0.3%	0.0%	10.4%	0.0%	0.0%
Mitsubishi Trucks	0.0%	0.0%	0.0%	62.3%	0.0%	23.3%	0.0%	0.0%	0.0%	0.0%	14.4%	0.0%	0.0%	0.0%
Mitsubishi Cars	0.0%	0.0%	0.0%	30.8%	4.5%	7.6%	0.0%	0.0%	11.6%	1.4%	44.2%	0.0%	0.0%	0.0%
Nissan Trucks	0.0%	0.0%	0.0%	0.0%	81.6%	0.0%	0.0%	0.0%	0.7%	1.2%	16.5%	0.0%	0.0%	0.0%
Nissan Cars	1.1%	0.0%	0.0%	7.0%	19.1%	0.0%	0.0%	0.0%	0.0%	4.5%	69.4%	0.0%	0.0%	0.0%
Porsche Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	98.6%	0.0%	0.0%	0.0%	1.4%	0.0%	0.0%	0.0%	0.0%
Porsche Cars	0.0%	0.0%	0.0%	0.0%	33.7%	0.0%	0.0%	0.0%	14.4%	51.9%	0.0%	0.0%	0.0%	0.0%
Suzuki Trucks	0.0%	0.0%	0.0%	0.0%	99.5%	0.0%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%
Suzuki Cars	0.0%	0.0%	0.0%	76.2%	13.1%	0.0%	0.0%	0.0%	10.7%	0.0%	0.0%	0.0%	0.0%	0.0%
Toyota Trucks	4.7%	0.0%	0.0%	9.0%	63.9%	19.2%	0.0%	0.0%	1.9%	1.4%	4.7%	0.0%	0.0%	0.0%
Toyota Cars	16.9%	0.0%	0.0%	35.7%	19.5%	19.8%	0.0%	2.6%	5.5%	0.1%	16.7%	0.0%	0.0%	0.0%
VW Trucks	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
VW Cars	0.0%	0.0%	0.0%	0.0%	0.0%	65.7%	0.0%	0.0%	8.2%	6.4%	5.4%	0.0%	14.3%	0.0%

As noted at proposal, these technology tables indicate that some manufacturers are already implementing some of these technologies in their 2008 fleet. VW stands out as having a significant number of turbocharged direct injection engines, though it is

uncertain whether their engines are also downsized. Some of the valve and cam technologies are quite common today: for example, nearly half the fleet has dual cam phasing, while Honda and GM are have considerable levels of engines with cylinder deactivation (DEAC). Honda also has already implemented continuously variable valve lift (CVVL) on a majority of their engines. Moreover, Toyota has the highest penetration of hybrid technologies. Finally, regarding the technologies obtained from the product plans, many of the manufacturers who reported the lubricating oil information indicated that low friction (or low viscosity) oil will be used more frequently in the future. Therefore, it is likely that this technology is underreported for the fleet as a whole since it was assumed that the usage of low viscosity oils was zero for the companies who did not provide product plans. The lack of reporting of these types of technologies (if they exist in the fleet) will probably lead to a slightly higher cost of compliance for these companies. However, these technologies alone do not necessarily guarantee a better fuel economy compared to other vehicles in their footprint class. There are many other considerations at play, most notably, weight and power.

The section below provides further detail on the conversion of the MY 2008 baseline into the MY 2011-2016 reference fleet. It also describes more of the data contained in the baseline spreadsheet.

1.3 The MY 2011-2016 Reference Fleet

The reference fleet aims to reflect the current market conditions and expectations about conditions of the vehicle fleet during the model years to which the agencies' rules apply. Fundamentally, constructing this fleet involved projecting the MY 2008 baseline fleet into the MY 2011-2016 model years. It also included the assumption that none of the models had changes during this period. Projecting what the fleet will look like in the future is a process that is inherently uncertain. NHTSA and EPA therefore relied on many sources of reputable information to make these projections.

1.3.1 On what data is the reference vehicle fleet based?

As explained at proposal, EPA and NHTSA have based the projection of total car and light truck sales on recent projections made by the Energy Information Administration (EIA). EIA publishes a mid-term projection of national energy use annually called the Annual Energy Outlook (AEO).[4] No commenter challenged the appropriateness of using the AEO. At proposal, the agencies used the various AEO 2009 reports for the sales projections used in constructing the reference fleet used as the basis for the proposed rule. However, EIA also recently published an early version of its 2010 Annual Energy Outlook. This early 2010 report was published in December, in time to be used in this rule making. The differences in projected sales in the updated 2009 report and the early 2010 report are very small, so the agencies just scaled the data from the 2009 report data to the absolute number of vehicles (cars and trucks) in the 2010 report. The agencies recognize that AEO 2010 Early Release does include some impacts of future projected increases in CAFE stringency. We have closely examined the difference between AEO 2009 and AEO 2010 Early Release and we believe the differences in total

sales and the car/truck split attributed to considerations of the standard in the final rule are small. [5]

Table 1-3below shows the scaling factors that were used for each model year. We use the sales projections from the scaled updated 2009 Annual Energy Outlook.

Table 1-3 Annual Energy Outlook 2010 Scaling Factor[a]

	2011	2012	2013	2014	2015	2016
Multiplier	0.958339	1.004719	1.011593	0.997677	0.992585	0.995178

[a] The scaling factors were determined by dividing the absolute number of vehicles in AEO 2010 for each model year shown by the absolute number of vehicles in AEO 2009 for each of those model years.

In the AEO 2010 Early Release, EIA projects that total light-duty vehicle sales gradually recover from their currently depressed levels by roughly 2013. In 2016, car and light truck sales are projected to be 9.4 and 7.1 million units, respectively. While the total level of sales of 16.5 million units is similar to pre-2008 levels, the fraction of car sales is projected to be higher than that existing in the 2000-2007 timeframe. This projection reflects the impact of higher fuel prices, as well as the effects of the EISA (which called for a minimum fleet average of 35 mpg by 2020). Note that EIA's definition of cars and trucks follows that used by NHTSA prior to the MY 2011 CAFE final rule published earlier this year. The MY 2011 CAFE final rule reclassified a number of 2-wheel drive sport utility vehicles from the truck fleet to the car fleet. EIA's sales projections of cars and trucks for the 2011-2016 model years under both the new and old NHTSA truck definition are shown in Table 1-4 and Table 1-5 below, respectively. Actual vehicle sales for MY 2008 are also shown under the new NHTSA truck definition. Slight differences exist between the total car and truck sales projections. These differences are less than 0.1 percent and are due to the iterative process described further below to shift sales between car and truck market segments.

Table 1-4 AEO 2010 Volumes New NHTSA Car Truck Definition After Projections

	2008 Baseline Sales	2011 Projected Volume	2012 Projected Volume	2013 Projected Volume	2014 Projected Volume	2015 Projected Volume	2016 Projected Volume
All Trucks	5,620,847	5,457,758	5,798,588	6,038,484	5,947,819	5,826,579	5,669,683
All Cars	8,220,517	7,922,992	9,123,197	9,797,738	10,231,974	10,627,055	10,832,348
Total	13,841,364	13,380,750	14,921,784	15,836,222	16,179,793	16,453,634	16,502,032

Table 1-5 AEO 2010 Volumes Old NHTSA Car Truck Definition Before Projections

		2011 Projected Volume	2012 Projected Volume	2013 Projected Volume	2014 Projected Volume	2015 Projected Volume	2016 Projected Volume
All Trucks		6,665,386	7,160,069	7,478,667	7,423,880	7,280,946	7,079,323
All Cars		6,715,364	7,761,715	8,357,555	8,755,912	9,172,688	9,422,709
Total		13,380,750	14,921,784	15,836,222	16,179,793	16,453,634	16,502,032

In addition to a shift towards more car sales, sales of segments within both the car and truck markets have also been changing and are expected to continue to change in the future. Manufacturers are continuing to introduce more crossover models which offer much of the utility of SUVs but use more car-like designs and unibody structures. In order to reflect these changes in fleet makeup, EPA and NHTSA considered several available forecasts. After reviewing information from a number of forecasting organizations, the agencies decided to purchase forecasts from two well-known industry analysts, CSM Worldwide (CSM) and J.D. Powers.[6] NHTSA and EPA decided to use the forecast from CSM, for several reasons. One, CSM agreed to allow us to publish their high level data, on which the forecast is based, in the public domain. Two, it covered nearly all the timeframe of greatest relevance to this rule (2012-2015 model years). Three, it provided projections of vehicle sales both by manufacturer and by market segment. Four, it utilized market segments similar to those used in the EPA emission certification program and fuel economy guide. EPA did need to have CSM's standard forecast (that covers all vehicles below 14,000 lbs GVW) customized to cover only light duty vehicles and medium duty passenger vehicles. As discussed further below, the CSM forecast is combined with other data obtained by NHTSA and EPA. The breakdown of car and truck sales by manufacturer and by market segment for the 2016 model year and beyond were assumed to be the same as CSM's forecast for the 2015 calendar year, because CSM forecasts for 2016 will not be available until the 1st quarter of 2010.

1.3.2 How do the agencies develop the reference vehicle fleet?

The process of producing the 2011-2016 reference fleet involved combining the baseline fleet with the projection data described above. This was a complex multistep procedure, which is described in this section.

1.3.2.1 How was the 2008 baseline data merged with the CSM data?

As explained at proposal, merging the 2008 baseline data with the 2011-2016 CSM data required a thorough mapping of certification vehicles to CSM vehicles by individual make and model. One challenge the agencies faced when determining a reference case fleet was that the sales data projected by CSM had different market segmentation than the data contained in EPA's internal database. In order to create a

common segmentation between the two databases, side-by-side comparison of the specific vehicle models in both datasets was performed, and an additional "CSM segment" modifier in the spreadsheet was created, thus mapping the two datasets. The reference fleet sales based on the "CSM segmentation" was then projected.

The baseline data and reference fleet volumes are available to the public. The baseline Excel spreadsheet in the docket is the result of the merged files.[7] It provides specific details on the sources and definitions for the data. The Excel file contains several tabs. They are: "Data", "Data Tech Definitions", "SUM", "SUM Tech Definitions", "Truck Vehicle Type Map", and "Car Vehicle Type Map". "Data" is the tab with the raw data. "Data Tech Definitions" is the tab where each column is defined and its data source named. "SUM" is the tab where the raw data is processed to be used in the OMEGA and Volpe models. The "SUM" tab minus columns A-F and minus the Generic vehicles is the input file for the models. The "Generic" manufacturer (shown in the "SUM" tab) is the sum of all manufacturers and is calculated as a reference, and for data verification purposes. It is used to validate the manufacturers' totals. It also gives an overview of the fleet. Table 1-6 shows the sum of the models chosen. The number of models is determined by the number of unique segment and vehicle type combinations. These combinations of segment and vehicle type (the vehicle type number is the same as the technology package number) are determined by the technology packages discussed in.the EPA RIA (chapter 1). "SUM Tech Definitions" is the tab where the columns of the "SUM" tab are defined. The "Truck Vehicle Type Map" and "Car Vehicle Type Map" map the number of cylinder and valve actuation technology to the "tech package" vehicle type number.

Table 1-6 Models from the SUM Tab Model

Model
Car Like LargeSuv >=V8   Vehicle Type: 13
Car Like LargeSuv V6   Vehicle Type: 16
Car Like LargeSuv V6   Vehicle Type: 12
Car Like LargeSuv V6   Vehicle Type: 9
Car Like LargeSuv I4 and I5   Vehicle Type: 7
Car Like MidSizeSuv V6   Vehicle Type: 8
Car Like MidSizeSuv V6   Vehicle Type: 5
Car Like MidSizeSuv I4   Vehicle Type: 7
Car Like SmallSuv V6   Vehicle Type: 12
Car Like SmallSuv V6   Vehicle Type: 4
Car Like SmallSuv I4   Vehicle Type: 3
LargeAuto >=V8   Vehicle Type: 13
LargeAuto >=V8   Vehicle Type: 10
LargeAuto >=V8   Vehicle Type: 6
LargeAuto V6   Vehicle Type: 12
LargeAuto V6   Vehicle Type: 5
MidSizeAuto >=V8   Vehicle Type: 13
MidSizeAuto >=V8   Vehicle Type: 10
MidSizeAuto >=V8 (7 or >)   Vehicle Type: 6
MidSizeAuto V6   Vehicle Type: 12
MidSizeAuto V6   Vehicle Type: 8

MidSizeAuto V6   Vehicle Type: 5
MidSizeAuto I4   Vehicle Type: 3

In the combined EPA certification and CSM database, all of the 2008 vehicle models were assumed to continue out to 2016, though their volumes changed in proportion to CSM projections. Also, any new models expected to be introduced within the 2009-2016 timeframe are not included in the data. These volumes are reassigned to the existing models. All MY 2011-2016 vehicles are mapped to the existing vehicles by a process of mapping to manufacturer market share and overall segment distribution. The mappings are discussed in the next section. Further discussion of this limitation is discussed below in section 1.3.4. The statistics of this fleet will be presented below since further modifications were required to the volumes as the next section describes.

1.3.2.2   How were the CSM forecasts normalized to the AEO forecasts?

As also explained at proposal, the next step in the production of the reference fleet is one of the more complicated steps to explain. Here, the projected CSM forecasts for relative sales of cars and trucks by manufacturer and by market segment was normalized (set equal) to the total sales estimates of the preliminary 2010 Annual Energy Outlook (AEO). NHTSA and EPA used projected car and truck volumes for this period from AEO 2009. However, the AEO projects sales only at the car and truck level, not at the manufacturer and model-specific level, which are needed for the analysis. The CSM data provided year-by-year percentages of cars and trucks sold by each manufacturer as well as the percentages of each vehicle segment. Using these percentages normalized to the AEO-projected volumes then provided the manufacturer-specific market share and model-specific sales for model years 2011-2016 (it is worth clarifying that the agencies are not using the model-specific sales volumes from CSM, only the volumes by manufacturer and segment). This process is described in greater detail in the following paragraphs.

In order to determine future production volumes, multipliers were developed by manufacturer and vehicle segment that could be applied to MY 2008 volumes. The process for developing the multipliers is complicated, but is easiest to explain as a three-step process, though the first step is combined with both the second and third step, so only one multiplier per manufacturer and vehicle segment is developed.

The three steps are:
1. Adjust total car and truck sales to match AEO projections.
2. Adjust Car sales to match CSM market share projections for each manufacturer and car segment.
3. Adjust Truck sales to match CSM market share projections for each manufacturer and truck segment.

The first step is the adjustment of total car and truck sales in 2008 to match AEO projections of total car and truck sales in 2011-2016. The volumes for all of the trucks in 2008 were added up (TruckSum2008), and so were the volumes of all the cars (CarSum2008). A multiplier was developed to scale the volumes in 2008 to the AEO

projections. The example equation below shows the general form of how to calculate a car or truck multiplier. The AEO projections are shown above in Table 1-4.

<u>Example Equation</u> :
$$TruckMultiplier(Year\ X) = AEOProjectionforTrucks(Year\ X) / TruckSum2008$$
$$CarMultiplier(Year\ X) = AEOProjectionforCars(Year\ X) / CarSum2008$$

Where: Year X is the model year of the multiplier.

The AEO projection is different for each model year. Therefore, the multipliers are different for each model year. The multipliers can be applied to each 2008 vehicle as a first adjustment, but multipliers based solely on AEO have limited value since it can only give an adjustment that will give the correct total numbers of cars and trucks without the correct market share or vehicle mix. A correction factor based on the CSM data, which does contain market share and vehicle segment mix, is therefore necessary, so combining the AEO multiplier with CSM multipliers (one per manufacturer, segment, and model year) will give the best multipliers.

There were several steps in developing an adjustment for Cars based on the CSM data. CSM provided data on the market share and vehicle segment distribution. The first step in determining the adjustment for Cars was to total the number of Cars in each vehicle segment by manufacturer in MY 2008. A total for all manufacturers in each segment was also calculated. The next step was to multiply the volume of each segment for each manufacturer by the CSM market share. The AEO multiplier was also applied at this time. This gave projected volumes with AEO total volumes and market share correction for Cars. This is shown in the "Adjusted for 2011 AEO and Manufacturer Market Share" column of Table 1-7.

The next step is to adjust the sales volumes for CSM vehicle segment distribution. The process for adjusting for vehicle segment is more complicated than a simple one step multiplication. In order to keep manufacturers' volumes constant and still have the correct vehicle segment distribution, vehicles need to move from segment to segment while maintaining constant manufacturers' totals. Six rules and one assumption were applied to accomplish the shift. The assumption (based on the shift in vehicle sales in the last year) is that people are moving to smaller vehicles in the rulemaking time frame. A higher level (less detailed) example of this procedure is provided in the preamble section II.

1. Vehicles from CSM's "Luxury Car," "Specialty Car," and "Other Car" segments, if reduced will be equally distributed to the remaining four categories ("Full-Size Car," "Mid-Size Car," "Small Car," "Mini Car"). If these sales increased, they were taken from the remaining four categories so that the relative sales in these four categories remained constant.
2. Vehicles from CSM's "Luxury Car," "Specialty Car," and "Other Car" segments, if increased will take equally from the remaining categories ("Full-Size Car," "Mid-Size Car," "Small Car," "Mini Car").

3. All manufacturers have the same multiplier for a given segment shift based on moving all vehicles in that segment to achieve the CSM distribution. Table 1-7 shows how the 2011 vehicles moved and the multipliers that were created for each adjustment. This does not mean that new vehicle segments will be added (except for Generic Mini Car described in the next step) to manufacturers that do not produce them. Vehicles within each manufacturer will be shifted as close to the distribution as possible given the other rules. Table 1-8 has the percentages of Cars per CSM segment. These percentages are multiplied by the total number of vehicles in a given year to get the total sales in the segment. Table 1-7 shows the totals for 2011 in the "2011 AEO-CSM Sales Goal" column.

4. When "Full-Size Car," "Mid-Size Car," "Small Car" are processed, if vehicles need to move in or out of the segment, they will move into or out of the next smaller segment. So, if Mid-Size Cars are being processed they can only move to or be taken from Small Cars. Note: In order to accomplish this, a "Generic Mini Car" segment was added to manufacturers who did not have a Mini (type) Car in production in 2008, but needed to shift down vehicles from the Small Car segment.

5. The data must be processed in the following order: "Luxury Car," "Specialty Car," "Other Car," "Full-Size Car," "Mid-Size Car," "Small Car." The "Mini Car" does not need to be processed separately. By using this order, it works out that vehicles will always move toward the correct distribution. There are two exceptions, BMW and Porsche only have "Luxury Car," "Specialty Car," and "Other Car" vehicles, so their volumes were not changed or shifted since these rules did not apply to them.

6. When an individual manufacturer multiplier is applied for a segment, the vehicles move to or from the appropriate segments as specified in the previous rules and as shown in Table 1-7.

Table 1-7 Example: 2011 Model Year Volume Shift*

CSM Segment	2008 MY Sales	Adjusted for 2011 AEO and Manufacturer Market Share	Luxury, Specialty, Other Adjustment	Full Size Adjustment	Midsize Adjustment	Small Car Adjustment	2011 AEO-CSM Sales Goal
All Full-Size Car	730,355	501,245	520,885	411,025	411,025	411,025	411,025
All Luxury Car	1,057,875	1,076,470	970,680	970,680	970,680	970,680	970,666
All Mid-Size Car	1,970,494	1,946,981	2,033,087	2,142,948	1,838,095	1,838,095	1,838,095
All Mini Car	599,643	686,738	733,339	733,339	733,339	991,309	991,349
All Small Car	1,850,522	2,007,527	2,099,343	2,099,343	2,404,196	2,146,226	2,146,226
All Specialty Car	754,547	783,982	637,785	637,785	637,785	637,785	637,759
All Others	3,259	4,355	12,178	12,178	12,178	12,178	12,178
Number Vehicles that shift and Where							
All Full-Size Car			19,640	(109,861)	-	-	
All Luxury Car			(105,790)	-	-	-	
All Mid-Size Car			86,107	109,861	(304,853)	-	
All Mini Car			46,601	-	-	257,970	
All Small Car			91,816	-	304,853	(257,970)	
All Specialty Car			(146,198)	-	-	-	
All Others			7,823	-	-	-	
Individual Manufacturer Multiplier							
All Full-Size Car				0.789			
All Luxury Car			0.902				
All Mid-Size Car					0.858		
All Mini Car						1.352	
All Small Car							
All Specialty Car			0.814				
All Others			2.796				

*Note: The data in this table is based on the NPRM data.

Table 1-8 Example: CSM – Percent of Cars per Segment*

CSM Segment	2011	2012	2013	2014	2015	2016
Compact Car	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Full-Size Car	5.9%	4.3%	4.7%	4.9%	4.9%	4.9%
Luxury Car	13.9%	13.7%	14.6%	15.0%	15.1%	15.1%
Mid-Size Car	26.2%	29.0%	27.9%	27.5%	27.9%	27.9%
Mini Car	14.1%	15.5%	15.5%	15.4%	15.4%	15.4%
Small Car	30.6%	27.5%	26.5%	26.1%	25.8%	25.8%
Specialty Car	9.1%	9.8%	10.7%	10.9%	10.6%	10.6%
Others	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%

*Note: The data in this table is based on the NPRM data.

Mathematically, an individual manufacturer multiplier is calculated by making the segment the goal and dividing by the previous total for the segment (shown in Table 1-7). If the number is greater than 1, the vehicles are entering the segment, and if the number is less than 1, the vehicles are leaving the segment. So, for example, if Luxury Cars have an adjustment of 1.5, then for a specific manufacturer who has Luxury Cars, a multiplier of 1.5 is applied to its luxury car volume, and the total number of vehicles that shifted into the Luxury segment is subtracted from the remaining segments to maintain that company's market share. On the other hand, if Large Cars have an adjustment of 0.7, then for a specific manufacturer who has Large Cars, a multiplier of 0.7 is applied to its Large Cars, and the total number of vehicles leaving that segment is transferred into that manufacturer's Mid-Size Cars.

After the vehicle volumes are shifted using the above rules, a total for each manufacturer and vehicle segment is maintained. The total for each manufacturer segment for a specific model year (*e.g.*, 2011 General Motors Luxury Cars) divided by the MY 2008 total for that manufacturer segment (*e.g.*, 2008 General Motors Luxury Cars) is the new multiplier used to determine the future vehicle volume for each vehicle model. This is done by taking the multiplier (which is for a specific manufacturer and segment) times the MY 2008 volume for the specific vehicle model (*e.g.*, 2008 General Motors Luxury Car Cadillac CTS). This process is repeated for each model year (2011-2016).

The method used to adjust CSM Trucks to the AEO market share was different than the method used for Cars. The process for Cars is different than Trucks because it is not possible to predict how vehicles would shift between segments based on current market trends. This is because of the added utility of some trucks that makes their sales more insensitive to factors like fuel price. Again, CSM provided data on the market share and vehicle segment distribution. The process for having the fleet match CSM's market share and vehicle segment distribution was iterative.

The following totals were determined:
- The total number of trucks for each manufacturer in 2008 model year.
- The total number of trucks in each truck segment in 2008 model year.
- The total number of truck in each segment for each manufacturer in 2008 model year.
- The total number of trucks for each manufacturer in a specific future model year based on the AEO and CSM data. This is the goal for market share.
- The total number of trucks in each truck segment in a specific future model year based on the AEO and CSM data. This is the goal for vehicle segment distribution. Table 1-9 has the percentages of Trucks per CSM segment

Table 1-9 Example: CSM – Percent of Trucks per Segment*

CSM Segment	2011	2012	2013	2014	2015	2016
Full-Size CUV	4.1%	3.3%	4.0%	4.4%	4.5%	4.5%
Full-Size Pickup	20.0%	17.9%	18.1%	20.1%	20.8%	20.8%
Full-Size SUV	3.3%	2.8%	1.6%	1.2%	1.3%	1.3%
Full-Size Van	3.5%	3.3%	4.0%	3.9%	4.0%	4.0%
Mid-Size CUV	14.5%	15.8%	17.5%	18.1%	18.4%	18.4%
Mid-Size MAV	3.8%	3.3%	2.6%	2.2%	2.2%	2.2%
Mid-Size Pickup	3.6%	5.8%	6.4%	6.4%	6.6%	6.6%
Mid-Size SUV	3.2%	2.3%	1.8%	1.6%	1.6%	1.6%
Mid-Size Van	11.9%	11.3%	10.7%	10.0%	8.7%	8.7%
Small CUV	27.3%	28.4%	27.0%	26.1%	26.2%	26.2%
Small MAV	1.9%	3.4%	4.1%	4.1%	4.1%	4.1%
Small SUV	2.8%	2.4%	2.2%	2.0%	1.8%	1.8%

*Note: The data in this table is based on the NPRM data.

To start, two different types of tables were created. One table had each manufacturer with its total sales for 2008 (similar to Table 1-10). This table will have the goal for each manufacturer, and a column added for each iteration with the current total. The second table has a truck segment total by manufacturer. The second table starts out with a "Generic" manufacturer (Table 1-11) which is the table where the goal resides. Each manufacturer (BMW is shown in Table 1-12) is then listed below the "Generic" manufacturer. With each iteration, a new total is added for each segment that is calculated and added to the table. This is not shown in the tables below. A process of first adjusting the numbers in the tables to the goal for market share distribution was done. This was followed by adjusting to the goal for vehicle segment distribution. Each time an adjustment was done a new column was added. An adjustment was done by creating a multiplier (either segment distribution-based or manufacturer distribution-based) and applying it to each vehicle segment total in the current iteration. A manufacturer-based multiplier is calculated by taking the goal total for a manufacturer and dividing by the current total (starting with 2008 model year volumes) for a manufacturer. A segment distribution-based multiplier is calculated by taking the goal distribution volumes in the Generic manufacturer set and dividing them by the current volume. Table 1-10, Table 1-11, and Table 1-12 below illustrates two iterations using BMW as an example.

Table 1-10 Example:Manufacturer Truck Totals*

	2008 Model Year Sales	Manufacturer Distribution 2011Volume Goal	Multiplier for Iteration 1
BMW	61,324	139948	139948/61324=2.28

*Note: The data in this table is based on the NPRM data.

Table 1-11 Example: Segment Specific Truck Totals for All Manufacturers*

Manufacturer	CSM Segment	2008 Model Year Sales	Segment Distribution 2011Volume Goal	Multipliers
Generic**	Full-Size Pickup	1,195,073	1,390,343	1.30
Generic	Mid-Size Pickup	598,197	251,433	0.38
Generic	Full-Size Van	33,384	244,393	8.30
Generic	Mid-Size Van	719,529	826,733	1.37
Generic	Mid-Size MAV	191,448	263,765	1.26
Generic	Small MAV	235,524	133,309	0.57
Generic	Full-Size SUV	530,748	232,375	0.46
Generic	Mid-Size SUV	347,026	221,607	0.70
Generic	Small SUV	377,262	194,496	0.75
Generic	Full-Size CUV	406,554	287,313	0.69
Generic	Mid-Size CUV	798,335	1,007,583	0.99
Generic	Small CUV	1,441,589	1,901,229	1.16

* The data in this table is based on the NPRM data.
** Generic means all manufacturers.

Table 1-12 Example: Segment Specific Truck Totals for BMW*

Manufacturer	CSM Segment	2008 Model Year Sales	Iteration 1 Adjust for Market Share	Iteration 2 Adjust for Segment Distribution
BMW	Full-Size Pickup			
BMW	Mid-Size Pickup			
BMW	Full-Size Van			
BMW	Mid-Size Van			
BMW	Mid-Size MAV	3,882	2.28*3,882=8,551	1.26*8,851=11,137
BMW	Small MAV			
BMW	Full-Size SUV			
BMW	Mid-Size SUV			
BMW	Small SUV			
BMW	Full-Size CUV			
BMW	Mid-Size CUV	36,409	2.28*36,409=83,013	0.99*83,013=82,603
BMW	Small CUV	21,033	2.28*21,033=47,955	1.16*47,955=55,592
Total BMW Vehicles		61,324	139,819	149,332

*Note: The data in this table is based on the NPRM data.

Using this process, the numbers will get closer to the goal of matching CSM's market share for each manufacturer and distribution for each vehicle segment after each of the iterations. The iterative process is carried out until the totals nearly match the goals.

After 19 iterations, all numbers were within 0.01% of CSM's distributions. The calculation iterations could have been stopped sooner, but they were continued to observe how the numbers would converge.

After the market share and segment distribution were complete, the totals need to be used to create multipliers that could be applied to the original individual 2008 model year vehicle volumes (each unique manufacture models volume). The total for each manufacturer segment divided by the 2008 model year total for each manufacturer segment gives a multiplier that can be applied to each vehicle based on its manufacturer and segment.

The above process is done for each model year needed (2011-2016). The multipliers are then applied to each vehicle in 2008 model year, which gives a volume for each vehicle in 2011 through 2016 model year. The "reference case" (which is the technology being applied to 2012-2016 fleet to meet the 2011 cafe standard) is discussed below in section 4.1, with the results being presented in section 4.2.

1.3.3 How has the reference fleet changed from the NPRM to the Final Rule?

The agencies updated the projected reference (2011-2016) fleet file for the final rule, though the baseline fleet (MY 2008) remains unchanged. The NPRM reference fleet used CSM Worldwide's second quarter, 2009 projections and the April 2009 Annual Energy Outlook. The reference for the final rule uses a filtered version of CSM Worldwide's fourth quarter, 2009 projections, and (as noted above) an early version of the 2010 Annual Energy Outlook that was released in December of 2009.

CSM Worldwide's standard forecast includes heavy duty class 2b and heavy duty class 3 vehicles. Including these extra vehicles in the second quarter forecast caused the baseline to have an increased number of full size trucks and full size vans. EPA did not discover this discrepancy between CSM's definition of heavy truck and the one used by NHTSA/EPA until after the proposal had been published. For the final rule, the EPA requested CSM to filter their 4th quarter projections to only include light duty and medium duty passenger vehicles. The filtered CSM data allowed the agencies to produce a more accurate projection of future sales.

Table 1-13 and Table 1-14 below show the difference in volumes per each CSM segment in the final rule baseline and the NPRM reference. The significant decrease in the number of full size vans can be attributed to the new filtered version of the CSM data. Full size trucks show some decrease, but did not have as obvious an impact from the data filtering since CSM increase their predicted volume for full size trucks. The overall decrease in cars and trucks for some of the year in the 2011-2016 time frame is due to the decreased volumes projected in the 2010 Annual Energy Outlook.

Table 1-13 Difference Truck Segment Volumes (Final-NPRM)

Model	2011	2012	2013	2014	2015	2016
Full-Size Pickup	(36,639)	209,466	224,624	(74,421)	(110,407)	(103,495)
Mid-Size Pickup	56,153	(91,457)	(61,634)	(90,397)	(145,580)	(180,099)
Full-Size Van	(138,346)	(118,196)	(214,794)	(216,209)	(225,771)	(218,776)
Mid-Size Van	(119,480)	(39,675)	136,637	159,127	224,405	219,798
Mid-Size MAV	(96911)	(92,668)	(68,927)	(58,747)	(45,077)	(43,413)
Small MAV	(74545)	(172,269)	(231,829)	(230,774)	(234,930)	(227,667)
Full-Size SUV	75,909	54,140	90,095	128,390	144,629	140,861
Mid-Size SUV	85,265	114,268	99,228	64,284	52,735	51,563
Small SUV	(42,807)	(31,396)	(41,079)	(31,821)	(16,856)	(16,064)
Full-Size CUV	(48,893)	11,197	(32,095)	(35,457)	(62,356)	(59,796)
Mid-Size CUV	85,731	80,897	(67,541)	15,205	57,194	59,019
Small CUV	(35,350)	109,182	253,249	353,827	307,846	304,197
All Trucks	(289,913)	33,489	85,933	(16,993)	(54,166)	(73,873)

Table 1-14 Difference Car Segment Volumes (Final-NPRM)

Model	2011	2012	2013	2014	2015	2016
Full-Size Car	245,467	219,990	117,266	60,568	52,287	54,945
Mid-Size Car	179,734	(88,360)	(109,151)	(102,313)	(119,548)	(116,040)
Small Car	(364,311)	(47,099)	91,824	39,821	26,360	33,401
Subcompact/Mini Car	10,613	107,422	202,059	167,808	138371	146,009
Luxury Car	1,971	98,741	32,604	55,014	78055	83,925
Specialty Car	(173,163)	(176,256)	(267,196)	(296,546)	(255347)	(259,743)
Others	(12,178)	(12,350)	(14,739)	(17,811)	(20646)	(21,153)
All Cars	(111,868)	102,089	52,668	(93,460)	(10,0467)	(78,656)

Table 1-15below shows the differences in projected manufacturer volumes between the final rule projected volumes and the NPRM projected volumes. The 2010 Annual Energy Outlook reduced the volumes for 2011, and 2014-2016. This would have reduced all of the manufacturer projected production volumes if we had not used the 4th quarter CSM projections. All manufactures that have an increase shown in those years are projected by CSM to have increased market share. The most notable change in projected production volume is from Chrysler. Chrysler was projected to have 138,602 cars, and 109,674 trucks for 2016 in the NPRM based on using 2nd quarter CSM (and 2009 Annual Energy Outlook). 4th quarter CSM projections for Chrysler are much more optimistic, and the baseline for the final rule has 399,762 for Chrysler's cars and 462,150 for Chrysler's trucks in 2016.

Table 1-15 Difference Car and Truck Volumes by Manufacturer (Final-NPRM)

Manufacturer	2011	2012	2013	2014	2015	2016
Total Vehicles All Manufacturers	(401,780)	135,578	138,601	(110,453)	(154,633)	(152,529)
All Manufacturers Trucks	(89,568)	268,005	318,204	136,923	109,279	82,731
All Manufacturers Cars	(312,212)	(132,427)	(179,603)	(247,376)	(263,912)	(235,260)
BMW Trucks	62,770	61,336	41,601	46,988	36,579	35,180
BMW Cars	(41,587)	6,160	(29,286)	17,731	39,985	42,070
Chrysler Trucks	334,846	409,643	349,651	292,257	362,932	352,476
Chrysler Cars	132,623	230,827	251,382	242,273	255,900	261,160
Ford Trucks	(151,056)	(173,698)	(167,456)	(236,552)	(294,109)	(291,602)
Ford Cars	114,699	119,923	61,456	121,665	39,295	47,956
Subaru Trucks	(13,064)	9,058	12,351	22,381	42,630	43,160
Subaru Cars	16,044	34,293	39,224	49,380	74,158	75,882
GENERAL MOTORS Trucks	33,594	301,275	215,632	(6,059)	23,993	19,092
GENERAL MOTORS Cars	92,543	101,513	(75,325)	(255,948)	(302,495)	(305,754)
HONDA Trucks	14,156	(35,243)	(47,772)	(52,602)	(130,896)	(129,956)
HONDA Cars	(145,521)	(248,912)	(287,759)	(406,166)	(650,062)	(662,741)
HYUNDAI Trucks	(80,886)	(82,864)	(34,222)	(30,417)	(38,372)	(37,777)
HYUNDAI Cars	(188,181)	(204,255)	(163,401)	(167,347)	(79,342)	(78,446)
Tata Trucks	(618)	(12,521)	(12,506)	(13,041)	(4,879)	(4,879)
Tata Cars	4,615	13,499	17,706	13,782	23,165	23,905
Kia Trucks	(9,888)	8,854	28,177	42,230	48,498	46,803
Kia Cars	3,362	(4,913)	16,985	95,993	191,184	196,973
Mazda Trucks	(1,909)	(11,147)	(6,352)	861	14,853	14,160
Mazda Cars	(25,356)	(30,361)	11,242	39,804	73,259	75,028
Daimler Trucks	(1,296)	(1,299)	(1,152)	11,265	16,512	15,740
Daimler Cars	36,309	39,481	12,426	40,218	34,189	35,735
Mitsubishi Trucks	36,069	38,193	34,739	43,711	49,546	48,149
Mitsubishi Cars	36,473	45,440	43,385	31,673	29,942	29,228
Nissan Trucks	(89,599)	(72,880)	(87,000)	(68,513)	(62,754)	(63,585)
Nissan Cars	(182,244)	(134,666)	(199,962)	(219,176)	(178,793)	(176,968)
PORSCHE Trucks	(8,270)	(7,577)	(6,031)	(3,346)	323	(603)
PORSCHE Cars	(5,853)	9,511	7,486	(4,446)	(3,750)	(3,755)
Suzuki Trucks	(18,299)	(25,798)	(13,193)	(10,485)	(6,657)	(6,548)
Suzuki Cars	(41,871)	(14,240)	(4,439)	9,117	24,635	25,575
TOYOTA Trucks	(171,045)	(132,755)	(28,733)	50,277	25,938	18,761
TOYOTA Cars	(118,360)	(106,708)	79,278	93,978	62,371	72,407
VOLKSWAGEN Trucks	(25,074)	(4,573)	40,469	47,969	25,144	24,160
VOLKSWAGEN Cars	92	10,979	40,000	50,093	102,448	106,486

1.3.4 What are the sales volumes and characteristics of the reference fleet?

Table 1-16 and Table 1-17 below contain the sales volumes and percentages that result from the process above for MY 2008 and 2011-2016.

Table 1-16 Vehicle Segment Volumes

Reference Class Segment[a]	Actual and Projected Sales Volume						
	2008	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Large Auto	557,693	479,329	438,780	422,094	438,346	461,663	474,260
Mid-Size Auto	3,097,859	2,747,665	3,028,262	3,174,985	3,361,926	3,524,000	3,619,798
Compact Auto	1,976,424	1,671,674	2,024,030	2,232,209	2,340,408	2,454,466	2,520,777
Sub-Compact Auto	1,364,434	1,763,860	2,222,516	2,483,365	2,564,754	2,663,349	2,735,809
All Cars	6,996,410	6,662,527	7,713,589	8,312,653	8,705,434	9,103,479	9,350,644
Large Pickup	1,581,880	1,515,406	1,649,043	1,774,535	1,629,457	1,594,363	1,550,212
Small Pickup	177,497	120,816	128,754	168,070	150,225	129,421	125,837
Large SUV	2,783,949	2,692,979	2,808,069	2,796,947	2,904,358	2,932,045	2,851,169
Mid-Size SUV	1,263,360	1,462,069	1,630,310	1,677,100	1,722,783	1,687,445	1,645,170
Small SUV	285,355	113,652	111,539	97,954	90,729	80,754	78,518
Mini Van	642,055	631,390	665,307	799,280	784,215	737,003	716,594
Cargo Van	110,858	181,911	215,174	209,684	192,590	189,124	183,887
All Trucks	6,844,954	6,718,223	7,208,196	7,523,569	7,474,358	7,350,155	7,151,387

[a] This is no longer the CSM segment, but the segment used for the subsequent analysis in this rule.

Table 1-17 Manufacturer Volumes

	2008 Baseline Sales	2011 Projected Volume	2012 Projected Volume	2013 Projected Volume	2014 Projected Volume	2015 Projected Volume	2016 Projected Volume
Total Vehicles	13,841,364	13,380,750	14,921,784	15,836,222	16,179,793	16,453,634	16,502,032
All Trucks	6,844,954	6,718,223	7,208,196	7,523,569	7,474,358	7,350,155	7,151,387
All Cars	6,996,410	6,662,527	7,713,589	8,312,653	8,705,434	9,103,479	9,350,644
BMW Trucks	61,324	202,729	204,197	183,550	191,010	175,612	170,749
BMW Cars	291,796	230,986	289,631	293,905	369,979	411,653	422,874
Chrysler Trucks	956,792	737,504	692,115	594,092	514,802	475,312	462,150
Chrysler Cars	700,413	326,327	409,462	426,454	411,319	392,483	399,762
Ford Trucks	846,596	792,527	851,877	940,080	965,589	936,781	910,840
Ford Cars	1,021,792	1,344,461	1,468,182	1,485,801	1,567,762	1,542,470	1,559,310
Subaru Trucks	82,546	104,832	97,935	89,944	99,293	116,055	117,295
Subaru Cars	116,035	169,688	183,486	175,170	184,521	204,746	206,903
GM Trucks	1,512,047	1,347,521	1,510,917	1,536,070	1,336,797	1,379,813	1,341,604
GM Cars	1,607,460	1,248,909	1,586,094	1,544,975	1,452,559	1,487,318	1,514,479
Honda Trucks	505,140	585,334	634,705	676,729	634,606	560,745	545,217
Honda Cars	1,006,639	850,875	906,096	1,064,848	1,087,076	912,434	930,350
Hyundai Trucks	53,158	46,314	58,164	101,529	103,857	94,606	91,986
Hyundai Cars	337,869	382,250	376,284	395,573	395,515	511,236	518,445
Tata Trucks	55,584	30,726	29,647	33,749	40,294	43,703	42,493
Tata Cars	9,596	23,187	36,377	50,527	49,316	63,751	65,489
Kia Trucks	59,472	87,819	87,643	102,773	114,423	118,391	115,113
Kia Cars	221,980	305,709	299,611	326,652	427,191	538,717	548,055
Mazda Trucks	55,885	57,873	60,783	64,784	67,780	74,213	72,158
Mazda Cars	246,661	292,592	283,128	329,911	378,291	413,328	420,516
Daimler Trucks	79,135	96,630	108,053	114,531	136,455	129,878	126,281
Daimler Cars	208,052	213,801	211,652	202,559	244,554	263,751	270,940
Mitsubishi Trucks	15,371	45,337	48,290	46,179	52,835	56,896	55,320
Mitsubishi Cars	85,358	104,252	110,284	104,555	88,150	82,310	82,688
Nissan Trucks	305,546	331,067	405,017	391,572	406,045	391,733	380,886
Nissan Cars	717,869	611,629	824,030	831,607	854,131	925,478	946,518
Porsche Trucks	18,797	13,131	13,190	14,608	16,033	17,145	16,670
Porsche Cars	18,909	25,056	41,117	43,299	34,024	32,426	33,309
Suzuki Trucks	35,319	6,895	4,593	16,557	20,060	20,547	19,978
Suzuki Cars	79,339	49,484	72,297	81,781	90,597	100,600	103,003
Toyota Trucks	951,136	888,116	886,621	990,315	1,095,949	1,107,261	1,076,598
Toyota Cars	1,260,364	1,355,639	1,591,054	1,941,480	2,079,011	2,176,644	2,226,522
VW Trucks	26,999	83,403	104,842	141,421	151,992	127,888	124,346
VW Cars	290,385	388,146	434,412	498,641	517,978	567,711	583,185

Table 1-18 also shows how the change in fleet make-up may affect the footprint distributions over time. The resulting data indicate that footprint will not change

significantly between 2008 and 2016. There will be an increase in the number of cars sold, which will cause the average footprints for cars and trucks combined to be slightly smaller (about 2%). This is the result of AEO projecting an increased number of cars, and CSM predicting that most of that increase will be in the subcompact segment. It is important to note that the AEO and CSM projections were made without accounting for the effects of this rulemaking, and thus are not influenced by the new regulations.[d]

Table 1-18 Production Foot Print Mean

Model Year	Foot Print Mean for Car & Truck Combined	Foot Print Mean for Car	Foot Print Mean for Truck
2008	49.0	45.4	54.1
2011	48.9	45.2	54.2
2012	48.6	45.0	54.3
2013	48.5	44.9	54.3
2014	48.2	44.9	54.0
2015	48.2	44.9	54.0
2016	48.1	44.9	54.0

Table 1-19 and Table 1-20 below show the changes in engine cylinders over the model years. The current assumptions show that engines will be downsized over the model years to which these rules apply. The biggest projected shift occurs between MY 2008 and 2013. This shift is a projected consequence of the expected changes in class and segment mix as predicted by AEO and CSM, and does not represent engine downsizing attributable to the rules.

Table 1-19 Truck Percentages of 4, 6, 8 Cylinder Engines by Model Year

Model	Percent of Total Sales of 4,6,8 Cylinders Trucks						
	2008	2011	2012	2013	2014	2015	2016
All Trucks 8 Cylinders	33.7%	31.4%	30.9%	29.7%	28.3%	28.8%	28.8%
All Trucks 6 Cylinders	55.8%	57.1%	57.1%	58.2%	59.4%	59.0%	59.0%
All Trucks 4 Cylinders	10.5%	11.5%	12.0%	12.0%	12.4%	12.2%	12.3%

Table 1-20 Car Percentages of 4, 6, 8 Cylinder Engines by Model Year

Model	Percent of Total Sales of 4,6,8 Cylinders Cars						
	2008	2011	2012	2013	2014	2015	2016
All Cars 8 Cylinders	5.2%	5.2%	5.0%	4.8%	4.8%	5.0%	5.1%
All Cars 6 Cylinders	36.7%	34.5%	33.0%	31.9%	32.2%	32.3%	32.2%
All Cars 4 Cylinders	58.1%	60.3%	62.0%	63.3%	63.0%	62.6%	62.7%

---

[d] Refer to the memo to the docket (Docket EPA-HQ-OAR-2009-0472) for a more detailed description of the updated AEO2010 fleet projection.

1.3.5 How is the development of the baseline and reference fleet for this final rule different from NHTSA's historical approach and why is this approach preferable?

As described in detail at the opening of this chapter, and as explained at proposal, NHTSA has historically based its analysis of potential new CAFE standards on detailed product plans the agency has requested from manufacturers planning to produce light vehicles for sale in the United States. Although the agency has never compelled manufacturers to submit such information, most major manufacturers and some smaller manufacturers have voluntarily provided it when requested.

As in other prior rulemakings, NHTSA has requested extensive and detailed information regarding the models that manufacturers plan to offer, as well as manufacturers' estimates of the volume of each model they expect to produce for sale in the U.S. NHTSA's recent requests have sought information regarding a range of engineering and planning characteristics for each vehicle model (*e.g.*, fuel economy, engine, transmission, physical dimensions, weights and capacities, redesign schedules), each engine (*e.g.*, fuel type, fuel delivery, aspiration, valvetrain configuration, valve timing, valve lift, power and torque ratings), and each transmission (*e.g.*, type, number of gears, logic).

The information that manufacturers have provided in response to this request has varied in completeness and detail. Some manufacturers have submitted nearly all of the information NHTSA has requested, for most or all of the model years covered by NHTSA's requests, and have closely followed NHTSA's guidance regarding the structure of the information. Other manufacturers have submitted partial information, information for only a few model years, and/or information in a structure less amenable to analysis. Still other manufacturers have not responded to NHTSA's requests or have responded on occasion, usually with partial information.

One of the primary reasons for the request for data in 2009 was to obtain permission from the manufacturers to make public their product plan information for model years 2010 and 2011. There are a number of reasons that this could be advantageous in the development of a reference fleet. First some changes to the fleet may not be captured by this approach of solely using publicly available information. For example, the agencies' current market forecast includes some vehicles for which manufacturers have announced plans for elimination or drastic production cuts such as the Chevrolet Trailblazer, the Chrysler PT Cruiser, the Chrysler Pacifica, the Dodge Magnum, the Ford Crown Victoria, the Hummer H2, the Mercury Sable, the Pontiac Grand Prix, and the Pontiac G5. These vehicle models appear explicitly in market inputs to NHTSA's analysis, and are among those vehicle models included in the aggregated vehicle types appearing in market inputs to EPA's analysis.

Second, the agencies' market forecast does not include some forthcoming vehicle models, such as the Chevrolet Volt, the Chevrolet Camaro, the Ford Fiesta and several publicly announced electric vehicles, including the announcements from Nissan. Nor

does it include several MY 2009 and 2010 vehicles, such as the Honda Insight, the Hyundai Genesis and the Toyota Venza, as the starting point for vehicle definitions was MY 2008. Additionally, the market forecast does not account for publicly-announced technology introductions, such as Ford's EcoBoost system, whose product plans specify which vehicles and how many are planned to have this technology. Were the agencies to rely on manufacturers' product plans, this market forecast would account for not only these specific examples, but also for similar examples that have not yet been announced publicly.

Finally, some technical information manufacturers that have provided in product plans regarding specific vehicle models is, at least as far as NHTSA and EPA have been able to determine, not available from public or commercial sources. While such gaps do not bear significantly on the agencies' analysis, the diversity of pickup configurations necessitated utilizing a sales-weighted average footprint value[7] for many manufacturers' pickups. Since the modeling only utilizes footprint in order to estimate each manufacturer's CO_2 or fuel economy standard and all the other vehicle characteristics are available for each pickup configuration, this approximation has no practical impact on the projected technology or cost associated with compliance with the various standards evaluated. The only impact which could arise would be if the relative sales of the various pickup configurations changed, or if the agencies were to explore standards with a different shape or attribute. This would necessitate recalculating the average footprint value in order to maintain accuracy.

In an effort to update the 2008 baseline to account for the expected changes in the fleet in the near-term model years 2009-2011 described above, NHTSA requested permission from the manufacturers to make this limited product plan information public. Unfortunately, virtually no manufacturers agreed to allow the use of their data after the 2009 model year. A few manufacturers stated we could use their 2009 product plan data after the end of production (December 31). Unfortunately, this does not afford us sufficient time to do the analysis for the final rule. Also, the 2009 product plan data that was permitted to be used was not consistent with the data already in the baseline, and in some cases was determined to be inaccurate. Since the agencies were unable to obtain consistent updates, the baseline and reference fleets were not updated beyond 2008 model year for this final rule. The 2008 baseline fleet and projections were instead updated using the latest AEO and CSM data, as explained above.

---

[7] A full-size pickup might be offered with various combinations of cab style (*e.g.*, regular, extended, crew) and box length (*e.g.*, 5½', 6½', 8') and, therefore, multiple footprint sizes. CAFE compliance data for MY2008 data does not contain footprint information, and does not contain information that can be used to reliably identify which pickup entries correspond to footprint values estimable from public or commercial sources. Therefore, the agencies have used the known production levels of average values to represent all variants of a given pickup line (*e.g.*, all variants of the F-150 and the Sierra/Silverado) in order to calculate the sales-weighted average footprint value for each pickup family. Again, this has little impact on the results of the modeling effort. In the extreme, one single footprint value could be used for every vehicle sold by a single manufacturer as long as the fuel economy standard associated with this footprint value represented the sales-weighted, harmonic average of the fuel economy standards associated with each vehicle's footprint values.

1.3.6 How does manufacturer product plan data factor into the baseline used in this final rule?

In the spring and fall of 2009, many manufacturers submitted product plans in response to NHTSA's recent requests that they do so. NHTSA and EPA both have access to these plans, and both agencies have reviewed them in detail. A small amount of product plan data was used in the development of the baseline. The specific pieces of data are:

- Wheelbase
- Track Width Front
- Track Width Rear
- EPS (Electric Power Steering)
- ROLL (Reduced Rolling Resistance)
- LUB (Advance Lubrication i.e. low weight oil)
- IACC (Improved Electrical Accessories)
- Curb Weight
- GVWR (Gross Vehicle Weight Rating)

The track widths, wheelbase, curb weight, and GVWR for vehicles could have been looked up on the internet (159 were), but were taken from the product plans when available for convenience. To ensure accuracy, a sample from each product plan was used as a check against the numbers available from Motortrend.com. These numbers will be published in the baseline file since they can be easily looked up on the internet. On the other hand, EPS, ROLL, LUB, and IACC are difficult to determine without using manufacturer's product plans. These items will not be published in the baseline file, but the data has been aggregated into the agencies' baseline in the technology effectiveness and cost effectiveness for each vehicle in a way that allows the baseline for the model to be published without revealing the manufacturers data.

References

All references can be found in the EPA DOCKET: **EPA-HQ-OAR-2009-0472.**

---

[1] CFEIS (Certification Fuel Emissions Information System) Database: CFEIS is an EPA database system.

[2] WardsAuto.com: Used as a source for engine specifications.

[3] Motortrend.com and Edmunds.com: Used as a source for foot print and vehicle weight data.

[4] Energy Information Administration's 2009 Annual Energy Outlook.

[5] The agencies have also looked at the impact of the rule in EIA's projection, and concluded that the impact was small. EPA and NHTSA have evaluated the differences between the AEO 2010 (early draft) and AEO 2009 and found little difference in the fleet projections (or fuel prices). This analysis can be found in the memo to the docket: (Docket EPA-HQ-OAR-2009-0472).

[6] CSM World Wide, CSM World Wide is a paid service provider; J.D. Power Automotive Forecasting, J.D. Power Automotive Forecasting is a paid service provider.

[7] The baseline Excel file ("2008-2016 Production Summary Data _Definitions Docket 08_27_2009") is available in the docket (Docket EPA-HQ-OAR-2009-0472).

CHAPTER 2: What are the Attribute-Based Curves the Agencies are Using, and How Were They Developed?

2.1 Standards are attribute-based and are defined by a mathematical function

As discussed in Section II.B of the final rule preamble, NHTSA and EPA are setting attribute-based CAFE and CO_2 standards for MYs 2012-2016 passenger cars and light trucks, which are expressed by a mathematical function. EPCA, as amended by EISA, expressly requires that CAFE standards for passenger cars and light trucks be based on one or more vehicle attributes related to fuel economy, and be expressed in the form of a mathematical function.[1] The CAA has no such requirement, although such an approach is permissible under section 202 (a) and EPA has used the attribute-based approach in issuing standards under analogous provisions of the CAA (*e.g.*, standards for non-road diesel engines using engine size as the attribute). Given the advantages of using attribute-based standards for light duty vehicles, and given the goal of coordinating and harmonizing CO_2 standards promulgated under the CAA and CAFE standards promulgated under CAA and EPCA, as expressed by President Obama in his announcement of the new National Program and by the agencies in the joint NOI and NPRM, EPA is also finalizing standards that are attribute-based and expressed as mathematical functions.

Under an attribute-based standard approach, each vehicle model has a fuel economy (mpg) or CO_2 target, the stringency of which depends on the value of the attribute for the vehicle model. Thus, fuel economy and CO_2 targets are set for individual vehicles, and vary directly with the attribute, *i.e.*, becoming more stringent as the attribute decreases and vice versa. For example, size-based (*i.e.*, size-indexed) standards assign higher fuel economy targets (lower CO_2 targets) to smaller vehicles and lower fuel economy targets (higher CO_2 targets) to larger vehicles. However, we emphasize that the targets themselves are not standards. The CAFE or fleet-wide average CO_2 level required of a particular manufacturer is actually determined by calculating the production-weighted average of the applicable model-specific fuel economy or CO_2 targets.

The form of the fuel economy or CO_2 standard can have a dramatic effect on the level of improvement required from various types of vehicles and on the relative stringency of the standard for various manufacturers. These disparate impacts derive from two facts concerning the current automotive market: 1) consumers currently demand a wide variety of vehicle types and sizes, and 2) individual manufacturers focus their product offerings on different portions of this demand. Therefore, a comparison of the advantages and disadvantages of attribute-based and flat (universal) standards needs to consider both of these factors.

Methods to reduce the CO_2 emissions from and increase the fuel economy of individual vehicles can be generally grouped into four main categories: 1) reducing vehicle size, 2) reducing vehicle performance and/or utility, 3) increasing the efficiency of the

powertrain and accessories while maintaining constant performance and utility, and 4) reducing weight and aerodynamic drag while maintaining vehicle size and utility.[a] Stringent flat standards encourage all four of these methods. However, the level of encouragement differs between manufacturers. Manufacturers of generally larger vehicles face a more difficult task in meeting a flat standard than those of generally smaller vehicles. Thus, the stringency of flat standards will tend to be limited by the capabilities of the manufacturers of larger vehicles. Conversely, manufacturers of smaller vehicles will tend to face lower compliance costs and may not even need to change their vehicles at all.[b] Thus, the overall level of achieved stringency of a flat standard may be limited. A flat standard will encourage smaller, less powerful vehicles, as these vehicles face the least compliance costs. Sales will tend to be shifted to manufacturers of generally smaller vehicles as their overall compliance costs will be lower than those of manufacturers of average or larger vehicles. Finally, because smaller vehicles face lower costs than larger vehicles, consumers will be encouraged to purchase smaller vehicles. Or, to avoid these outcomes, the standard may not be of sufficient stringency to result in significant fuel economy improvements or emission reductions.

Attribute-based fuel economy and CO_2 standards are preferable to universal industry-wide average standards for several reasons. First, if the shape is chosen properly, every manufacturer is more likely to be required to continue adding more fuel efficient technology each year, because the level of the compliance obligation of each manufacturer is based on its own particular product mix.

Second, attribute-based standards minimize the incentive for manufacturers to respond to CAFE and CO_2 standards in ways that may be harmful to safety.[2] Because each vehicle model has its own target based on the attribute chosen, attribute-based standards can, depending on the corresponding mathematical function (*i.e.*, the shape of the attribute based standards), reduce or eliminate the incentive to build smaller vehicles simply to meet a fleet-wide average. Since smaller vehicles are subject to more stringent fuel economy targets, a manufacturer's increasing its proportion of smaller vehicles would not necessarily ease its compliance obligation. For the purposes of this rule, the agencies believe that setting attribute-based standards with careful attention to the slope of the target curves will not encourage wholesale changes in fleet mix to either smaller or larger vehicles.

Third, attribute-based standards provide a more equitable regulatory framework for different vehicle manufacturers.[3] A flat industry-wide average standard imposes disproportionate compliance obligations on (full-line) manufacturers that need to significantly

---

[a] Another method of increasing fleet fuel economy is to increase the number of high-fuel-economy vehicles and reduce production of low-fuel-economy vehicles, for instance, by changing their relative prices. EPA and NHTSA believe that existing technologies allow automakers to meet the requirements of the rules without changing the mix of vehicles produced (although the rules do not prohibit such changes in mix).

[b] Trading of credits could encourage fuel economy improvements or CO_2 emission reductions from manufacturers of smaller vehicles. This would probably create a shift of wealth between the two sets of manufacturers. However, most manufacturers have indicated that they would be unlikely to trade credits with their direct competitors. In addition, EPCA does not permit NHTSA, in determining maximum feasible CAFE standards, to consider manufacturers' ability to earn, transfer, trade, and use CAFE credits.

change their product plans and little obligation on those manufacturers that have minimal need to change their plans because, for example, they may build smaller vehicles. Attribute-based standards that have the proper shape spread the regulatory cost burden for fuel economy more broadly across all of the vehicle manufacturers within the industry.

And fourth, attribute-based standards respect economic conditions and consumer choice. Manufacturers are required to invest in technologies that improve the fuel economy of their fleets, regardless of vehicle mix. Thus the consumer is likely to enjoy the same wide range of vehicles to choose from in 2016 as they do now. The difference will be, of course, that the vehicles will be more fuel efficient.

The agencies recognize that, because manufacturers' compliance obligations under attribute-based standards are based in part on the mix of vehicles that they produce, the fuel savings and emissions reductions produced under attribute-based standards can vary depending on market conditions. For example, fuel prices lower than those anticipated at the time of rulemaking could tend to shift consumer demand toward larger vehicles. If manufacturers sell a greater number of larger vehicles than the agencies anticipate, fuel savings and CO_2 reductions would be lower than anticipated. In contrast, if fuel prices rise significantly, more fuel savings and CO_2 reductions than anticipated should be likely.

One potential way to mitigate the variability of results under attribute-based standards due to market conditions is through the use of a universal standard—that is, an average standard set at a (single) absolute level below which manufacturers' fuel economy/CO_2 standards may not drop/exceed. This is often described as a "backstop standard." For purposes of the CAFE program, EISA expressly requires a backstop for domestically-manufactured passenger cars—a universal minimum, non-attribute-based standard of either "27.5 mpg or 92 percent of the average fuel economy projected by the Secretary of Transportation for the combined domestic and non-domestic passenger automobile fleets manufactured for sale in the United States by all manufacturers in the model year…"[4], whichever is greater. Backstops are generally permissible under section 202(a) of the CAA (as are universal standards generally).

For purposes of the CAFE and CO_2 standards proposed in the NPRM, NHTSA and EPA recognized that the risk, even if small, does exist that low fuel prices in MYs 2012-2016 might lead indirectly to less than currently anticipated fuel savings and emissions reductions. The NPRM sought comment on whether backstop standards, or any other method within the agencies' statutory authority, should and can be implemented for the import and light truck fleets in order to achieve the fuel savings that attribute-based standards might not absolutely guarantee.

As discussed in Section II.C of the final rule preamble, the agencies have reviewed the comments received on this issue and have made the policy choice not to adopt backstop standards for MYs 2012-2016 other than those for domestic passenger cars, as required by EISA. EPA and NHTSA remain confident that their projections of the future fleet mix are reliable, and that future changes in the fleet mix of footprints and sales are not likely to lead to more than modest changes in projected emissions reductions or fuel savings. Both agencies

remain confident in these fleet projections and the resulting emissions reductions and fuel savings from the standards. As explained in section II.B of the preamble and chapter 1 of the TSD, the agencies' projections of the future fleet are based on the best, transparent data obtained to date. In addition, there are only a relatively few model years at issue. Moreover, market trends today are consistent with the agencies' estimates showing shifts from light trucks to passenger cars and increased emphasis on fuel economy. Finally, the shapes of the curves, including the "flattening" at the largest footprint values, tend to avoid or minimize regulatory incentives for a manufacturer to upsize their fleet to change their compliance burden.

At the same time, adding another backstop standard would directionally impose increased costs for some manufacturers, with greater costs commensurate with more stringent backstops. This would occur unless the backstop standard was relatively weak, in which case it would have a minimal effect. It would be difficult to establish the level of a backstop standard such that costs are likely to be imposed on manufacturers only when there is a failure to achieve the projected reductions across the industry as a whole. An example of this could be when there is a significant shift to larger vehicles across the industry as a whole, or if there is a general market shift from cars to trucks. The problem the agencies are concerned about is not with respect to any single manufacturer, but rather is based on concerns over shifts across the fleet as a whole, as compared to shifts in one manufacturer's fleet that may be more than offset by shifts the other way in another manufacturer's fleet. However a backstop does not directly deal with fleetwide trends because it acts as a manufacturer specific standard. The concept of a ratchet mechanism recognizes this issue, and aims to impose the new more stringent standard only when the problem arises across the industry as a whole. However, this approach fails to provide the lead time necessary for making vehicle changes to meet a new, more stringent standard.

In addition, we do not believe that the risk of vehicle upsizing or changing vehicle offerings to "game" the passenger car and light truck definitions is as great as commenters imply for the model years in question. The changes that commenters suggest manufacturers might make are neither so simple nor so likely to be accepted by consumers. For example, 4WD versions of vehicles tend to be more expensive and, other things being equal, have inherently lower fuel economy than their 2WD equivalent models. Therefore, many consumers may not desire to purchase 4WD vehicles because of the cost premium; conversely, many manufacturers often require the 2WD option to satisfy demand for base vehicle models. Additionally, increasing the footprint of vehicles requires platform changes, which usually requires a product redesign phase (the agencies estimate that this occurs on average once every 5 years for a model). Alternatively, turning many 2WD SUVs into (2WD) light trucks would require manufacturers to squeeze a third row of seats in or significantly increase their GVWR, which also requires a significant change in the vehicle.

For these reasons, and in the interest of harmonization and given that neither EISA nor the CAA provide specific directives on this issue plus the agencies' belief that backstops are not the only mechanisms to ensure fuel savings and emissions reductions, the agencies have reached the conclusion not to incorporate backstops in these final rules but will consider the issue further if the evidence warrants. The agencies discuss this issue further in the final rule preamble.

2.2 What attribute do the agencies use, and why?

Consistent with the MY 2011 CAFE standards, EPA and NHTSA are using footprint as the attribute for the MY 2012-2016 CAFE standards and CO2 emissions standards. There are several policy reasons why the agencies believe that footprint is the most appropriate attribute on which to base the standards, as discussed below.

It is important that the CAFE and CO_2 standards be set in a way that does not encourage manufacturers to respond by selling vehicles that are in any way less safe. Although NHTSA's research also indicates that certain types of reductions in vehicle mass tend to compromise vehicle safety, footprint-based standards provide an incentive to use new and advanced lightweight materials and structures that could be otherwise discouraged by weight-based standards, because manufacturers can use them to improve a vehicle's fuel economy without their use necessarily resulting in a change in the vehicle's target level of fuel economy or CO_2 emissions and without a substantial impact on the safety (in terms of crashworthiness) of that vehicle.

Further, although the agencies recognize the point raised by some commenters that weight is better correlated with fuel economy and CO_2 emissions than is footprint, the agencies continue to believe that there is less risk of "gaming" (artificial manipulation of the attribute(s) to achieve a more favorable target) by increasing footprint under footprint-based standards than by increasing vehicle mass under weight-based standards—it is relatively easy for a manufacturer to add enough weight to a vehicle to decrease its applicable fuel economy target by a significant amount, as compared to increasing vehicle footprint. For a manufacturer to change a vehicle's footprint, a significant redesign of the chassis and many components would be required. (See the related discussion of this issue above in the discussion of whether to adopt universal backstop standards.) In addition, despite requests from some manufacturers that the agencies consider multi-attribute standards, or adjust the target curves to "accommodate" other attributes like towing/hauling capability, the agencies continue to agree with concerns raised in 2008 by some commenters to NHTSA's MY 2011 CAFE rulemaking that there would be greater potential for gaming under multi-attribute standards, such as standards under which targets would also depend on attributes such as weight, torque, power, towing capability, and/or off-road capability. Standards that incorporate such attributes in conjunction with footprint would not only be significantly more complex, but by providing degrees of freedom with respect to more easily-adjusted attributes, they would make it less certain that the future fleet would actually achieve the average fuel economy improvement and CO_2 reduction levels projected by the agencies.

2.3 What mathematical function do the agencies use, and why?

The MY 2011 CAFE standards are defined by a continuous, constrained logistic function, which takes the form of an S-curve, and is defined according to the following formula:

$$TARGET = \cfrac{1}{\cfrac{1}{a} + \left(\cfrac{1}{b} - \cfrac{1}{a}\right) \cfrac{e^{(FOOTPRINT-c)/d}}{1 + e^{(FOOTPRINT-c)/d}}}$$

Here, *TARGET* is the fuel economy target (in mpg) applicable to vehicles of a given footprint (*FOOTPRINT*, in square feet), *b* and *a* are the function's lower and upper asymptotes (also in mpg), *e* is approximately equal to 2.718,[c] *c* is the footprint (in square feet) at which the inverse of the fuel economy target falls halfway between the inverses of the lower and upper asymptotes, and *d* is a parameter (in square feet) that determines how gradually the fuel economy target transitions from the upper toward the lower asymptote as the footprint increases. Figure 2-1 shows an example of a logistic target function, where *b* = 20 mpg, *a* = 30 mpg, *c* = 40 square feet, and *d* = 5 square feet.
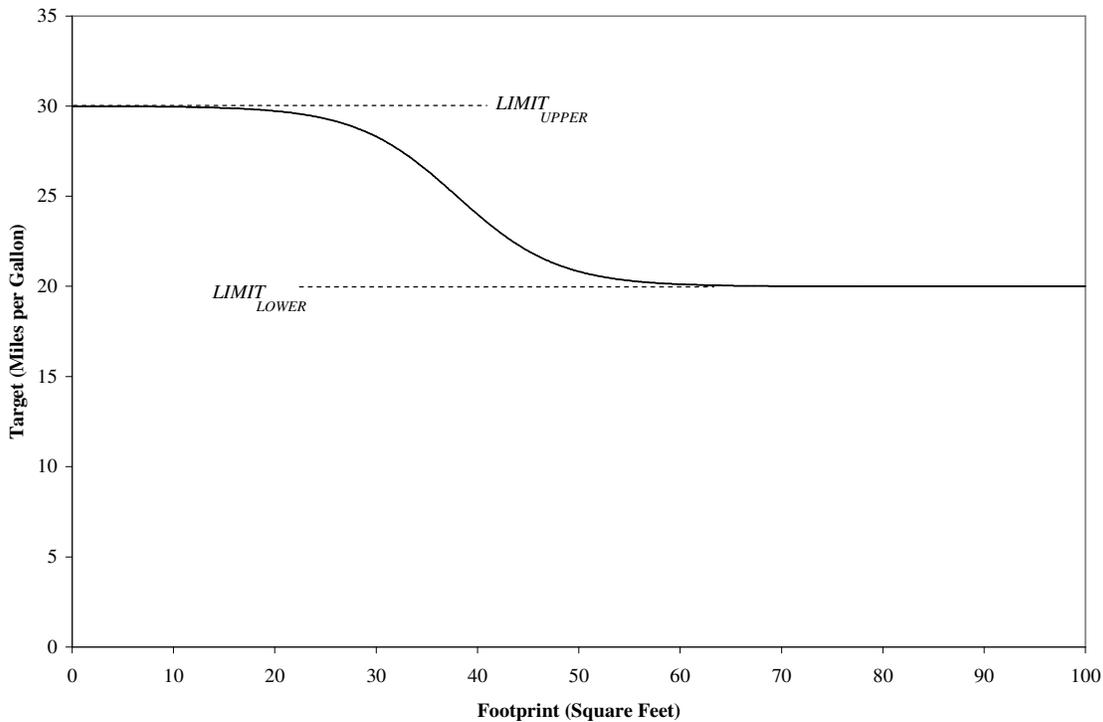
Figure 2-1 Sample Logistic Curve

After fitting this mathematical form (separately) to the passenger car and light truck fleets and determining the maximum feasible stringency of the standards (*i.e.*, the vertical

---

[c] *e* is the irrational *number* for which the slope of the function *y* = *number*^{x} is equal to 1 when *x* is equal to zero. The first 8 digits of *e* are 2.7182818.

positions of the curves), NHTSA arrived at the curves shown in Figure 2-2 to define the MY 2011 standards.
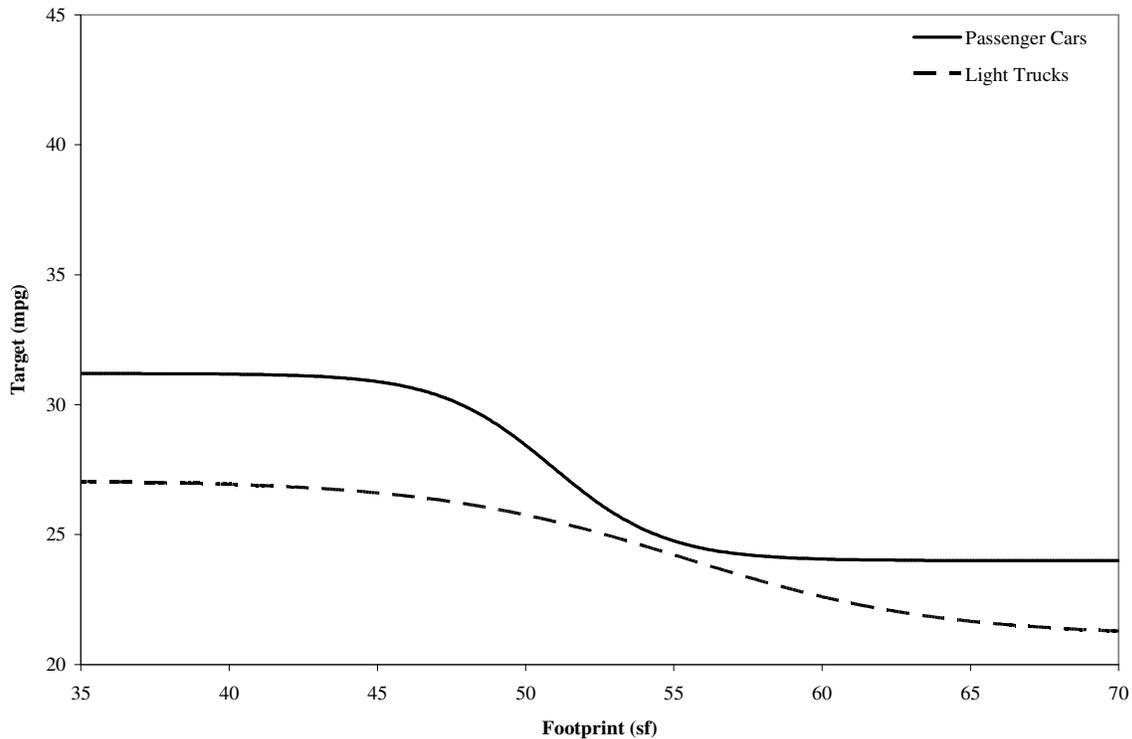
Figure 2-2 MY 2011 CAFE Standards for Passenger Cars and Light Trucks

In finalizing the MY 2011 standards, NHTSA noted that the agency is not required to use a constrained logistic function and indicated that the agency may consider defining future CAFE standards in terms of a different mathematical function. NHTSA and EPA have done so jointly for the MYs 2012-2016 CAFE standards and CO_2 emissions standards.

In revisiting this question jointly, EPA and NHTSA found that the final MY 2011 CAFE standard for passenger cars, though less steep than the MY 2011 standard NHTSA proposed in 2008, continues to concentrate the sloped portion of the curve (from a compliance perspective, the area in which upsizing results in a slightly lower applicable target) within a relatively narrow footprint range (approximately 47-55 square feet). In practical terms, this results in a portion of the fleet that has a large change in emissions and fuel consumption with just a minor change in footprint. This potentially increases the incentive for gaming by upsizing slightly to meet less stringent standards. Further, most passenger car models have footprints smaller than the curve's 51.4 square foot inflection point, and many passenger car models have footprints at which the curve is relatively flat (see figure above). The resulting

fit to the data was forced by choice of asymptotes defining the constrained logistic function. The agencies discuss below the alternative function that seeks to prevent this from occurring.

For both passenger cars and light trucks, a mathematical function that has some slope at most footprints where vehicles are produced is advantageous in terms of fairly balancing regulatory burdens among manufacturers, and in terms of providing a disincentive to respond to new standards by downsizing vehicles in ways that compromise vehicle safety. For example, a flat standard has drawbacks discussed above: it may be very difficult for a full-line manufacturer to meet, while requiring very little of a manufacturer concentrating on small vehicles, and a flat standard may provide an incentive to manufacturers to downsize certain vehicles, in order to "balance out" other vehicles subject to the same standard.

As a potential alternative to the constrained logistic function, NHTSA had, in proposing MY 2011 standards, presented information regarding a constrained linear function (or piecewise linear function). As shown in the 2008 NPRM, a constrained linear function has the potential to avoid creating a localized region (in terms of vehicle footprint) over which the slope of the function is relatively steep. Although NHTSA did not receive public comments on this option, the agency indicated that it still believed a linear function constrained by upper (on a gpm basis) and possibly lower limits could merit reconsideration in future CAFE rulemakings.

Having re-examined a piecewise linear function or constrained linear function for purposes of the proposed standards, NHTSA and EPA tentatively concluded that for both passenger cars and light trucks, it remained important to maintain a function with a meaningfully sloped section covering a wide footprint range, thereby providing a well-distributed disincentive to downsize vehicles in ways that could compromise highway safety. Also, the function proposed was not so steeply sloped that it would provide a strong incentive to increase vehicle size in order to obtain a lower CAFE requirement and higher CO_2 limit, thereby compromising energy and environmental benefits. Therefore, the CAFE and CO_2 emissions standards proposed in the NPRM were defined by constrained linear or piecewise linear functions.

The NHTSA constrained linear function was defined according to the following formula:

$$TARGET = \frac{1}{MIN\left[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}\right]}$$

Here, *TARGET* is the fuel economy target (in mpg) applicable to vehicles of a given footprint (*FOOTPRINT*, in square feet), *b* and *a* are the function's lower and upper asymptotes (also in mpg), respectively, *c* is the slope (in gpm per square foot) of the sloped portion of the function, and *d* is the intercept (in gpm) of the sloped portion of the function (that is, the value the sloped portion would take if extended to a footprint of 0 square feet. The *MIN* and *MAX* functions take the minimum and maximum, respectively of the included values; for example, *MIN*(1,2) = 1, *MAX*(1,2) = 2, and *MIN*[*MAX*(1,2),3)]=2. Figure 2-3 shows an example of a linear target function, where *a* = 0.0241 gpm (41.6 mpg), *b* = 0.032

gpm (31.2 mpg), c = 0.000531 gpm per square foot, and d = 0.002292 gpm (436 mpg). Because the function is linear on a gpm basis, not an mpg basis, it is plotted on this basis.
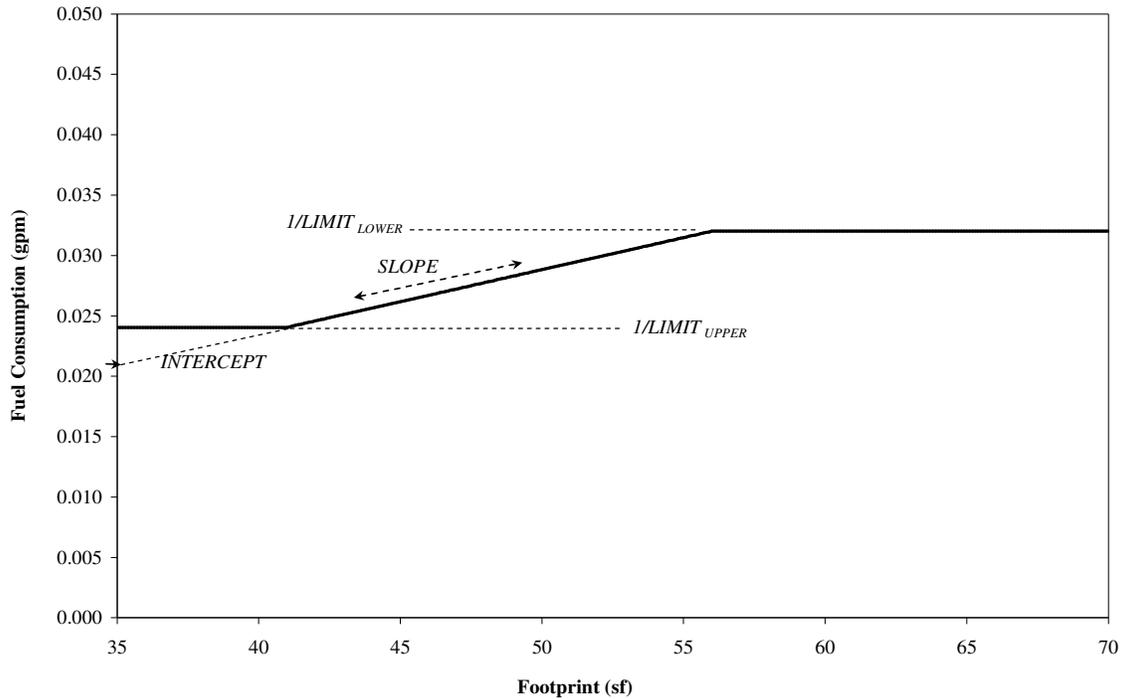
Figure 2-3 Sample Linear Function

The EPA piecewise linear function has the same shape as the NHTSA equation but has a slightly different mathematical specification. It is defined according to the following formula:

$$\text{Target} = a, \text{ if } x \leq l$$

$$\text{Target} = cx + d, \text{ if } l < x \leq h$$

$$\text{Target} = b, \text{ if } x > h$$

This equation also takes the simplified form (consistent with NHTSA's functional form):

$$\text{Target} = \text{MIN} \, [\, \text{MAX} \, (\, c * x + d \, , \, a) \, , \, b]$$

Where,

Target = the CO2 target value for a given footprint (in g/mi)
a = the minimum target value (in g/mi CO_2)
b = the maximum target value (in g/mi CO_2)
c = the slope of the linear function (in g/mi per sq ft CO_2)
d = is the intercept or zero-offset for the line (in g/mi CO_2)
x = footprint of the vehicle model (in square feet, rounded to the nearest tenth)
l & h are the lower and higher footprint limits or constraints or the boundary ("kinks")
between the flat regions and the intermediate sloped line (in sq ft)

Figure 2-4 shows the basic curve.
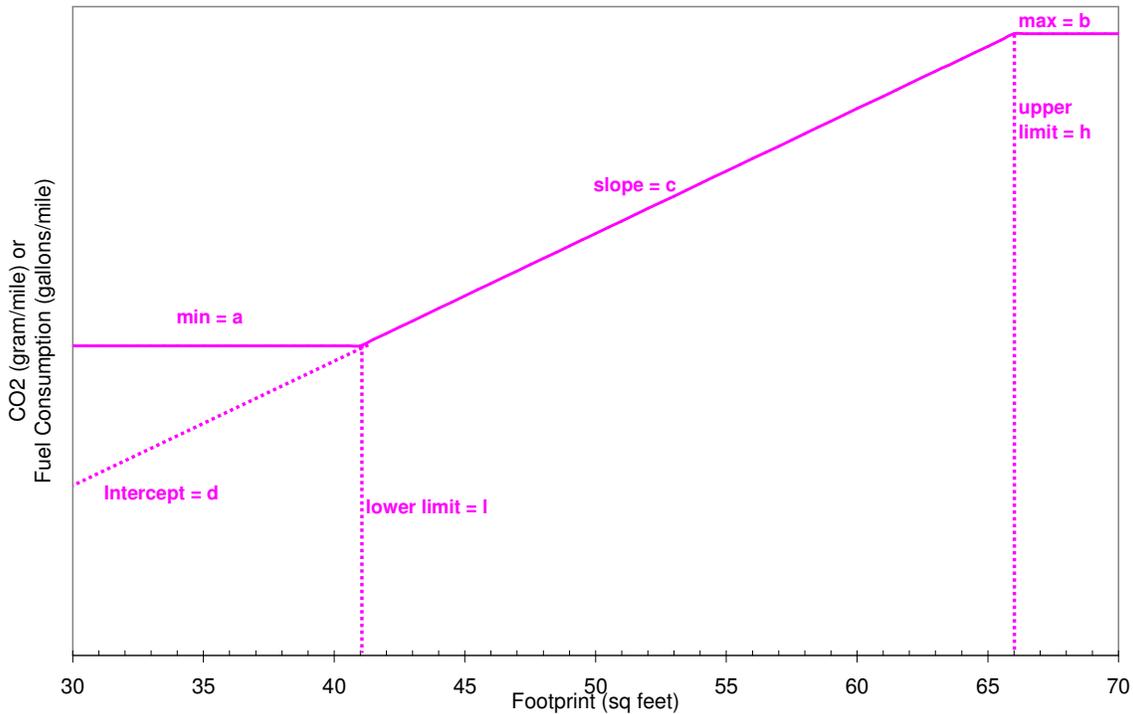
Figure 2-4 The Shape of the Piecewise Linear Attribute Based Curve

For purposes of the NPRM, NHTSA, working with EPA, developed the basic curve shapes for both agencies' respective standards, using statistical fitting methods similar to those applied by NHTSA in fitting the curves defining the MY 2011 standards. The first step began with the market inputs discussed above, but because the baseline fleet was technologically heterogeneous, NHTSA used the CAFE model to develop a fleet to which nearly all the technologies listed in Ch. 3 of the TSD[d] were applied, by taking the following

---

[d] The agencies excluded diesel engines and strong hybrid vehicle technologies from this exercise (and only this exercise) because the agencies expect that manufacturers would not need to rely heavily on these technologies in

steps: (1) applying all non-diesel and non-hybrid technologies to each vehicles according to their applicability, (2) treating all manufacturers as unwilling to pay civil penalties rather than applying technology, (3) applying any technology at any time, irrespective of scheduled vehicle redesigns or freshening, and (4) ignoring "phase-in caps" that constrain the overall amount of technology that can be applied by the model to a given manufacturer's fleet. These steps helped to increase technological parity among vehicle models, thereby providing a better basis (than the baseline fleet) for estimating the statistical relationship between vehicle size and fuel economy. In other words, this process normalized the fleet such that differences in technology had a minimal contribution to the variation (scatter) in the data. This process also served to eliminate the influence of differing degrees of pre-existing fuel-saving technology at various footprint values. This slightly flattened the slope of the line, indicating that a regression without adjusting for different 2008 vehicle technologies would not only have overestimated the dependence of fuel economy on footprint, but would also have provided an inappropriate incentive to upsize vehicles.

In fitting the curves, EPA and NHTSA also continued to apply constraints to limit the function's value for both the smallest and largest vehicles. Without a limit at the smallest footprints, the function—whether logistic or linear—can reach values that would be unfairly burdensome for a manufacturer that elects to focus on the market for small vehicles; depending on the underlying data, an unconstrained form could apply targets to the smallest vehicles that are simply unachievable. Limiting the function's value for the smallest vehicles thus assures that the function remains technologically achievable and economically practicable for manufacturers focusing on small vehicles. Obviously, passenger compartments can only become so small; this means, among other things, that a vehicle's frontal area—a key determinant of aerodynamic drag—can only become so small. Also, as vehicle size decreases, complying with federal motor vehicle safety standards can necessitate the addition of structural elements that add mass and thereby reduce fuel economy and increase CO_2 emissions. On the other side of the function, without a limit at the largest footprints, the function may provide no floor on required fuel economy. Also, the safety considerations that support the provision of a disincentive for downsizing as a compliance strategy apply weakly—if at all—to the very largest vehicles. Limiting the function's value for the largest vehicles leads to a function with an inherent absolute minimum level of fuel economy (or maximum emissions), while remaining consistent with safety considerations.

Before fitting the sloped portion of the constrained linear form, NHTSA and EPA selected footprints above and below which to apply constraints (*i.e.*, minimum and maximum values) on the function. For passenger cars, the agencies noted that several manufacturers offer small and, in some cases, sporty coupes below 41 square feet, examples including the BMW Z4 and Mini, Saturn Sky, Honda Fit and S2000, Hyundai Tiburon, Mazda MX-5 Miata, Suzuki SX4, Toyota Yaris, and Volkswagen New Beetle. Because such vehicles represent a small portion (less than 10 percent) of the passenger car market, yet often have

---

order to comply with the standards. NHTSA and EPA did include diesel engines and strong hybrid vehicle technologies in all other portions of their analyses.

characteristics that could make it infeasible to achieve the very challenging targets that could apply in the absence of a constraint, the agencies proposed to "cut off" the linear portion of the passenger car function at 41 square feet. The agencies recognize that for manufacturers who make small vehicles in this size range, there is some incentive to downsize to make it easier to meet the target. However, at the same time, the agencies believe that there is a limit to the market for ever-smaller cars. Most consumers likely have some minimum expectation about interior volume, among other things. The agencies thus believe that the number of consumers who will want vehicles smaller than 41sq ft to be downsized even further is extremely small, and the incentive to downsize, if present, will be minimal. For consistency, the agencies proposed to "cut off" the light truck function at the same footprint, although no light trucks are currently offered below 41 square feet. If the agencies set the limit for small trucks at a level higher than that for cars, there could be an undue incentive for manufacturers to change their car designs to qualify as trucks between the two footprint limits. The agencies further noted that above 56 square feet, the only passenger car model present in the MY 2008 fleet were four luxury vehicles with extremely low sales volumes—the Bentley Arnage and three versions of the Rolls Royce Phantom. The agencies therefore proposed to "cut off" the linear portion of the passenger car function at 56 square feet. Finally, the agencies noted that although public information is limited regarding the sales volumes of the many different configurations (cab designs and bed sizes) of pickup trucks, the largest pickups (*e.g.*, the Ford F-150, GM Sierra/Silverado, Nissan Titan, and Toyota Tundra), appear to fall above 66 square feet in footprint. The agencies therefore proposed to "cut off" the linear portion of the light truck function at 66 square feet. These "cut-off" values of footprint serve as the constraints to the functions shown above. The lower and upper levels are determined from where the sloped line meets these cut-off points.

Having developed a set of baseline data to which to fit the mathematical fuel consumption function, the initial values for parameters *c* and *d* were determined for cars and trucks separately. Values for *c* and *d* were initially set such that the average (equivalently, sum) of the absolute values of the differences was minimized between the "maximum technology" fleet fuel consumption (within the footprints between the upper and lower limits) and the straight line function defined above at the same corresponding vehicle footprints. That is, *c* and *d* were determined by minimizing the average absolute residual, commonly known as the MAD (Mean Absolute Deviation) approach, of the corresponding straight line. The curve was fit in fuel consumption (*i.e.*, CO_2) space rather than fuel economy space because the manufacturer targets are in terms of the harmonic average fuel economy (or average CO_2), and so it is more important that the curve fit the fuel consumption (*i.e.*, CO_2) data well than that it fit the fuel economy data well. NHTSA also explained in the MY 2011 final rule that it chose to use MAD in this step instead of minimizing the sum of the square errors ("least squares," a more common approach in curve fitting) in order to lessen the influence of outliers.

NHTSA and EPA currently believe that it is more appropriate to use unweighted data in fitting the curve rather than weighting the data by sales because of large variations in model sales. The agencies find that the market forecast used for analysis supporting both the NPRM and the final rule exhibits the two key characteristics that previously led NHTSA to use minimization of the unweighted Mean Absolute Deviation (MAD) rather than weighted least-squares analysis. First, projected model-specific sales volumes in the agencies' market

forecast cover an extremely wide range, such that, as discussed in NHTSA's rulemaking for MY 2011, although unweighted regression gives low-selling vehicle models and high-selling vehicle models equal emphasis, sales-weighted regression would give some vehicle models considerably more emphasis than other vehicle models.[e] The agencies' intention is to fit a curve that describes a technical relationship between fuel economy and footprint, given comparable levels of technology, and this supports weighting discrete vehicle models equally. On the other hand, sales weighted regression would allow the difference between other vehicle attributes to be reflected in the analysis, and also would reflect consumer demand.

Second, even after NHTSA's "maximum technology" analysis to increase technological parity of vehicle models before fitting curves, the agencies' market forecast contains many significant outliers. As discussed in NHTSA's rulemaking for MY 2011, MAD is a statistical procedure that has been demonstrated to produce more efficient parameter estimates than least-squares analysis in the presence of significant outliers.[f] In addition, the agencies remain concerned that the steeper curves resulting from weighted least-squares analysis would increase the risk that energy savings and environmental benefits would be lower than projected, because the steeper curves would provide a greater incentive to increase sales of larger vehicles with lower fuel economy levels. Based on these technical considerations and these concerns regarding potential outcomes, the agencies have decided not to re-fit curves using weighted least-squares analysis, but note that they may reconsider using least-squares regression in future analyses.

---

[e] For example, the agencies' market forecast shows MY 2016 sales of 187,000 units for Toyota's 2WD Sienna, and shows 27 model configurations with MY 2016 sales of fewer than 100 units. Similarly, the agencies' market forecast shows MY 2016 sales of 268,000 for the Toyota Prius, and shows 29 model configurations with MY 2016 sales of fewer than 100 units. Sales-weighted analysis would give the Toyota Sienna and Prius more than a thousand times the consideration of many vehicle model configurations. Sales-weighted analysis would, therefore, cause a large number of vehicle model configurations to be virtually ignored. *See* discussion in NHTSA's final rule for MY 2011 passenger car and light truck CAFE standards, 74 Fed. Reg. at 14368 (Mar. 30, 2009), and in NHTSA's NPRM for that rulemaking, 73 Fed. Reg. at 24423-24429 (May 2, 2008).

[f] *Id.* In the case of a dataset not drawn from a sample with a Gaussian, or normal, distribution, there is often a need to employ robust estimation methods rather than rely on least-squares approach to curve fitting. The least-squares approach has as an underlying assumption that the data are drawn from a normal distribution, and hence fits a curve using a sum-of-squares method to minimize errors. This approach will, in a sample drawn from a non-normal distribution, give excessive weight to outliers by making their presence felt in proportion to the square of their distance from the fitted curve, and, hence, distort the resulting fit. With outliers in the sample, the typical solution is to use a robust method such as a minimum absolute deviation, rather than a squared term, to estimate the fit (*see*, *e.g.*, ''AI Access: Your Access to Data Modeling,'' at http://www.aiaccess.net/English/Glossaries/GlosMod/e_gm_O_Pa.htm#Outlier). The effect on the estimation is to let the presence of each observation be felt more uniformly, resulting in a curve more representative of the data (*see*, *e.g.*, Peter Kennedy, *A Guide to Econometrics*, 3rd edition, 1992, MIT Press, Cambridge, MA).

Finally, the agencies calculated the values of the upper and lower limits based on the corresponding footprint constraints discussed above (41 and 56 square feet for passenger cars, and 41 and 66 square feet for light trucks).

The result of this methodology is shown below in Figure 2-5 and Figure 2-6 for passenger cars and light trucks, respectively. The fitted curves are shown with the underlying "maximum technology" passenger car and light truck fleets. For passenger cars, the mean absolute deviation of the sloped portion of the function was 14 percent. For trucks, the corresponding mean absolute deviation was 10 percent.
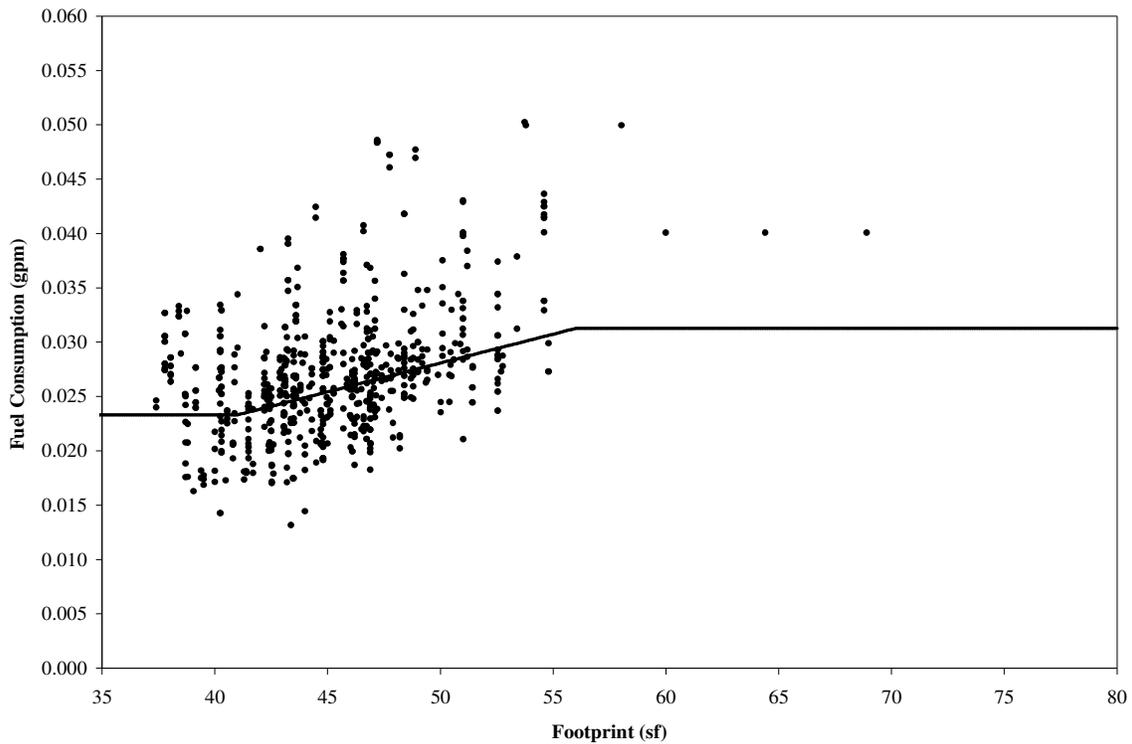
Figure 2-5 "Maximum Technology" Passenger Fleet with Fitted Constrained Linear Function
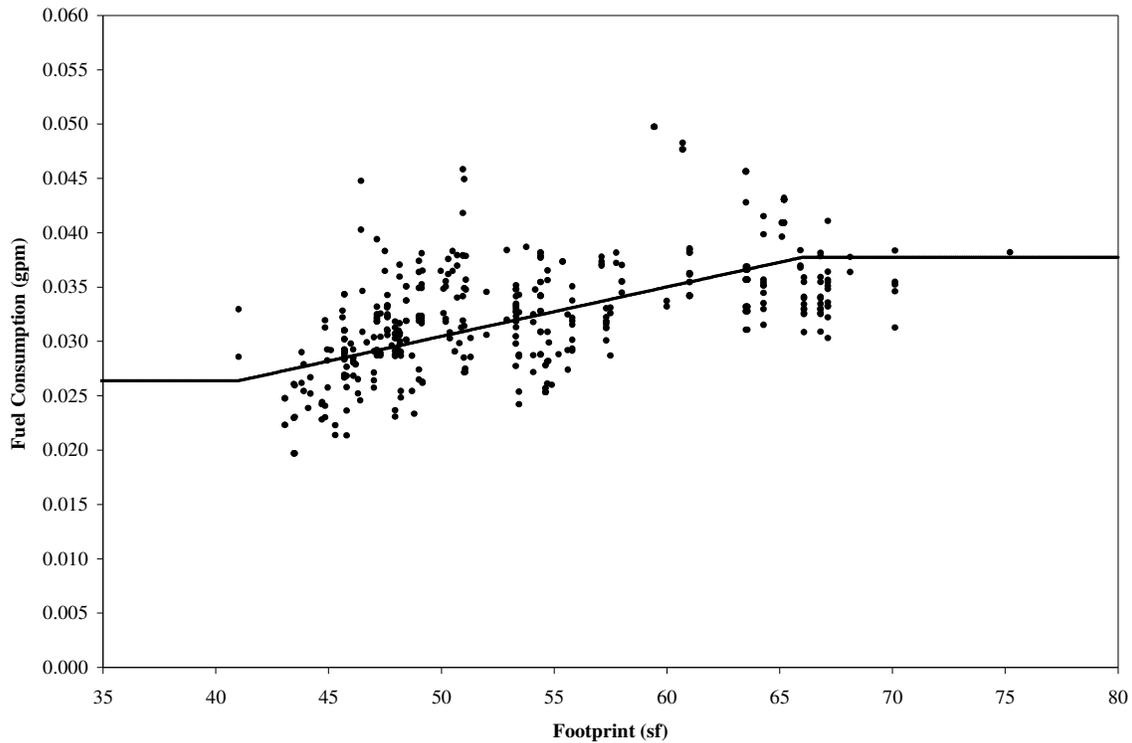
Figure 2-6 "Maximum Technology" Light Truck with Fitted Constrained Linear Function

The agencies used these functional forms as a starting point to develop mathematical functions defining actual proposed standards. As discussed in Sections II.C of the preamble, the agencies transposed these functions vertically (*i.e.*, on a gpm basis, uniformly downward) to produce the maximum feasible passenger car and light truck CAFE standards, and corresponding CO_2 emissions standards.

Having considered public comments as discussed in greater detail in the final rule preamble, NHTSA and EPA have re-examined the development of curves underlying the standards proposed in the NPRM, and are promulgating standards based on the same underlying curves. The agencies have made this decision considering that, while EISA mandates that CAFE standards be defined by a mathematical function in terms of one or more attributes related to fuel economy, neither EISA nor the CAA expressly require that the mathematical function be purely descriptive of an observed or theoretical dependence of fuel economy on the selected attribute or attributes. As a means by which CAFE and GHG standards are specified, the mathematical function plays a normative role.[g] Therefore,

---

[g] That is, tending to encourages some types of responses more than others – in this case, generally preferring increased use of fuel-saving technologies over simple reductions in vehicle size.

NHTSA and EPA have concluded that the mathematical function can reasonably be selected based on a blend of analytical and policy considerations.

Considering comments by UC Santa Barbara students regarding difficulties reproducing NHTSA's analysis, NHTSA re-examined its analysis, and discovered some erroneous entries in model inputs underlying the analysis used to develop the curves proposed in the NPRM. These errors, which are also discussed in NHTSA's final Regulatory Impact Analysis (RIA) and have since been corrected, include the following: incorrect valvetrain phasing and lift inputs for many BMW engines, incorrect indexing for some Daimler models, incorrectly enabled valvetrain technologies for rotary engines and Atkinson cycle engines, omitted baseline applications of cylinder deactivation in some Honda and GM engines, incorrect valve phasing codes for some 4-cylinder Chrysler engines, omitted baseline applications of advanced transmissions in some VW models, incorrectly enabled advanced electrification technologies for several hybrid vehicle models, and incorrect DCT effectiveness estimates for subcompact passenger cars.

After correcting these errors and repeating the curve development analysis presented in the NPRM, NHTSA obtained curves shown below in Figures 2-7 and 2-8 for passenger cars and light trucks, respectively. The fitted curves are shown with the underlying "maximum technology" passenger car and light truck fleets. For passenger cars, the mean absolute deviation of the sloped portion of the function was 14 percent. For trucks, the corresponding mean absolute deviation was 10 percent.
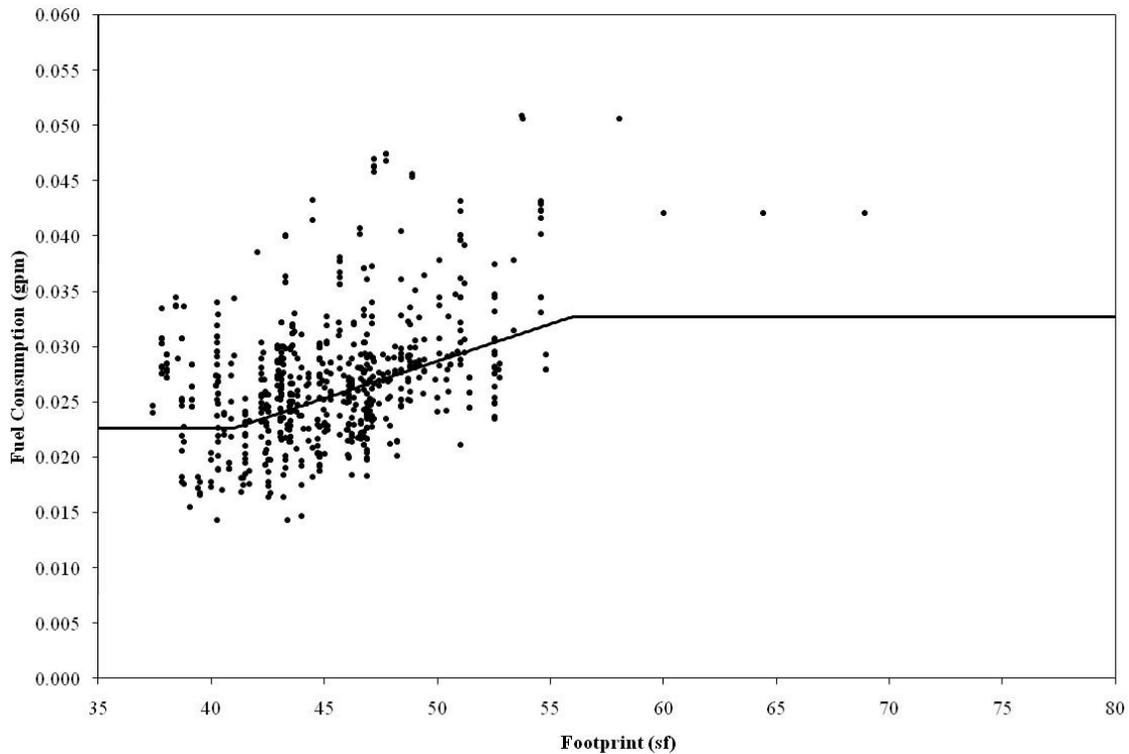

Figure 2-7 Revised "Maximum Technology" Passenger Fleet with Fitted Constrained Linear Function
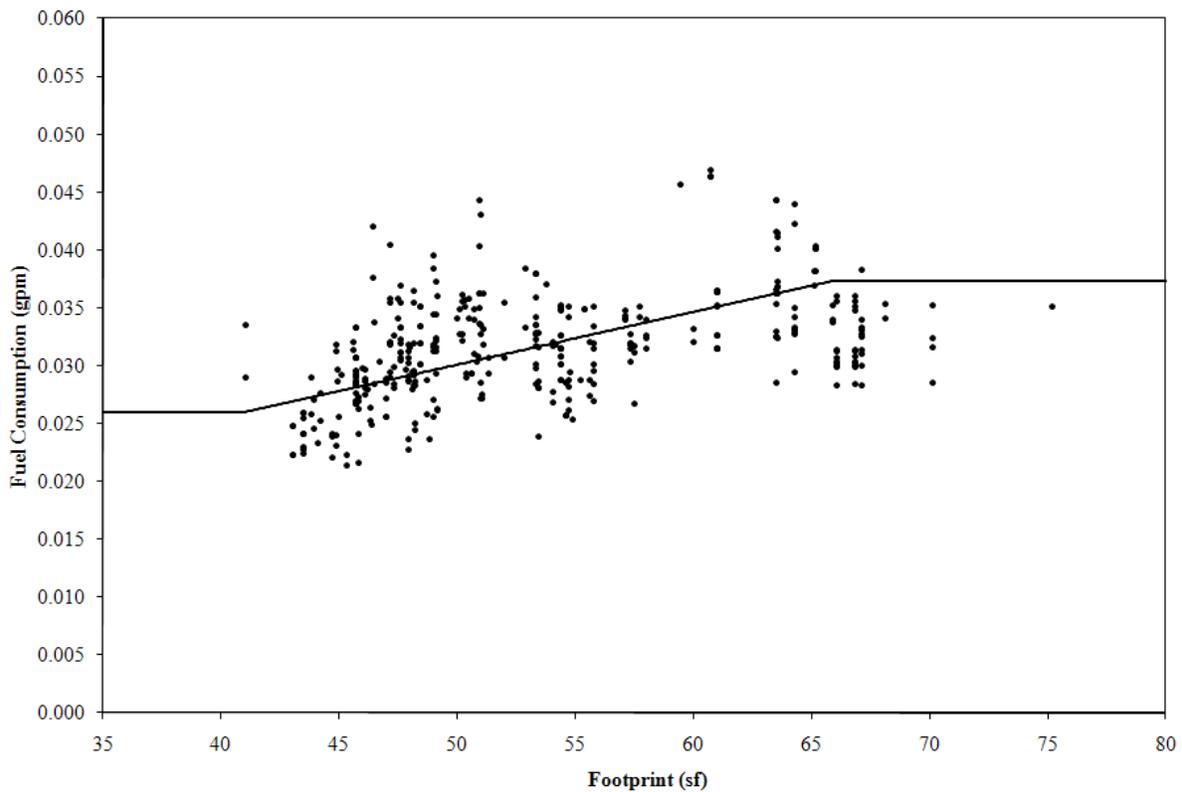
Figure 2-8 Revised "Maximum Technology" Light Truck with Fitted Constrained Linear Function

This refitted passenger car curve is similar to that presented in the NPRM, and the refitted light truck curve is nearly identical the corresponding curve in the NPRM. However, the slope of the passenger car curve is about 27 percent steeper (on a gpm per sf basis) than the curve presented in the NPRM. For passenger cars and light trucks, respectively,   Figure 2-9 and Figure 2-10 show the results of adjustment—discussed below—of the above curves to yield the average required fuel economy levels corresponding to the announced national policy.
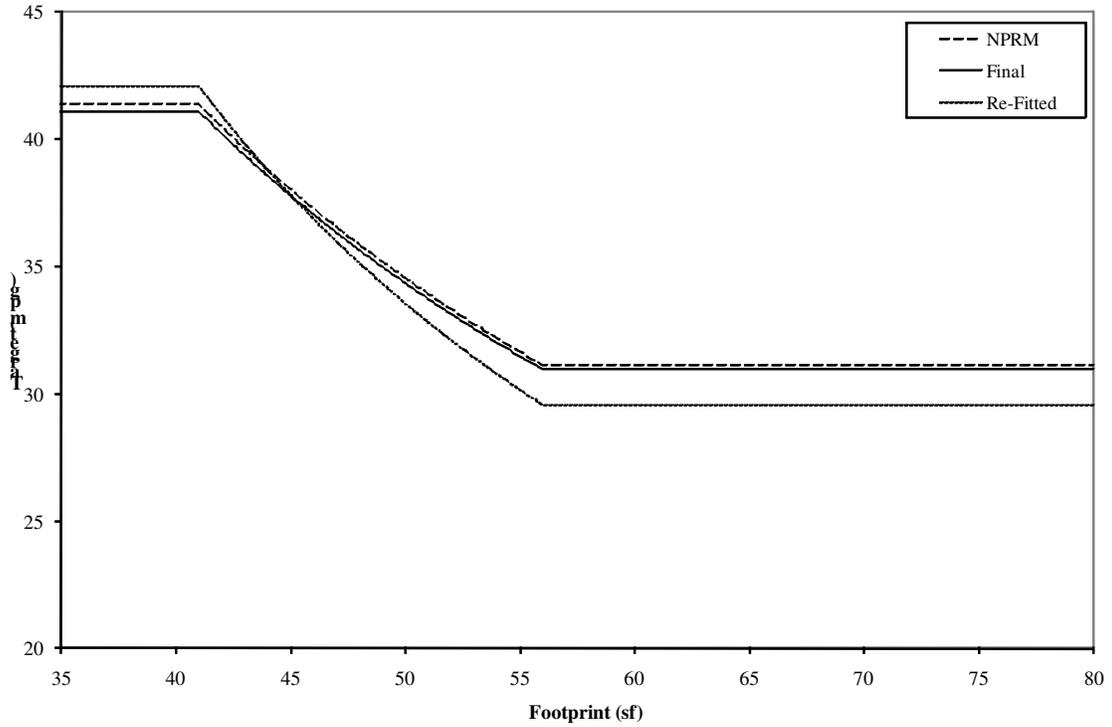
Figure 2-9 MY2016 Passenger Car Targets: NPRM, Final Rule, and if Using Re-Fitted Curve
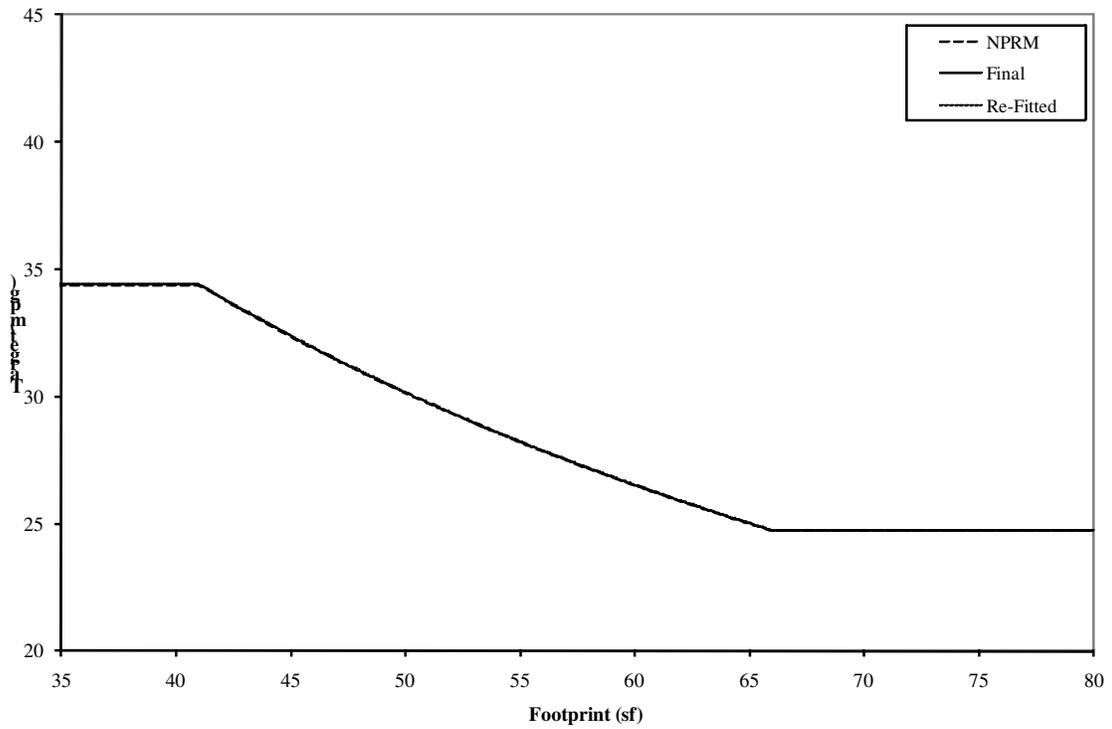
Figure 2-10 MY2016 Light Truck Targets: NPRM, Final Rule, and if Using Re-Fitted Curve

As the figures show, the resultant light truck curves are visually indistinguishable from one another. For passenger cars, in contrast, the refitted curve would increase stringency for the smallest cars, decrease stringency for the largest cars, and provide a greater incentive to increase car size throughout the range of footprints within which NHTSA and EPA project most passenger car models will be sold through MY 2016. The agencies are concerned that these changes would make it unduly difficult for manufacturers to introduce new small passenger cars in the United States, and unduly risk forgoing achievable and cost-effective energy and environmental benefits by increasing incentives for the passenger car market to shift toward larger vehicles.

Also, the agencies note that the refitted passenger car curve produces only a slightly closer fit to the corrected fleet than would the curve estimated in the NPRM; with respect to the corrected fleet (between the "cut off" footprint values, and after the "maximum technology" analysis discussed above), the mean absolute deviation for the refitted curve is 13.887 percent, and that of a refitted curve held to the original slope is 13.933 percent. In other words, the data support the original slope very nearly as well as they support the refitted slope.

Although these refitted curves reflect the agencies' best technical judgment at this time regarding the use of statistical analysis for this purpose, based on NHTSA's and EPA's concerns regarding the undesirable changes in incentives that would result from a refitted curve for passenger cars, and given that the data support the original curves essentially as well as they would support refitted curves, the agencies are finalizing CAFE and GHG standards based on the curves presented in the NPRM.

Finally, regarding some commenters' inability to reproduce the agencies' NPRM analysis, NHTSA believes that its correction of the errors discussed above and its release (on NHTSA's web site) of the updated Volpe model and all accompanying inputs and external analysis files should enable outside parties to independently reproduce the agencies' analysis. If outside parties continue to experience difficulty in doing so, we encourage them to contact NHTSA, and the agency will do its best to provide assistance.

References

[1] 49 U.S.C. 32902(a)(3)(A).

[2] The 2002 NAS Report described at length and quantified the potential safety problem with average fuel economy standards that specify a single numerical requirement for the entire industry. *See* NAS Report at 5, finding 12. Docket EPA-HQ-OAR-2009-0472-0147.

[3] *Id*. at 4-5, finding 10. Docket EPA-HQ-OAR-2009-0472-0147.

[4] 49 U.S.C. 32902(b)(4).

CHAPTER 3: Technologies Considered in the Agencies' Analysis

This Chapter of the joint TSD describes the technologies NHTSA and EPA evaluated as potential inputs in their respective models and provides estimates of the technologies' costs, effectiveness and availability. This Chapter also describes, in general terms, how the agencies use these inputs in their respective models. For greater detail on this subject, please see Section V of NHTSA's FRIA and Chapter 4 of EPA's RIA.

3.1 How do the agencies decide which technologies to include in the analysis?

Technology assumptions, *i.e.*, assumptions about their availability, cost, effectiveness, and the rate at which they can be incorporated into new vehicles, are often very controversial as they have a significant impact on the levels of the standards. Agencies must, therefore, take great care in developing and justifying these assumptions. In developing technology inputs for MY 2012-2016 standards the agencies reviewed the technology assumptions that NHTSA used in setting the MY 2011 standards, the agencies reviewed the technology input assumptions identified in EPA's 2008 Staff Technical Report,[1] the comments that NHTSA received in response to its May 2008 Notice of Proposed Rulemaking, and the comments that the agencies received in response to its September 2009 Notice of Proposed Rulemaking. In addition, the agencies supplemented their review with information from the sources described in the following section.

3.1.1 Reports and papers in the literature

NHTSA and EPA have done extensive research in identifying the most credible sources of information. These sources included: the 2002 NAS report on the effectiveness and impact of CAFE standards;[2] the 2004 study done by NESCCAF;[3] the California Air Resources Board (CARB) Initial Statement of Reasons in support of their carbon rulemaking;[4] a 2006 study done by Energy and Environmental Analysis (EEA) for the Department of Energy;[5] a study done by the Martec Group for the Alliance of Automobile Manufacturers, and an update by the Martec Group to that study;[6] and vehicle fuel economy certification data. Both agencies also reviewed the published technical literature which addressed the issue of CO_2 emission control and fuel economy, such as papers published by the Society of Automotive Engineers and the American Society of Mechanical Engineers, as well as papers submitted by commenters (for example, the Aluminum Association) to the agencies' joint NPRM. In addition, confidential data submitted by vehicle manufacturers in response to NHTSA's request for product plans,[7] and confidential information shared by automotive industry component suppliers in meetings with EPA and NHTSA staff held during the second half of the 2007 calendar year were used as a cross check of the public data mentioned above and not as a significant basis for this rulemaking.

EPA also has a contracted study ongoing with FEV that consists of complete system tear-downs to evaluate technologies down to the nuts and bolts to arrive at very detailed estimates of the costs associated with manufacturing them. For the NPRM, the agencies used a completed analysis to estimate costs of turbocharging with downsizing for I4 engines only. The NPRM stated that tear-down cost estimates from FEV for additional engine and transmission technologies became available shortly before the release of the NPRM, but not in time to be incorporated into the agencies' cost analysis of the proposed standards. These preliminary results were made available for review and the agencies stated they would consider this information for use in the final rule analysis.[8] The NPRM also stated that a detailed report would be submitted to the docket on these additional technologies during the public comment period for the proposal. That deadline was not met but all additional technologies for which cost study tear downs have been completed from this study with FEV (studies have now been completed on turbocharging and downsizing for V6 and V8 engines, stoichiometric gasoline direct injection, 6/7/8-speed automatic transmission and dual clutch transmission technologies) have been considered for the final rule and details are contained in two reports placed in the docket.[9,10] EPA and NHTSA reviewed all of the above information in order to develop the best estimates of availability, cost and effectiveness of these fuel-saving/CO_2-reducing technologies.

The agencies would also like to note that per the Energy Independence and Security Act (EISA), the National Academies of Sciences has been conducting a study for NHTSA to update chapter 3 of their 2002 NAS Report, which presents technology effectiveness estimates for light-duty vehicles. The update takes a fresh look at that list of technologies and their associated cost and effectiveness values. The updated NAS report was expected to be available on September 30, 2009, but has not been completed and released to the public. The results from this study thus are unavailable for this rulemaking. The agencies look forward to considering the results from this study as part of the next round of rulemaking for CAFE/GHG standards.

3.1.2 Fuel economy certification data

Where available, data from recent model years of EPA's Fuel Economy Certification Data were used for helping to determine the effectiveness of specific technologies. CO_2 and fuel consumption reduction estimates were estimated from EPA's fuel economy database on the two-cycle (FTP city & highway) fuel economy test results. During the standard fuel economy test cycles, direct measurements of CO_2 emissions are made. This data, along with other measurements, are then used to calculate the estimated fuel economy performance in gallons of fuel consumed per mile. Vehicle certification data are an obviously reliable source for determination of the CO_2 and fuel consumption reduction potential when a directly comparable vehicle was offered both with and without the specific CO_2 and fuel consumption reducing technology, because a comparison between the emissions data between the two vehicles directly reflect the application of the technologies on the vehicle test cycles. Where possible, technology-specific effectiveness numbers were extracted for vehicles where only the specific technology would be changed from a reference vehicle, in order to eliminate any confounding of

values across several technologies. In some hybrid vehicle cases, the exact same vehicle may not be offered, and a similar vehicle was selected for comparison.

3.2 Which technologies will be applicable during the model years to which the rules apply?

One of the key factors that NHTSA and EPA considered in developing the standards for each model year is the availability and feasibility of fuel-saving/CO_2-reducing technologies. A variety of technologies can be used to reduce fuel consumption and CO_2 emissions, whether they be engine-related (*e.g.*, turbocharging), transmission-related (*e.g.*, six forward gears in place of four), accessory-related (*e.g.*, electric power steering), or vehicle-related (*e.g.*, low rolling resistance tires). In taking a fresh look at the availability and feasibility of technologies for purposes of setting the MYs 2012-2016 standards, the agencies reviewed NHTSA's MY 2011 CAFE final rule and EPA's 2008 Staff Report, as well as the public comments to the proposed rule and updated the assumptions based on the most current information. As a check on this new analysis, NHTSA and EPA also reviewed the product plans submitted by manufacturers to the agencies in response to NHTSA's November 2009 request for product plans.

Many technologies considered by the agencies, such as variable valve timing (VVT), low rolling resistance tires, etc., are well known and readily available during the rulemaking time period, and could be incorporated into vehicles once production decisions are made. The agencies did not consider technologies in the research stage, such as homogeneous charge compression ignition (HCCI), lean-burn direct injection technology, etc., because their effectiveness and/or cost estimates contain a high level of uncertainty.

The technologies considered by the NHTSA and EPA models are briefly described below. They fall under the five broad categories of engine, transmission, vehicle, electrification/accessory, and hybrid technologies. A more detailed description of each technology, and the technology's costs and effectiveness, is described in greater detail in section 3.5 of this TSD.

Types of engine technologies that improve fuel economy and reduce CO_2 emissions include the following:

- *Low-friction lubricants* – low viscosity and advanced low friction lubricants oils are now available with improved performance and better lubrication.

- *Reduction of engine friction losses* – can be achieved through low-tension piston rings, roller cam followers, improved material coatings, more optimal thermal management, piston surface treatments, and other improvements in the design of engine components and subsystems that improve engine operation.

- *Conversion to dual overhead cam with dual cam phasing* – as applied to overhead valves designed to increase the air flow with more than two valves per cylinder and reduce pumping losses.

- *Cylinder deactivation* – deactivates the intake and exhaust valves and prevents fuel injection into some cylinders during light-load operation. The engine runs temporarily as though it were a smaller engine which substantially reduces pumping losses

- *Variable valve timing* – alters the timing or phase of the intake valve, exhaust valve, or both, primarily to reduce pumping losses, increase specific power, and control residual gases.

- *Discrete variable valve lift* – increases efficiency by optimizing air flow over a broader range of engine operation which reduces pumping losses. Accomplished by controlled switching between two or more cam profile lobe heights.

- *Continuous variable valve lift* – is an electromechanically controlled system in which cam period and phasing is changed as lift height is controlled. This yields a wide range of performance optimization and volumetric efficiency, including enabling the engine to be valve throttled.

- *Stoichiometric gasoline direct-injection technology* – injects fuel at high pressure directly into the combustion chamber to improve cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency.

- *Combustion restart* – can be used in conjunction with gasoline direct-injection systems to enable idle-off or start-stop functionality. Similar to other start-stop technologies, additional enablers, such as electric power steering, accessory drive components, and auxiliary oil pump, might be required.

- *Turbocharging and downsizing* – increases the available airflow and specific power level, allowing a reduced engine size while maintaining performance. This reduces pumping losses at lighter loads in comparison to a larger engine.

- *Exhaust-gas recirculation boost* – increases the exhaust-gas recirculation used in the combustion process to increase thermal efficiency and reduce pumping losses.

- *Diesel engines* – have several characteristics that give superior fuel efficiency, including reduced pumping losses due to lack of (or greatly reduced) throttling, and a combustion cycle that operates at a higher compression ratio, with a very lean air/fuel mixture, than an equivalent-performance gasoline engine. This technology requires additional enablers, such as NO_x trap catalyst after-treatment or selective catalytic reduction NO_x after-treatment.

Types of transmission technologies considered include:

- *Improved automatic transmission controls* – optimizes shift schedule to maximize fuel efficiency under wide ranging conditions, and minimizes losses associated with torque converter slip through lock-up or modulation.

- *Six-, seven-, and eight-speed automatic transmissions* – the gear ratio spacing and transmission ratio are optimized to enable the engine to operate in a more efficient operating range over a broader range of vehicle operating conditions.

- *Dual clutch or automated shift manual transmissions* – are similar to manual transmissions, but the vehicle controls shifting and launch functions. A dual-clutch automated shift manual transmission uses separate clutches for even-numbered and odd-numbered gears, so the next expected gear is pre-selected, which allows for faster and smoother shifting.

- *Continuously variable transmission* – commonly uses V-shaped pulleys connected by a metal belt rather than gears to provide ratios for operation. Unlike manual and automatic transmissions with fixed transmission ratios, continuously variable transmissions can provide fully variable and an infinite number of transmission ratios that enable the engine to operate in a more efficient operating range over a broader range of vehicle operating conditions.

- *Manual 6-speed transmission* – offers an additional gear ratio, often with a higher overdrive gear ratio, than a 5-speed manual transmission.

Types of vehicle technologies considered include:

- *Low-rolling-resistance tires* – have characteristics that reduce frictional losses associated with the energy dissipated in the deformation of the tires under load, therefore reducing the energy needed to move the vehicle.

- *Low-drag brakes* – reduce the sliding friction of disc brake pads on rotors when the brakes are not engaged because the brake pads are pulled away from the rotors.

- *Front or secondary axle disconnect for four-wheel drive systems* – provides a torque distribution disconnect between front and rear axles when torque is not required for the non-driving axle. This results in the reduction of associated parasitic energy losses.

- *Aerodynamic drag reduction* – is achieved by changing vehicle shape or reducing frontal area, including skirts, air dams, underbody covers, and more aerodynamic side view mirrors.

- *Mass reduction and material substitution* – Mass reduction encompasses a variety of techniques ranging from improved design and better component

integration to application of lighter and higher-strength materials. Mass reduction is further compounded by reductions in engine power and ancillary systems (transmission, steering, brakes, suspension, etc.).

Types of electrification/accessory and hybrid technologies considered include:

- *Electric power steering (EPS)* – is an electrically-assisted steering system that has advantages over traditional hydraulic power steering because it replaces a continuously operated hydraulic pump, thereby reducing parasitic losses from the accessory drive.

- *Improved accessories (IACC)* – may include high efficiency alternators, electrically driven (i.e., on-demand) water pumps and cooling fans. This excludes other electrical accessories such as electric oil pumps and electrically driven air conditioner compressors.

- *Air Conditioner Systems* – These technologies include improved hoses, connectors and seals 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.   These technologies are covered separately in the EPA RIA.

- *12-volt micro-hybrid (MHEV)* – also known as idle-stop or start stop and commonly implemented as a 12-volt belt-driven integrated starter-generator, this is the most basic hybrid system that facilitates idle-stop capability. Along with other enablers, this system replaces a common alternator with an enhanced power starter-alternator, both belt driven, and a revised accessory drive system.

- *Higher Voltage Stop-Start/Belt Integrated Starter Generator (BISG)* – provides idle-stop capability and uses a high voltage battery with increased energy capacity over typical automotive batteries. The higher system voltage allows the use of a smaller, more powerful electric motor and reduces the weight of the motor, inverter, and battery wiring harnesses. This system replaces a standard alternator with an enhanced power, higher voltage, higher efficiency starter-alternator, that is belt driven and that can recover braking energy while the vehicle slows down (regenerative braking).

- *Integrated Motor Assist (IMA)/Crank integrated starter generator (CISG)* – provides idle-stop capability and uses a high voltage battery with increased energy capacity over typical automotive batteries. The higher system voltage allows the use of a smaller, more powerful electric motor and reduces the weight of the motor, inverter, and battery wiring harnesses. This system replaces a standard alternator with an enhanced power, higher voltage, higher efficiency starter-alternator that is crankshaft mounted and can recover braking energy while the vehicle slows down (regenerative braking).

- *2-mode hybrid (2MHEV)* – is a hybrid electric drive system that uses an adaptation of a conventional stepped-ratio automatic transmission by replacing some of the transmission clutches with two electric motors that control the ratio of engine speed to vehicle speed, while clutches allow the motors to be bypassed. This improves both the transmission torque capacity for heavy-duty applications and reduces fuel consumption and CO_2 emissions at highway speeds relative to other types of hybrid electric drive systems.

- *Power-split hybrid (PSHEV)* – a hybrid electric drive system that replaces the traditional transmission with a single planetary gearset and a motor/generator. This motor/generator uses the engine to either charge the battery or supply additional power to the drive motor. A second, more powerful motor/generator is permanently connected to the vehicle's final drive and always turns with the wheels. The planetary gear splits engine power between the first motor/generator and the drive motor to either charge the battery or supply power to the wheels.

- *Plug-in hybrid electric vehicles (PHEV)* – are hybrid electric vehicles with the means to charge their battery packs from an outside source of electricity (usually the electric grid). These vehicles have larger battery packs with more energy storage and a greater capability to be discharged. They also use a control system that allows the battery pack to be substantially depleted under electric-only or blended mechanical/electric operation.

- *Electric vehicles (EV)* – are vehicles with all-electric drive and with vehicle systems powered by energy-optimized batteries charged primarily from grid electricity.

3.3 What technology assumptions have the agencies used for the final rule?

3.3.1 How are the technologies applied in the agencies' respective models?

Although both NHTSA and EPA are basing their fuel economy and emission modeling on the same baseline vehicle fleet and cost and effectiveness estimates for control technologies, differences in the Volpe and OMEGA models require that this common information be processed in different ways prior to their use in the respective models.. With respect to the vehicle fleet, the Volpe Model evaluates the addition of technology to individual vehicle configurations or models, while the OMEGA model does so for vehicle platforms broken down further by engine size. Thus, NHTSA used the vehicle sales estimates described above directly, while EPA combined the sales of certain vehicle models. The Volpe Model evaluates technologies individually. This, coupled with the modeling of individual vehicle models, means that only the presence or absence of any particular technology needs to be indicated, as described above. OMEGA

applies technology in combinations or packages. This, plus the grouping of individual vehicle models, requires that the total effectiveness of the technology already applied in the baseline fleet must be calculated and must be reflected as a percentage of the various technology packages available to be added to those vehicles.

With respect to the cost and effectiveness of technologies, as mentioned above, the Volpe Model applies technologies individually. It does this following certain specified pathways for several categories of technologies (*e.g.*, engine, transmission, accessories, etc.). The Volpe Model applies technology incrementally, so the effectiveness of each subsequent technology needs to be determined relative to the previous one. The same is true for cost. In addition, because of interaction in the effectiveness of certain technologies, herein referred to as the synergy/dis-synergy, any such interaction between the next technology on a specified pathway with those which have already been potentially applied in other pathways must be determined. For example, the incremental effectiveness of switching from a six-speed automatic transmission to a dual clutch transmission will depend on the level of engine technology already applied (*e.g.*, intake cam phasing on a port-fuel injected engine or a down-sized, turbocharged, direct injection engine).

EPA's OMEGA model applies technologies in packages and according to a fixed sequence for any particular group of vehicles. This requires that the overall cost and effectiveness of each package be determined first, considering any and all dis-synergies which may exist. Then, the incremental cost and effectiveness of each subsequent package is determined relative to the prior one.

Thus, while the same baseline vehicle fleet and cost and effectiveness estimates for technologies are being used in both the Volpe and OMEGA models, the form of the actual inputs to the model will appear to be different. For more information on EPA's and NHTSA's unique approaches to modeling, please refer to each agency's respective final RIA.

In order to estimate both technology costs and fuel consumption/CO_2 reduction estimates, it is necessary for each agency to describe the baseline vehicle characteristics from which the estimates can be compared. This "baseline" is different from the usage in Chapter 1 of this joint TSD. In Chapter 1, the baseline fleet is the projected fleet in MY 2016 before accounting for technologies needed to meet the MY 2011 CAFE standards and before accounting for changes in fleet composition attributable to that rule (those later steps accounted for independently by each agency in developing their separate reference fleets). In the present context, it indicates the vehicle types and technologies that will be used for comparison from a strict cost and effectiveness point of view. These baselines may be slightly different for the two agencies. For EPA, unless noted elsewhere, the baseline vehicle is defined as a vehicle with a port-fuel injected, naturally aspirated gasoline engine with two intake and two exhaust valves and fixed valve timing and lift. The baseline transmission is a 4-speed automatic, and the vehicle has no hybrid systems. For NHTSA, unless noted elsewhere, the baseline vehicle is the actual vehicle as it exists in the baseline fleet, because NHTSA models each unique vehicle separately.

For details on how the technology cost and effectiveness estimates presented below are used in each agency's model, refer to each agency's respective final RIA.

3.3.2 How did the agencies develop technology cost and effectiveness estimates for the final rule?

3.3.2.1   Considerations that affect technology effectiveness

As mentioned above, regarding estimates for technology effectiveness, NHTSA and EPA's primary approach was to reexamine the estimates from NHTSA's MY 2011 CAFE final rule and EPA's ANPRM and Staff Technical Report, which largely mirrored NHTSA's NPRM estimates in the 2008 proposal to establish CAFE standards for MYs 2011-2015. The agencies also reconsidered other sources such as the 2002 NAS Report, the 2004 NESCCAF report, recent CAFE compliance data (comparing similar vehicles with different technologies against each other in fuel economy testing, such as a Honda Civic Hybrid versus a directly comparable Honda Civic conventional drive), and confidential manufacturer estimates of technology effectiveness. Using the BOM framework utilized in the MY 2011 CAFE final rule, NHTSA and EPA engineers reviewed effectiveness information from the multiple sources for each technology. Together, they compared the multiple estimates and assessed their validity, taking care to ensure that common BOM definitions and other vehicle attributes such as performance, refinement, and drivability were taken into account. However, because the agencies' respective models employ different numbers of vehicle subclasses and use different technology decision trees to arrive at the standards, direct comparison of BOMs was somewhat more complicated. To address this and to assure an apples-to-apple comparison, NHTSA and EPA developed mapping techniques, devising technology packages and corresponding incremental technology estimates. This approach helped compare incremental and packaged estimates and derive results that are consistent and could be translated into the respective models of the agencies. In general, most effectiveness estimates used in the 2008 EPA Staff Report, the MY 2011 CAFE final rule and the MY 2012-2016 joint NPRM were determined to be accurate and were carried forward without significant change into the analysis for this final rule. When NHTSA and EPA's estimates for effectiveness diverged slightly due to differences in how the agencies apply technologies to vehicles in their respective models, the agencies report the ranges for the effectiveness values used in each model, as well as the reasons why the range is reasonable. There were only a few comments on technology effectiveness. For the most part, the non-confidential comments were consistent with the range of effectiveness reported in this rule. Where there were differences, EPA and NHTSA did not see sufficient evidence to warrant a change in the technology effectiveness. Further details can be found in EPA's Response to Comments document (section 4.4) and Chapter V of NHTSA's FRIA.

3.3.2.1.1 **Technology synergies**
The benefits of these technologies are generally but not always additive. That is, adding cylinder deactivation to dual cam phasing does not necessarily result in a 10 percent improvement. This is true because some of the technologies address the same

shortcomings of the internal combustion engine, although in different ways. Where that is the case, negative (or dis-) synergies are said to exist between two (or more) technologies. It is also true that combining some technologies can provide more benefit than a simple additive effect. In those cases, positive synergies are said to exist. The analysis accounts for these positive and negative synergies wherever appropriate so as to ensure no double or insufficient counting of effects. Synergies are discussed in more detail in each agency's respective final RIA.

3.3.2.2 Technology Cost Considerations

As a general matter, NHTSA and EPA believe the best way to derive technology cost estimates is to conduct real-world tear down studies. This position is supported by commenters and we received no comments to the contrary.[a] These studies are based to a large degree on tear downs of vehicles or vehicle systems that employ the new technologies, and of similar vehicles or systems without the new technologies. Analysts with expertise in automotive design, materials, and manufacturing then compare the tear down components and evaluate the differences. Using databases for materials, labor, manufacturing overhead, and mark-up costs, the overall costs to manufacture individual parts are calculated and summed into final results. However, as such, tear down studies require a significant amount of time and are very costly. EPA has begun conducting tear down studies to assess the costs of 4-5 technologies under a contract with FEV Inc., an independent engine and powertrain systems research, design and development company. To date, four technologies (downsizing and turbocharging, stoichiometric gasoline direct-injection, dual clutch transmission and 6-speed automatic transmission) have been evaluated. The tear down study has been peer-reviewed and the report for these tear down studies and the peer-review report have been made public in the rulemaking docket.[11] The agencies have considered these studies and the comments received on them, as practicable and appropriate, in developing technology cost assumptions for this final rule.

These recently completed tear-downs include the following technologies:

1. 3.0L V6 port fuel-injected (PFI) downsized and turbocharged to a 2.0L I4 gasoline direct injection (GDI)
2. 5.4L V8 PFI downsized and turbocharged to a 3.0L V6 twin-turbo GDI
3. 5-speed automatic transmission to 6-speed automatic transmission
4. 6-speed automatic transmission to 6-speed wet dual-clutch transmission

A comparison between costs reported in the NPRM and the final rule can be found in Table 3-1 below.

Table 3-1 A comparison of NPRM costs and the final rule for five updated technologies ($2007 in 2012).

Technology	Incremental To	NPRM Direct	Final Rule Direct	Change

---

[a] See comments from ICCT (EPA-HQ-OAR-2009-0472-7156), CARB (EPA-HQ-OAR-2009-0472-7189), NESCAUM (EPA-HQ-OAR-2009-0472-7235)

		Manufacturing Cost	Manufacturing Cost	
2.0L I4 Turbo GDI	3.0L V6 MPFI	$248	$152	-$96
3.0L V6 twin-turbo GDI	5.4L V8 MPFI	$1,081	$964	-$117
5-speed auto trans	4-speed auto trans	$91	$91	$0
6-speed auto trans	4-speed auto trans	$153	$101	-$52
6-speed auto trans	5-speed auto trans	$62 *	$9	-$53
6-speed dual-clutch trans (wet)	6-speed auto trans	$126	-$11	-$137

* Calculated as the difference between the 4 to 6 speed trans ($153) and the 4 to 5 speed trans ($91).

Most notable in Table 3-1 is the change in costs for the 6-speed dual-clutch transmission relative to the 6-speed automatic transmission. We discuss this change in more detail in section 3.4.2.2.5, FEV's tear down work found that a wet clutch DCT is $147 less costly than a 6 speed auto transmission (see table 3-15). This cost savings is not unexpected when one considers that the DCT is less complex than an auto transmission. However, FEV tear down cost analysis studies were conducted based on the assumption that the analyzed technologies and the manufacturing for those technologies were both fully "mature," in that designs and manufacturing processes have been reasonably optimized. The studies also assumed that manufacturing facilities have annual production levels of 450,000 units. EPA and NHTSA recognize that in early implementation years, designs and manufacturing processes may not be optimized to that extent, and investment cost may exceed those of fully mature technologies. To account for higher cost in the earlier implementation years of the rulemaking period, NHTSA and EPA estimated MY 2012 costs as the average of the FEV tear down study cost and the NPRM cost for technologies for which there were completed FEV tear down studies. Time-based learning is used to reflect cost in later years. This approach is applied to downsizing and turbocharging for V6 and V8, stoichiometric gasoline direct-injection for V6 and V8, dual clutch transmission and 6-speed automatic transmission. In the NPRM, the costs for turbocharging, downsizing and SGDI for I4 engines were based on an FEV teardown cost study that was completed prior to release of the NPRM. For the final rule, these costs were carefully reviewed and updated to better account for early year implementation costs. We discuss all of the costs presented in Table 3-1 in greater detail in section 3.4.2 of this joint TSD.

Regarding the other technologies, because tear down studies were not yet available, the agencies decided to continue the BOM approach as outlined in NHTSA's MY 2011 final rule and EPA's 2008 Staff Report. This approach was recommended to NHTSA by Ricardo, an international engineering consulting firm retained by NHTSA to aid in the analysis of public comments on its proposed standards for MYs 2011-2015 because of its expertise in the area of fuel economy technologies. A BOM approach is similar in concept to the approach used in tear down studies. The difference is that under a BOM approach, the build up of cost estimates is conducted based on a review of cost and effectiveness estimates for each component from available literature. To the extent that the agencies departed from the MY 2011 CAFE final rule and the 2008 Staff Report estimates, the agencies have explained the reasons and provided supporting analyses. For example, while NHTSA and Ricardo engineers had relied considerably in the MY 2011

final rule on the 2008 Martec Report for costing contents of some technologies, upon further joint review and for purposes of the MY 2012-2016 standards, the agencies decided that some of the costing information in that report was no longer accurate due to downward trends in commodity prices since the publication of that report. The agencies reviewed, revalidated or updated cost estimates for individual components based on new information.

The subsequent sections describe the costs associated with the new vehicle technologies. The costs represent the piece costs for an individual piece of hardware or system, *e.g.*, an intake cam phaser to provide variable valve timing. Costs are presented in terms of their hardware incremental compliance cost. This means that they include all potential costs associated with their application on vehicles, not just the cost of their physical parts. As discussed, the basis for the piece costs presented here is NHTSA's MY 2011 CAFE final rule and EPA's 2008 Staff Report.[12,1] In those analyses, piece costs were estimated based on a number of sources for cost related information. The objective was to use those sources of information considered to be most credible for projecting the costs of individual vehicle technologies. As a result of almost daily meetings between EPA and NHTSA staff during 2009, where both piece costs and fuel consumption efficiencies were discussed in detail, cost estimates have been adjusted slightly. Where estimates differ between sources, engineering judgment was used to arrive at what is believed to be the best cost estimate available today, and explained the basis for that exercise of judgment.

Note that EPA's 2008 Staff Report presented costs in terms of 2006 dollars. For this analysis, costs are expressed in terms of 2007 dollars. Any costs presented here that are based on costs expressed in 2006 dollars have been adjusted to reflect 2007 dollars using the Gross Domestic Product price deflator (see Appendix 3.A).[13,b] The following discussion summarizes the piece cost estimates and how these data sources were used to arrive at the best estimate of piece costs for individual technologies, as well as their respective effectiveness estimates. For purposes of this joint TSD, these estimates were developed jointly by NHTSA and EPA. Due to differences in the modeling and technology application methodologies employed by the two agencies, the estimates used by each agency may not match exactly but will be consistent given the different modeling tools used. Additional details are also provided in each agency's respective final RIAs.

3.3.2.2.1 Direct manufacturing costs

Building on NHTSA's estimates developed for the MY 2011 CAFE final rule and EPA's Advanced Notice of Proposed Rulemaking, which relied on the 2008 Staff Technical Report,[1] the agencies took a fresh look at technology cost and effectiveness values for purposes of the joint final rule under the National Program. 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 generally followed a bill of materials (BOM) approach as noted above. A bill of materials, in a general sense, is a list of components that make up a system—in this case, an item of fuel economy-

---

[b] The adjustment used to convert from 2006 dollars to 2007 dollars was 1.03.

improving technology. In order to determine what a system costs, one of the first steps is to determine its components and what they cost.

NHTSA and EPA estimated these components and their costs based on a number of sources for cost-related information. The objective was to use those sources of information considered to be most credible for projecting the costs of individual vehicle technologies. As discussed above, the agencies reviewed, revalidated or updated cost estimates for individual components based on new information. Thus although NHTSA and EPA found that much of the cost information used in NHTSA's MY 2011 CAFE final rule and EPA's staff report was consistent, the agencies, in reconsidering information from many sources (such as the new FEV cost studies), ultimately revised several component costs of several major technologies (turbocharging downsizing, mild and strong hybrids, diesels, SGDI, Valve Train Lift Technologies, DCT and 6-speed automatic transmissions).[14] These are discussed at length below. For turbocharging downsizing, SGDI, DCT and 6-speed automatic transmission, the agencies relied, to the extent possible, on the tear down data available and scaling methodologies used in EPA's ongoing study with FEV. As discussed above in detail in Section 3.3.2.2, 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.[15] The confidential information provided by manufacturers under their product plan submissions to the agencies or discussed in meetings between the agencies and the manufacturers and suppliers served largely as a check on publicly-available data.

Once costs were determined, they were adjusted to ensure that they were all expressed in 2007 dollars using the GDP price deflator as described in Appendix 3.A. Indirect costs were accounted for using a new approach developed by EPA for this rulemaking and explained below rather than using the Retail Price Equivalent (RPE) multiplier of 1.5 as was done in NHTSA's MY 2011 final rule and EPA's 2008 Staff Report. NHTSA and EPA also considered how costs should be adjusted to reflect manufacturer learning as discussed below. Lastly, costs were 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, although these adjustments were different for each agency due to the different vehicle subclasses used in their respective models.

3.3.2.2.2 **Cost markups to account for indirect costs**
Indirect costs include production-related costs (research, development, and other engineering), business-related costs (corporate salaries, pensions, and manufacturer profits), and retail-sales-related costs (dealer support, marketing, and dealer profits). For this analysis, direct cost estimates were first developed for each technology or system at the auto manufacturer level, *i.e.*, the price paid by the manufacturer to a Tier 1 component supplier. To these costs, an indirect cost markup factor was then applied that varied by the best estimate of the particular technology's complexity. This section describes the approach to determining the indirect cost multipliers (ICM) used in this analysis and the specific multipliers used for each piece of technology.

3.3.2.2.3 **Concept behind and development of indirect cost multipliers**

If all desirable data were available, when a new technology is implemented, the costs of that technology would include the direct and indirect costs particular to that technology. For instance, some changes may involve new tooling, while others may not; some may affect the way the car is marketed, while others are of limited interest to consumers. In a world of full information, the indirect costs of a new technology would be calculated specifically for that technology. In practice, though, it is often difficult, if not impossible, to identify the indirect costs specific to a particular new technology.

The automotive industry, EPA, and NHTSA have commonly used retail price equivalent (RPE) multipliers to approximate the indirect costs associated with a new technology. The RPE is a ratio of total revenues to direct manufacturing costs. Because, by definition, total revenues = direct costs + indirect costs + profit, the RPE is the factor that, when multiplied by direct manufacturing costs, recovers total revenue.[c] This multiplication is accurate only in the aggregate; it does not in reality apply to any specific technology. The RPE is a way to estimate indirect costs on the assumption that indirect costs are constant across all technologies and processes in a company. In the MY 2011 CAFE final rule NHTSA utilized a 1.5 RPE multiplier.

In fact, however, the indirect costs of new technologies vary, both with the complexity of the technology and with the time frame. For instance, a hybrid-electric engine is likely to involve greater research and development and marketing costs per dollar of direct costs than low-rolling-resistance tires; the research and development costs of any technology are likely to decrease over time. In recognition of this concern, EPA contracted with RTI International to provide a current estimate of the RPE multiplier and to examine whether the indirect costs of new technologies are likely to vary across technologies. The report "Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers," by Alex Rogozhin, Michael Gallaher, and Walter McManus,[16] calculates the RPE multiplier as 1.46 in 2007. The report then develops indirect cost (IC) multipliers that vary with the complexity of technology and the time frame. While any multiplier is only an approximation of the true indirect costs of a new technology, the IC multipliers in this report move away from the assumption that the proportion of indirect costs is constant across all technologies and take into account some of the variation in these costs. The multipliers developed in this report are presented in Table 3-2.

The indirect cost multipliers used adjustment factors, developed by a team of EPA engineers with expertise in the auto industry, which accounted for the differences in complexity of the specific technologies under study. To examine the sensitivity of the results to different technologies of the same complexity, and to provide more detailed documentation of the development of the adjustment factors, EPA convened a second panel,[17] with NHTSA's input, to develop adjustment factors for three different technologies. This latter process allowed for estimates of the variation in adjustment

---

[c] Note that unlike the RPE, the ICM does not include profits.

factors, and thus in the variation of indirect cost multipliers. These results are also presented in Table 3-2.

Table 3-2 Indirect Cost Multipliers

STUDY	TECHNOLOGY COMPLEXITY					
	Short Run			Long Run		
	Low	Medium	High	Low	Medium	High
RTI Report	1.05	1.20	1.45	1.02	1.05	1.26
EPA Memo: Average	1.16	1.29	1.64	1.12	1.20	1.39
Standard Deviation	0.14	0.15	0.21	0.14	0.13	0.15
Median	1.12	1.26	1.66	1.06	1.20	1.40
Max	1.43	1.53	2.15	1.42	1.45	1.69
Min	1.00	1.02	1.37	1.00	1.01	1.12
Multipliers Used in this Analysis	1.11	1.25	1.45 1.64	1.07	1.13	1.26 1.39

Table 3-2shows minor differences in the multipliers for low- and medium-complexity technologies (roughly 0.1), but larger differences in the high-complexity technologies. The EPA and NHTSA engineers who reviewed the results believed that the differences reflected actual differences in the technologies under study. In particular, for low complexity, low-rolling-resistance tires (the application in the RTI Report) would involve lower indirect costs than aerodynamic improvements (the application in the EPA memo); and, for medium complexity, dual-clutch transmissions (the application in the RTI Report) should have a smaller multiplier than engine downsizing done in conjunction with turbocharging (the application in the EPA Memo). For these two cases, EPA and NHTSA considered these technologies to span the range of technologies assigned to those classes; the costs in this study, then, use the averages of the values of the two reports, as shown in the last line of Table 3-2. For high complexity technologies, the agencies felt the technologies assigned to these categories—hybrid-electric vehicles in the RTI Report; plug-in hybrid electric vehicles in the EPA Memo—were sufficiently different that each deserved a different category. This is discussed in more detail in the next section which highlights the multipliers used for each specific technology.

3.3.2.2.3.1 Application of specific indirect cost multipliers to each technology

As noted in the previous section, and in the NPRM, a different ICM was applied to each technology's direct cost to arrive at its compliance cost. These different ICMs were chosen based on the complexity of integrating the technology into the vehicle in the opinions of staff engineers at EPA and NHTSA, most of whom have several years of experience in the auto industry. As shown in Table 3-2, ICMs were developed via two separate processes: that presented in the RTI report; and that presented in the EPA Memo. While all of the ICMs generated via these two processes were in general agreement, some differences did exist. In determining how to deal with these differences, EPA and NHTSA agreed that, for the low and medium complexity technologies, a simple

average of the two values would be used. However, for the high complexity technologies, it was decided that two separate high-multipliers should be used. The lower multiplier, deemed high, would be applied to those technologies of high complexity but with some level of use in the marketplace today. Such technologies would be power-split and 2-mode hybrid electric vehicles. The higher multiplier, deemed high+, would be applied to those technologies of high complexity but with no, or essentially no, use in the current fleet. Such technologies would be plug-in hybrids and full electric vehicles. Table 3-3 shows the complexity level for each technology considered in this analysis.

Table 3-3 Complexity Levels of Technologies

LOW COMPLEXITY	MEDIUM COMPLEXITY	HIGH COMPLEXTIY	HIGH+ COMPLEXITY
Low friction lubes	VVLT-continuous (OHV)	VVLT-continuous (OHC)	Plug-in hybrid
Engine friction reduction	VVLT-discrete (OHV)	Camless valve actuation	Full electric vehicle
VVT-intake (OHC)	GDI-lean burn	Homogeneous charge CI	
VVT-coupled (OHC & OHV)	Turbocharge with downsize	Weight reduction – 30%	
VVT-dual (OHC)	Conversion to diesel	Integrated motor assist hybrid	
Cylinder deactivation (OHC & OHV)	Dual clutch transmission	2-mode hybrid	
VVLT-discrete (OHC)	Continually variable trans	Power-split hybrid	
GDI-stoich	42 Volt conversion		
Turbocharge (with no downsize)	Weight reduction – 20%		
Downsize (with no turbocharge)	Integrated starter generator (stop-start)		
Cam configuration changes (with no downsize)	Combustion restart		
Aggressive shift logic	Cooled EGR/EGR boost		
Early torque converter lockup			
5-speed auto transmission			
6-speed auto transmission			
6-speed manual transmission			
Improved accessories			
Electric power steering			
Low rolling resistance tires			
Low drag brakes			
Secondary axle disconnect			
Improved aerodynamics			
Weight reduction – 3%			
Weight reduction – 5%			
Weight reduction – 10%			
A/C Leakage Reduction			
A/C Efficiency Improvement			

The estimates of vehicle compliance costs cover the years of implementation of the program – MYs 2012 through 2016. In EPA's analysis, compliance costs have also been estimated for the years following implementation to shed light on the long term – 2022 and later – cost impacts of the rule. The year 2022 is used by EPA because the short-term and long-term markup factors described above are applied in five year increments with the 2012 through 2016 implementation span and the 2017 through 2021 span both representing the short-term.

Commenters in general agreed with this methodology for determining indirect cost multipliers, though there was some disagreement as to the magnitude of the multipliers.

3.3.2.2.4 Cost reduction through manufacturer learning

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.[18] 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).[19]

NHTSA has a detailed description of the learning effect in the MY 2011 CAFE final rule, and EPA has a detailed description of the learning effect in the 2008 Staff Report and in several past rules.[20] The description here is focused on how the learning effect has been used in the analyses support each agency's rule.

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 factor of 20 percent for each doubling of production volume. NHTSA has used this approach in analyses supporting recent CAFE rules. In its analysis, 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 MY 2011 CAFE final rule, NHTSA considered not only this volume-based learning as described above, but also "time-based" learning. Time-based learning, estimated by NHTSA at three percent per year, occurs in years following the volume-

based learning steps and represents the smaller scale learning that occurs as manufacturers continue to innovate. The time-based learning is, in effect, represented by the flattened out, asymptotic portion of the learning curve.

For this analysis, each agency has employed both volume-based and time-based learning effects. In NHTSA's analysis, volume-based learning is estimated to result in 20 percent lower costs as production volumes of the given technology reach 300,000 units and again when they reach 600,000 units within the entire industry. The count of production units begins in the 2012 model year and/or with the first units produced, whichever is earlier. In EPA's analysis, as noted above, volume-based learning is estimated to result in 20 percent lower costs after two full years of implementation (*i.e.*, the 2014 MY costs are 20 percent lower than the 2012 and 2013 model year costs). In each agency's analysis, time-based learning is estimated to result in 3 percent lower costs in each year following first introduction of a given technology. Once two volume-based learning steps have occurred, or once the five year time-based learning period is completed, learning is assumed to be complete, at least for purposes of the analyses done to support each agency's rule.

Both agencies considered learning impacts on most but not all of the technologies expected to be used because some of the expected technologies are already used rather widely in the industry and, presumably, learning impacts have already occurred. Volume-based learning was considered for only a handful of technologies that are considered to be new or emerging technologies such as the hybrids and electric vehicles. Most technologies have been considered to be more established given their current use in the fleet and, hence, the lower time-based learning has been applied. The learning effects applied to each technology are summarized in Table 3-4.

Table 3-4 Learning Effects Applied to Each Technology

TECHNOLOGY	LEARNING EFFECT
Low friction lubricants	None
Engine friction reduction	None
VVT – intake cam phasing	Time
VVT – coupled cam phasing	Time
VVT – dual cam phasing	Time
Cylinder deactivation	Time
Discrete VVLT	Time
Continuous VVLT	Time
GDI – stoichiometric	Time
GDI – lean burn	Time
Turbocharge (with no downsize)	Time
Downsize (with no turbocharge)	Time
Turbocharge with downsize	Time
Cam configuration changes (with no downsize)	Time
Homogeneous charge CI	Time
Conversion to diesel	Time
Aggressive shift logic	Time
Early torque converter lockup	Time
5-speed automatic	Time
6-speed automatic	Time
6-speed DCT – dry clutch	Time
6-speed DCT – wet clutch	Time
6-speed manual	Time
CVT	Time
Stop-Start	Volume
IMA/ISA/BSG (includes engine downsize)	Volume
2-Mode hybrid electric vehicle	Volume
Power-split hybrid electric vehicle	Volume[d]
Plug-in hybrid electric vehicle	Volume
Full electric vehicle	Volume
Improved high efficiency alternator & electrification of accessories	Time
Upgrade to 42 volt electrical system	Time
Electric power steering (12 or 42 volt)	Time
Aero drag reduction (20% on cars, 10% on trucks)	Time
Low rolling resistance tires	None
Low drag brakes (ladder frame only)	None
Secondary axle disconnect (unibody only)	None
Front axle disconnect (ladder frame only)	Time
A/C Leakage Reduction	Time
A/C Efficiency Improvements	Time

Table 3-25 through Table 3-30 show Volpe model costs and effectiveness values for each particular technology described throughout this chapter. The costs shown are applicable for the 2012 model year. The Volpe Model handles learning effects within the model itself so that individual technology costs in the 2016 model year would be lower than those shown in the tables.

Table 3-31 through Table 3-40 show OMEGA model costs and effectiveness values for each particular technology described throughout this chapter. The costs shown are applicable for the 2016 model year and, therefore, represent fully learned costs in the

---

[d] Due to an error, the NPRM showed this as time-based learning.

context of EPA's analysis. For technologies added in years prior to MY 2016, EPA has backed out the learning effects relative to the costs shown in the tables. For example, Table 3-33 shows the small car stop-start vehicle cost as $351 in 2016. In the 2012 model year, this cost would be higher since the volume-based learning reflected in the 2016 cost would not have occurred yet. Backing out two volume-based learning steps (*i.e.*, dividing $351 by 80% twice) would result in a 2012 cost estimate of $548.

The different handling of learning effects across the two analyses (that done by EPA and that by NHTSA) would have little impact on the overall results of the analyses. NHTSA handles learning effects in the CAFE model. EPA handles learning effects outside of the OMEGA model since OMEGA is run for only one model year - 2016. Because the CAFE model adds technology on a year-by-year basis, it applies volume-based learning effects once the applicable production volume thresholds have been exceeded. In contrast, EPA would not apply volume-based learning until year 3 (assumed to be the point at which initial production volumes have doubled). Most technologies in both analyses are subject to time-based learning which is applied on an annual basis in the same way by both agencies (with the exception that NHTSA applies time-based learning in the CAFE model while EPA applies it outside the OMEGA model). Importantly, by the 2016 model year, both agencies will have applied two volume-based learning steps to the appropriate technologies (hybrid and electric vehicles only) and four time-based learning steps to the appropriate technologies (most other technologies) to arrive at the same technology costs.

3.4 Specific technologies considered and estimates of costs and effectiveness

It is important to note that the cost and effectiveness values presented by NHTSA and EPA in this Final TSD are used when creating input files for the agencies' respective models, but are not literally the inputs themselves. The Docket to this final rule contains the specific input files EPA and NHTSA used when modeling the technology cost.

3.4.1 What data sources did the agencies evaluate?

Refer to section 3.1 for a discussion of the specific data sources and reference material used for the analysis of this rulemaking.

3.4.2 Individual technology descriptions and cost/effectiveness estimates

The sections that follow describe the technologies applied by both EPA and NHTSA. It is important to note that there are distinct differences between the agencies in how cost and effectiveness estimations are reported and applied.

EPA reports the total cost and effectiveness associated with a respective technology. The technologies are then applied to a vehicle type as a package. To calculate a cost for a vehicle package, the individual technologies are summed. To estimate the overall effectiveness, the lumped parameter method is applied.

NHTSA applies cost and effectiveness through a series of decision trees. The progressive nature of this methodology results in conditions for which a portion of a technology has already been added. In this case, NHTSA would add an incremental value which is the difference between the total cost of a technology and the portion already existing. An example of this is cylinder deactivation. At the point in the decision tree that it is applied, valvetrain technologies which could enable this feature have already been added. NHTSA will add the delta in cost, which in this example accounts for the NVH attributes.

3.4.2.1 Engine Technologies

NHTSA and EPA have reviewed the engine technology estimates used in NHTSA's MY 2011 CAFE final rule and EPA's 2008 Staff Report and available comments to the NPRM. In doing so NHTSA and EPA reconsidered all available sources and updated the estimates as appropriate. The section below describes each of the engine technologies considered for this rulemaking.

3.4.2.1.1 *Low Friction Lubricants (LUB)*

One of the most basic methods of reducing fuel consumption in gasoline 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 will also improve the effectiveness of valvetrain technologies such as cylinder deactivation, which rely on a minimum oil temperature (viscosity) for operation.

Several manufacturers have previously commented confidentially, that low friction lubricants could have an effectiveness value between 0 to 1 percent. For purposes of this final rule, NHTSA and EPA are using effectiveness estimates within this range. Therefore 0.5 percent was used in both models.

The 2002 NAS study estimated the low friction lubricant RPE at $8 to $11 using a 1.4 markup factor. The NESCCAF study showed an RPE of $5 to $15 with a 1.4 markup. The EEA report to DOE showed manufacturer costs of $10 to $20 with no markup. Confidential Business Information (CBI) data estimates an average incremental cost of $3 for the use of low friction lubricants. EPA's 2008 Staff Report also confirms this $3 cost (2006$). Both NHTSA and EPA believe that manufacturer's estimates are

the most accurate, and thus continue to believe that the $3 cost estimate is appropriate and independent of vehicle class since the engineering work required should apply to any engine size. Applying an indirect cost multiplier (ICM) of 1.11, for a low complexity technology, results in a compliance cost of $3 per vehicle (2007$) for a MY 2012 through MY 2016 vehicle (learning effects are not applied to low friction lubes).[e]

3.4.2.1.2 *Engine Friction Reduction (EFR)*

In addition to low friction lubricants, manufacturers can also 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.[21] 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 economy improvement. The 2002 NAS, NESCCAF and EEA reports as well as confidential manufacturer data suggested a range of effectiveness for engine friction reduction to be between 1 to 3 percent. NHTSA and EPA continue to believe that this range is accurate. Because of the incremental nature of the CAFE model, NHTSA needed to continue to use the narrower range of 1-2 percent, which was also used in the MY 2011 CAFE final rule.

In the MY 2011 CAFE final rule, NHTSA estimated a range from $13 to $49 using a 1.5 RPE on a per cylinder basis, or $9 to $33 without RPE (2007$). In the 2008 NPRM engine friction reduction was estimated to cost up to $14 without RPE on a per cylinder basis (2006$). EPA's 2008 Staff Report estimated this at $11 using a 1.5 RPE on a per cylinder basis, or $7 without RPE (2006$). After review, NHTSA and EPA believe that the cost estimate is closer to the lower end of the MY 2011 CAFE final rule range and thus for this rulemaking is $13 per cylinder compliance cost (2007$), including the low complexity ICM markup value of 1.11, for a MY 2012 through MY 2016 vehicle (learning effects are not applied to engine friction reduction). This cost is multiplied by the number of engine cylinders.

3.4.2.1.3 *Variable Valve Timing (VVT)*

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 an optimum needed to sustain horsepower and torque. VVT can also improve volumetric efficiency at higher engine speeds and loads. Additionally, VVT can be used

---

[e] Note that the costs developed for low friction lubes for this analysis reflect the costs associated with any engine changes that would be required as well as any durability testing that may be required.

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 MY 2007, over half of all new cars and light trucks had engines with some method of variable valve timing.[22] Manufacturers are currently using many different types of variable valve timing, which have a variety of different names and methods. The three major types of VVT are listed below.

Each of the three 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.

3.4.2.1.3.1 Intake Cam Phasing (ICP)

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.

NHTSA's MY 2011 CAFE final rule and EPA 2008 Staff Report estimated an effectiveness of 1 to 2 percent for ICP, which was supported by the NESCCAF report and a majority of confidential manufacturer comments. The agencies have found no additional sources to suggest strongly that this estimate is inaccurate, and so have employed it for this rulemaking.

As for costs, NHTSA's MY 2011 CAFE final rule estimated a $61 RPE ($41 non-RPE) cost per cam phaser, based on the 2008 Martec Report and confidential manufacturer data (2007$). In the 2008 staff report, EPA estimated this at $59 using a 1.5 RPE or $40 without RPE (2006$). NHTSA and EPA believe that this estimate remains accurate. Using the new indirect cost multiplier of 1.11, for a low complexity technology, the compliance cost per cam phaser would be $45 per bank , yielding a $45 cost for and in-line engine configurations and $90 for V-engine configurations for a MY 2012 vehicle (2007$). Time-based learning is applied to ICP so the MY 2016 cost would be $40 for in in-line engine and $80 for the V-engine (2007$).

3.4.2.1.3.2 Coupled Cam Phasing (CCPS and CCPO)

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 a single overhead cam (SOHC) engine or an overhead valve (OHV) engine.[f] For overhead

---

[f] Although CCP appears only in the SOHC and OHV branches of the decision tree, it is noted that a single phaser with a secondary chain drive would allow CCP to be applied to DOHC engines. Since this would

cam engines, this requires the addition of a cam phaser on each bank of the engine. Thus, an in-line 4-cylinder engine has one cam phaser, while SOHC V-engines have two cam phasers. For overhead valve (OHV) engines, which have only one camshaft to actuate both inlet and exhaust valves, CCP is the only VVT implementation option available and requires only one cam phaser.[g]

Based on NHTSA's MY 2011 CAFE final rule, previously-received confidential manufacturer data, and the NESCCAF report, NHTSA and EPA estimated the effectiveness of CCP to be between 1 to 4 percent. NHTSA and EPA reviewed this estimate for purposes of the final rule, and continue to find it accurate.

The same cam phaser has been assumed for ICP and CCP applications, thus CCPs cost per cam phaser is identical to ICPs. This results in a cost of $45 for in-line SOHC and OHV engines and $90 for SOHC V-engine configurations for a MY 2012 vehicle (2007$). With time-based learning applied, these costs for a 2016 MY vehicle would be $40 and $80, respectively (2007$).

3.4.2.1.3.3 Dual Cam Phasing (DCP)

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/reduced CO_2 emissions. Increased internal EGR also results in lower engine-out NO_X emissions. The amount by which fuel consumption is improved and CO_2 emissions are reduced 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.

NHTSA MY 2011 CAFE final rule estimated the effectiveness of DCP to be between 3 to 5 percent relative to a base engine or 2 to 3 relative to an engine with ICP. NHTSA and EPA believe that this estimate remains applicable for the final rule.

As above, the same cam phaser has been assumed for ICP and DCP applications. Thus, DCP's cost per cam phaser is identical to ICP's. DCP requires two cam phasers per cylinder bank, one to control the intake valves and one to control the exhaust valves. This results in a cost of $90, relative to an engine without ICP, or $45 relative to an engine with ICP, minus $6 for the removal of the EGR valve, ultimately yielding costs of $84 and $39 respectively for in-line DOHC configurations (all in 2007$). For V-configuration engines, the cost is $180 relative to an engine without ICP, or $90 relative to an engine with ICP, minus $6 for the removal of the EGR valve, ultimately yielding

---

potentially be adopted on a limited number of DOHC engines NHTSA did not include it in that branch of the decision tree.

[g] It is also noted that coaxial camshaft developments would allow other VVT options to be applied to OHV engines. However, since they would potentially be adopted on a limited number of OHV engines NHTSA did not include them in the decision tree.

costs of $174 and $84, respectively (all in 2007$). These costs are appropriate for a MY 2012 vehicle. With time-based learning applied, these costs for a 2016 MY vehicle would be $157 and $73, respectively (2007$).

3.4.2.1.4 *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:

3.4.2.1.4.1 Discrete Variable Valve Lift (DVVLS, DVVLD, DVVLO)

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.

NHTSA's MY 2011 CAFE final rule, previously-received confidential manufacturer data, and the NESCCAF report, all estimate the effectiveness of DVVL to be between 1 to 4 percent above that realized by VVT systems. NHTSA and EPA believe this estimate continues to be applicable for the final rule.

In the MY 2011 CAFE final rule, NHTSA estimated an RPE (1.5 markup factor) of $201 for an inline 4-cylinder engine, $306 for a V6 engine and $396 for a V8 engine or without the RPE markup $134, $204, $264, respectively (all in 2007$). In the 2008 Staff Report, EPA estimated this at $169, $246, and $322, respectively, using a 1.5 RPE factor (2006$) or $113, $164 and $215, respectively without markup (all in 2006$). For this analysis, the agencies have estimated the compliance costs, including $25 for controls and using a 1.11 ICM for a low complexity technology, at $141 for an inline 4-cylinder engine, $205 for a V6 engine and $293 for a V8 for a 2012 MY vehicle (2007$). With time-based learning applied, these costs would be $125, $181, and $259, respectively for a 2016 MY vehicle (2007$).

3.4.2.1.4.2 Continuously Variable Valve Lift (CVVL)

In CVVL systems, valve lift is varied by means of a mechanical linkage, driven by an actuator controlled by the engine control unit. The valve opening and phasing vary as the lift is changed and the relation depends on the geometry of the mechanical system. BMW has considerable production experience with CVVL systems and has sold port-injected "Valvetronic" engines since 2001. CVVL allows the airflow into the engine to be regulated by means of intake valve opening reduction, which improves engine efficiency by reducing pumping losses from throttling the intake system further upstream as with a conventionally throttled engine.

Variable valve lift gives a further reduction in pumping losses compared to that which can be obtained with cam phase control only, with CVVL providing greater effectiveness than DVVL, since it can be fully optimized for all engine speeds and loads, and is not limited to a two or three step compromise. There may also be a small reduction in valvetrain friction when operating at low valve lift, resulting in improved low load fuel consumption for cam phase control with variable valve lift as compared to cam phase control only. Most of the fuel economy effectiveness is achieved with variable valve lift on the intake valves only. CVVL is only applicable to double overhead cam (DOHC) engines.

NHTSA's MY 2011 CAFE final rule estimated the effectiveness for CVVL at 1.5 to 3.5 percent over an engine with DCP, but also recognize that it could go up as high as 5 percent above and beyond DCP to account for the implementation of more complex CVVL systems such as BMW's "Valvetronic" engines. This coincides with EPA Staff Report estimates of the contribution of CVVL, which were based on the NESCCAF report, in which CVVL could improve effectiveness by 4 percent (minivans) and up to 6 percent (large cars) over dual cam phasing. Thus, the effectiveness range for CVVL in this joint TSD ranges from 1.5 to 6 percent depending on the complexity level of the application. However, due to the complexity and cost of this technology, the GHG model did not consider it and the CAFE model projected no application of the less complex version of this technology. The most recent submission of manufacturers' product plans confirmed that this technology will not be applied by most manufacturers.

In the MY 2011 CAFE final rule, NHTSA estimated and RPE (1.5 factor) of continuously variable valve lift to be $306 for an inline 4-cylinder engine, $432 for a V6 engine and $582 for a V8 engine or without RPE $204, $287, $388, respectively. In the 2008 Staff Report, EPA estimated this at $254, $466, and $508, respectively, using a 1.5 RPE factor (2006$) or $169, $311 and $339, respectively without markup (all in 2006$) For this analysis, the agencies have estimated the compliance costs, using a 1.45 ICM for a high complexity technology, at $277 for an inline 4-cylinder engine, $509 for a V6 engine and $554 for a V8 engine for a MY 2012 vehicle (2007$). With time-based learning applied, these costs would become $245, $449, and $489, respectively for a MY 2016 vehicle (2007$).

3.4.2.1.5 *Cylinder Deactivation (DEACS, DEACD, DEACO)*

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 (DEAC) 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 NVH concerns and to allow a greater operating range of activation. Manufacturers have stated that use of DEAC on 4 cylinder engines would cause unacceptable NVH; therefore cylinder deactivation has not been applied to 4-cylinder engines.

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. Honda (Odyssey, Pilot) offers V6 models with cylinder deactivation.

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.

NHTSA and EPA reviewed the MY 2011 CAFE final rule estimate and confirmed a range of 0.5 to 6 percent depending on the valvetrain configuration and other existing technologies. The OMEGA model, which is based on packages, applies 6 percent reduction in CO_2 emissions in all applications. The CAFE model, due to its incremental nature, uses a range depending on the engine valvetrain configuration. For example, for DOHC engines which are already equipped with DCP and DVVLD, there is little benefit that can be achieved from adding cylinder deactivation since the pumping work has already been minimized and internal Exhaust Gas Recirculation (EGR) rates are maximized, so the effectiveness is only up to 0.5 percent for DEACD. For SOHC engines which have CCP and DVVLS applied, effectiveness ranged from 2.5 to 3 percent for DEACS. For OHV engines, without VVT or VVL technologies, the effectiveness for DEACO ranged from 3.9 to 5.5 percent.

NHTSA and EPA considered a range of $170 to $190 (or $28 to $190 depending on whether an engine already has lost motion devices, oil control valves and camshaft position sensors). This is a departure from NHTSA's MY 2011 CAFE final rule, which used a range of $306 to $400. That range was primarily based on the 2008 Martec Report and applied a higher RPE value. In reviewing these assumptions, NHTSA and EPA amended the MY 2011 CAFE final rule estimates and adjusted the estimates to include the new ICM low complexity markup of 1.11. The EPA Staff Report estimated this ranging from $203 to $229 (RPE using a 1.5 factor) or $135 to $153 without RPE (2006$). NHTSA's MYs 2011-2015 NPRM showed estimates of a $170 for a 6-cylinder engine and $190 for an 8-cylinder engine—when adjusted for 2007 dollars and using the new ICM multipliers— for engines that do not have lost motion devices. These numbers were within the ranges described by the 2002 NAS and NESCCAF reports. The $170 and $190 costs are appropriate of a MY 2012 vehicle (2007$). With time-based learning applied, these would become $150 and $169, respectively, for a MY 2016 vehicle (2007$).

If lost motion devices are on the engine, the cost of DEAC as applied to SOHC and DOHC engines could be as low as $28.[h] This $28[i] accounts for the potential additional application of active engine mounts on SOHC and DOHC engines and can only be applied on 50 percent of the vehicles. Further, this SOHC and DOHC engine estimate is relevant to the CAFE model only because the OMEGA model does not apply technologies in the same incremental fashion as the CAFE model.

3.4.2.1.6 *Conversion to Double Overhead Camshaft Engine with Dual Cam Phasing (CDOHC)*

Double overhead camshaft engines achieve increased airflow at high engine speeds, improve volumetric efficiency and reductions of the valvetrain's moving mass. Such engines typically develop higher power at high engine speeds. Manufacturers may choose to replace OHV engines with DOHC engine designs with dual cam phasing (DCP). EPA and NHTSA reviewed the analysis of effectiveness for CDOHC in the MY 2011 CAFE final rule and found no information to indicate that these estimates were inaccurate. EPA and NHTSA estimate the effectiveness to be between 1 to 2.5 percent.

As for costs, NHTSA's MY 2011 CAFE final rule assumed that CDOHC would have an RPE of $746 ($497 non-RPE) for a V8 engine, $590 ($393 non-RPE) for a V6 engine and $373 ($249 non-RPE) for inline 4-cylinder engine (2007$). In the 2008 Staff Report, EPA did not estimate a cost for this specific technology. For purposes of this rulemaking, NHTSA revised the costs only by identifying this technology as a low complexity technology and applying an indirect cost multiplier of 1.11 resulting in a compliance cost of $552 for V8 engine, $436 for a V6 and $276 for an inline 4-cylinder engine. The above costs are for a MY 2012 vehicle and with the application of time-based learning will be slightly lower for MY 2016 vehicle

---

[h] The $28 is an adjustment from the $75 estimate used in the MY 2011 final rule to account for the new ICM markup factor and the fact that it could only be applied on up to 50 percent of the vehicles.

3.4.2.1.7 *Stoichiometric Gasoline Direct Injection (SGDI)*

Stoichiometric gasoline direct injection (SGDI), or Spark Ignition Direct injection (SIDI), 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 VW/Audi, BMW, Toyota (Lexus IS 350) and General Motors (Chevrolet Impala and Cadillac CTS 3.6L). BMW, GM, Ford and VW/Audi have announced their plans to increase dramatically the number of SGDI engines in their portfolios.

NHTSA's MY 2011 CAFE final rule estimated the effectiveness of SGDI to be between 2 and 3 percent. NHTSA and EPA reviewed estimates from the Alliance of Automobile Manufactures, which projects 3 percent gains in fuel efficiency and a 7 percent improvement in torque. The torque increase provides the opportunity to downsize the engine allowing an increase in efficiency of up to a 5.8 percent. NHTSA and EPA also reviewed other published literature, reporting 3 percent effectiveness for SGDI.[23] Another source reports a 5 percent improvement on the NEDC drive cycle.[24] Confidential manufacturer data reported an efficiency effectiveness range of 1 to 2 percent. NHTSA and EPA determined that the range of 2 to 3 percent continues to be appropriate. Combined with other technologies (*i.e.*, boosting, downsizing, and in some cases, cooled EGR), SGDI can achieve greater reductions in fuel consumption and CO_2 emissions compared to engines of similar power output.

The NHTSA and EPA cost estimates for SGDI take into account the changes required to the engine hardware, engine electronic controls, ancillary and Noise Vibration and Harshness (NVH) mitigation systems. Through contacts with industry NVH suppliers, and manufacturer press releases, the agencies believe that the NVH treatments will be limited to the mitigation of fuel system noise, specifically from the injectors and the fuel lines. In the final rule, the agencies have revised the SGDI costs based on the FEV work that was not yet available for the NPRM. Focusing on direct manufacturing costs, the NPRM estimates, the FEV values, and the final values are shown in Table 3-5. FEV did not directly estimate the SGDI costs shown here. Instead, FEV estimated costs associated with downsizing and turbocharging a V8 and V6 engine to a V6 and I4 engine, respectively, and simultaneously converting the PFI fuel system to a SGDI fuel system. The agencies, working closely with FEV, then "binned" the costs into three distinct bins: downsize, turbocharge, and SGDI. As such, the FEV results shown in Table 3-5 cannot

be found in the FEV reports, but instead are detailed in a memo to the docket which also provides details of this binning process.[25] Because the methodology used by FEV presumes high volume production, instead of using the FEV results directly the agencies have averaged those results with the NPRM results to estimate the final values (this is noted in section 3.3.2.2, 3.4.2.1.9, and 3.4.2.2.5). Note that the costs for the I3 and I4 engines have changed since the NPRM but have not been averaged with the NPRM values. The costs changed based on a more rigorous binning process than that conducted for the NPRM, but were not averaged because they are based on the I4 to I4 teardown conducted by FEV which was, in fact, used in the NPRM. While the final value of $213 is lower than the NPRM value of $226, the $13 difference has simply been shifted from SGDI to the downsizing bin.

Table 3-5 Direct Manufacturing Costs for SGDI (2007$ in 2012)

Technology	NPRM	FEV Results	Final Rule
I3	$226	$213	$213
I4	$226	$213	$213
V6	$293	$321	$307
V8	$317	$386	$352

For the final rule marked up costs, the agencies estimate SGDI costs at $236 for an inline 4-cylinder and $341 for V6 and $390 for V8 including the low complexity ICM markup value of 1.11 (2007$ in 2012). With time-based learning applied, these costs would be $209, $301, and $346 for a MY 2016 vehicle (2007$). As noted above, all of these costs differ slightly from those used in the NPRM analysis as shown in Table 3-6. These costs were not changed in response to public comments, but instead were changed due to updated information from the FEV teardown studies.[26]

Table 3-6 Marked up Costs for Stoichiometric GDI (2007$ in 2012)

Technology	NPRM	Final Rule
I3	$251	$236
I4	$251	$236
V6	$326	$341
V8	$353	$390

3.4.2.1.8 Combustion Restart (CBRST)

Combustion restart allows "start-stop" functionality of DI engines through the implementation of an upgraded starter with bi-directional rotation to allow precise crankshaft positioning prior to subsequent fuel injection and spark ignition, allowing engine restart. This method of implementing engine stop/start functionality allows not only the fuel savings from not idling the engine, but also reduces fuel consumption as the engine speeds up to its operational speed. A Direct Injection (DI) fuel system is required for implementation of this technology.

NHTSA reviewed the MY 2011 CAFE final rule assumptions and determined that due to technical risks implementation of combustion restart would likely not be feasible prior to MY 2014. Some of the risks are associated with unresolved issues regarding the impact of very high or very low ambient air temperatures on the ability to start the engine in the described manner. Although the starter motor can provide fail-safe starting capability in these temperature limited areas, strategies must be developed to manage the transitions. Other risks relate to production readiness.

Additional hardware is required to implement combustion restart, beyond SGDI. This includes a battery sensor, incremental wiring and high current switching, an incremental crank position sensor, and, in the case of an automatic transmission applications, a transmission oil pump to allow for torque converter continuity.

BMW has published a 3.5 percent fuel consumption effectiveness over the NEDC drive cycle for combustion restart,[27] and AVL a 4.8 percent effectiveness.[28] However, these reported effectiveness levels could potentially be reduced significantly on the EPA combined drive cycle, as combustion restart does not save fuel on the highway drive cycle. Therefore, NHTSA estimates the fuel consumption effectiveness for CBRST to range from 2 to 2.5 percent.

Regarding the cost estimate, NHTSA determined that the estimate of $118 from the 2008 Martec Report cost estimates for individual pieces was the best available. The total RPE cost (excluding transmission pump) is $141 at high volumes, which includes $70 for upgrading the starter, $10 for a battery sensor and wiring, $10 for high current switch and $4 for crank sensor a totaling $94 (non-RPE) cost. Applying an indirect cost multiplier of 1.25, for a medium complexity technology, results in a compliance cost of $118 for a MY 2012 vehicle and will be reduced in future years with the application of time-based learning.

3.4.2.1.9 *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 conservatively be downsized roughly 30 percent to achieve 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. 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 in order to provide adequate acceleration from standstill, particularly up grades or at high altitudes.

Use of GDI systems with turbocharged engines and air-to-air 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.[29]

NHTSA and EPA reviewed NHTSA's MY 2011 CAFE final rule estimates that a turbocharged and downsized engine at equivalent performance levels would offer an effectiveness improvement of 2 to 5 percent over a naturally-aspirated SGDI engine of comparable performance. This would equate to a 12 to 14 effectiveness improvement over baseline fixed-valve engine, similar to the estimate for Ford's Ecoboost. NHTSA and EPA kept these estimates for this final rule.

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;[30] 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;[31] and a Robert Bosch paper suggesting a 13 percent NEDC gain for downsizing to a turbocharged DI engine, again with wall-guided injection.[32] These reported fuel economy benefits show a wide range depending on the SGDI technology employed. Public comment was received on this issue and a summary of those comments with the agencies' response can be found in section 4.4 of EPA's Response to Comments document and in Chapter V of NHTSA's FRIA.

As noted above, the agencies relied on engine teardown analyses conducted by EPA, FEV and Munro to develop costs for turbocharged GDI engines.[33] Teardown studies are one of the most effective ways to estimate technology costs. For the proposal,

only the 2.4L I4 DOHC to 1.6L I4 DOHC teardown study had been completed in time for inclusion in the NPRM, and we used that study's results as the cost in the 2012 model year. For other turbo-downsize costs, the NPRM primarily used values developed for the 2008 staff report. Since issuing the NPRM, two more teardown studies have been completed and those results are being used in the final analysis with some adjustment. The agencies have adjusted the I4 to I4 turbo-downsize costs slightly to reflect an updated burden rate[j] employed by FEV and an updated binning approach employed by the agencies to distinguish turbo-related costs from downsize-related costs.[k] NHTSA and EPA modified the other FEV estimated costs as well. FEV made the assumption that these technologies would be mature when produced in large volumes (450,000 units or more). The agencies believe that there is potential for near term supplier-level engineering, design, and testing (ED&T) costs to be in excess of those considered in the FEV analysis (as existing equipment and facilities must be converted to production of new technologies). The agencies have therefore decided to average the FEV results with the NPRM values. We have also used the FEV results, where possible, to estimate costs for turbo-downsize scenarios that were not done via actual teardown study (e.g., FEV did not conduct a teardown of a V8 DOHC to turbocharged V6 DOHC). We have also used these values to estimate costs for other camshaft configuration changes that do not involve engine downsizing. Table 3-7 shows the NPRM, FEV and final rule direct manufacturing costs used for the turbo-downsize technologies.

Table 3-7 Direct Manufacturing Costs for Turbocharging, Downsizing, and Other Camshaft Configuration Changes applicable in the 2012 Model Year (2007 dollars)

Technology	NPRM	FEV Result	Final Rule	Comment
Turbo (I4 to I4 only)	$372	$404	$404	Use FEV result directly, no averaging with NPRM cost
Turbo (V6 to I4)	$450	$404	$427	Average of NPRM & actual FEV teardown
Turbo (V8 to V6)	$675	$681	$678	Average of NPRM & actual FEV teardown
I4 DOHC to I3 DOHC	-$101	-$193	-$147	FEV result calculated using binning of other teardown results then averaged with NPRM cost
I4 DOHC to smaller I4 DOHC	-$60	-$85	-$85	Use FEV result directly, no averaging with NPRM cost
I4 SOHC to smaller I4 DOHC	$65	-$80	-$80	FEV result calculated using binning of other teardown results then used directly, no averaging with NPRM cost
I4 OHV to smaller I4 DOHC	$65	n/a	$65	Not possible to calculate using binning of other teardown results; NPRM cost used as final
V6 DOHC to I4 DOHC	-$428	-$547	-$488	Average of NPRM & actual FEV teardown
V6 SOHC to I4 DOHC	-$68	-$382	-$225	FEV result calculated using binning of other teardown results then averaged with NPRM cost
V6 OHV to I4	$270	n/a	$270	Not possible to calculate using binning of other teardown

---

[j] Burden costs include the following fixed and variable costs: rented and leased equipment; manufacturing equipment depreciation; plant office equipment depreciation; utilities expense; insurance (fire and general); municipal taxes; plant floor space (equipment and plant offices); maintenance of manufacturing equipment - non-labor; maintenance of manufacturing building - general, internal and external, parts, and labor; operating supplies; perishable and supplier-owned tooling; all other plant wages (excluding direct, indirect and MRO labor); returnable dunnage maintenance; and intra-company shipping costs (see EPA-HQ-OAR-2009-0472-0149).

[k]This "binning" approach simply bins the turbo-downsize-GDI total cost generated by FEV into separate cost bins for the turbo portion, the downsize portion, and the GDI portion.

DOHC				results; NPRM cost used as final
V8 DOHC to V6 DOHC	-$203	-$274	-$238	FEV result calculated using binning of other teardown results then averaged with NPRM cost
V8 SOHC 3V to V6 DOHC	$113	-$155	-$21	Average of NRPM & actual FEV teardown
V8 SOHC 2V to V6 DOHC	$203	-$84	$60	FEV result calculated using binning of other teardown results then averaged with NPRM cost
V8 OHV to V6 DOHC	$315	n/a	$315	Not possible to calculate using binning of other teardown results; NPRM cost used as final
V6 SOHC to V6 DOHC	$360	$165	$262	FEV result calculated using binning of other teardown results then averaged with NPRM cost
V6 OHV to V6 DOHC	$473	n/a	$473	Not possible to calculate using binning of other teardown results; NPRM cost used as final
V8 SOHC 3V to V8 DOHC	$315	$119	$217	FEV result calculated using binning of other teardown results then averaged with NPRM cost
V8 SOHC 2V to V8 DOHC	$405	$190	$298	FEV result calculated using binning of other teardown results then averaged with NPRM cost
V8 OHV to V8 DOHC	$518	n/a	$518	Not possible to calculated using binning of other teardown results; NPRM cost used as final

For the OHV applications, the agencies maintained consistency with the EPA 2008 Staff Report and estimated direct manufacturing costs associated with downsizing to be $50 per cylinder, $10 per valve, and $100 per cam shaft for the 2015 model year (2006$). Therefore, these costs have not changed relative to the NPRM. Table 3-8 shows all of these turbo and downsize costs, the applicable ICMs, and the final costs for the 2012 MY (2007$). The agencies have applied time based learning to all of these costs. Estimated costs for the 2016 MY can be found in section 3.5.2 of this TSD.

Table 3-8 Direct Manufacturing and Marked up Costs for Turbocharging and Downsizing and Other Camshaft Configuration Changes in 2012 (2007 dollars)

	Technology	Incremental to	Direct Manufacturing Cost		IC Markup	Final Cost *
			Turbo	Downsize		
Turbo w/o Downsize / Downsize w/o Turbo	Turbo (I4 to I4 only)	Base engine	$404	n/a	1.11	$448
	Turbo (V6 to I4)	Base engine	$427	n/a	1.11	$474
	Turbo (V8 to V6)	Base engine	$678	n/a	1.11	$753
	Downsize to I4 DOHC	V6 DOHC	n/a	-$488	1.11	-$434
	Downsize to I4 DOHC	V6 SOHC	n/a	-$225	1.11	-$200
	Downsize to I4 DOHC	V6 OHV	n/a	$270	1.11	$300
	Downsize to I4 DOHC	I4 DOHC (larger)	n/a	-$85	1.11	-$76
	Downsize to I3 DOHC	I4 DOHC	n/a	-$147	1.11	-$131
	Downsize to V6 DOHC	V8 DOHC	n/a	-$238	1.11	-$212
	Downsize to V6 DOHC	V8 SOHC 2V	n/a	$60	1.11	$66
	Downsize to V6 DOHC	V8 SOHC 3V	n/a	-$21	1.11	-$19
	Downsize to V6 DOHC	V8 OHV	n/a	$315	1.11	$350
Turbo with Downsize	Downsize to I4 DOHC & add turbo	V6 DOHC w/o turbo	$427	-$488	1.25	$168
	Downsize to I4 DOHC & add turbo	V6 SOHC w/o turbo	$427	-$225	1.25	$365
	Downsize to I4 DOHC & add turbo	V6 OHV w/o turbo	$427	$270	1.25	$872
	Downsize to I4 DOHC & add turbo	I4 DOHC (larger) w/o turbo	$404	-$85	1.25	$441
	Downsize to I3 DOHC & add turbo	I4 DOHC w/o turbo	$404	-$147	1.25	$395
	Downsize to V6 DOHC & add twin turbo	V8 DOHC w/o turbo	$675	-$238	1.25	$669
	Downsize to V6 DOHC & add twin turbo	V8 SOHC 2V w/o turbo	$675	$60	1.25	$923
	Downsize to V6 DOHC & add twin turbo	V8 SOHC 3V w/o turbo	$675	-$21	1.25	$832
	Downsize to V6 DOHC & add twin turbo	V8 OHV w/o turbo	$675	$315	1.25	$1,242
Camshaft Changes	Convert to V6 DOHC	V6 SOHC	n/a	$262	1.11	$291
	Convert to V6 DOHC	V6 OHV	n/a	$473	1.11	$525
	Convert to V8 DOHC	V8 SOHC 2V	n/a	$298	1.11	$330
	Convert to V8 DOHC	V8 SOHC 3V	n/a	$217	1.11	$241
	Convert to V8 DOHC	V8 OHV	n/a	$518	1.11	$575

* Note that, where downsizing results in cost savings, the compliance cost is calculated as the IC markup less 1 which is then multiplied by the absolute value of the direct manufacturing cost. The absolute value of the direct manufacturing cost is then subtracted from that to arrive at the end result. For example, for the V6 DOHC downsized to the I4 DOHC at a direct manufacturing cost of -$488, the compliance cost would be (1.11-1) x │-$488│ - │-$488│ = -$434.

3.4.2.1.10 Cooled Exhaust Gas Recirculation/EGR Boost (EGRB)

Cooled exhaust gas recirculation (cooled EGR) or EGR Boost is a combustion concept that involves utilizing EGR as a charge dilutant 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. Cooled EGR reduces knock sensitivity which enables the use of more optimal spark advance or enables compression ratio to be increased for improved thermal efficiency, and increased fuel economy. Currently available turbo, charge air cooler, and EGR cooler technologies are sufficient to demonstrate the feasibility of this concept.

However, this remains a technology with a number of issues that still need to be addressed and for which there is no production experience. EGR system fouling characteristics could be potentially worse than diesel EGR system fouling, due to the higher HC levels found in gasoline exhaust. Turbocharger compressor contamination may also be an issue for low pressure EGR systems. Additionally, transient controls of boost pressure, EGR rate, cam phasers and intake charge temperature to exploit the cooled EGR combustion concept will require development beyond what has already been accomplished by the automotive industry. These are all "implementation readiness" issues that must be resolved prior to putting EGR Boost into high volume production.

NHTSA has concluded that these implementation issues could be resolved and this technology could be brought to production by MY 2013. Supporting this conclusion, MEMA has previously suggested a 5 to 7 percent effectiveness for cooled EGR systems, although without boosting.[34]

Two public sources indicate a 10 to 20 percent fuel consumption effectiveness for a downsized DI engine with cooled EGR compared to a naturally aspirated baseline engine[35] and a 4 percent fuel consumption effectiveness for cooled EGR compared to a conventional downsized DI turbocharged engine.[36] Based on the data from these reports, NHTSA estimates the incremental reduction in fuel consumption for EGR Boost to be 4 percent over a turbocharged and downsized DI engine. Thus, if TRBDS precedes EGRB, adding the 12 percent gain from TRBDS to the 4 percent gain from EGRB results in total fuel consumption reduction of 16 percent. This is in agreement with the range suggested in the Lotus report.

Regarding costs, the addition of EGR cooler and EGR valve were estimated in NHTSA's MY 2011 rule to have an incremental RPE cost impact of approximately $173 based on confidential individual component cost data from 2008 Martec describing EGR cooler costs of $75, EGR valve costs of $20 and associated piping costs of $20, totaling $115 (non-RPE). For purposes of this rulemaking, NHTSA found no information to indicate that these estimates were inaccurate. To that end, NHTSA applied an indirect

cost multiplier of 1.25, for a medium complexity technology, resulting in a compliance cost of $144 for MY 2012 vehicles with time-based learning applied.

3.4.2.1.11 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.[1] 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.

Diesel engines have emissions characteristics that present challenges to meeting federal Tier 2 NOx 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 combustion improvements and aftertreatment. These emission control strategies are being introduced on Tier 2 light-duty diesel vehicles today

To achieve U.S. Tier 2 emissions limits, roughly 45 to 65 percent more NO_x reduction is required compared to the Euro VI standards. Additionally, as discussed below, there may be a fuel consumption penalty associated with diesel aftertreatment since extra fuel is needed for the aftertreatment, and this extra fuel is not used in the combustion process of the engine that provides torque to propel the vehicle.

Light-duty diesel emissions control systems capable of meeting Tier 2 Bin 5 emission standards are already in production. Several key advances in diesel technology have made it possible to reduce emissions coming from the engine prior to aftertreatment. These technologies include 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.

On the aftertreatment side, the traditional 3-way catalyst aftertreatment found on gasoline-powered vehicles is ineffective due to the lean-burn combustion of a diesel. All diesels will require a diesel particulate filter (DPF) or catalyzed diesel particulate filter (CDPF), a diesel oxidation catalyst (DOC), and a NO_x reduction strategy to comply with Tier 2 emissions standards. The most common NO_x reduction strategies include the use of lean NO_x traps (LNT) or selective catalytic reduction (SCR), which are outlined below.

---

[1] 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.

3.4.2.1.11.1 Diesel Engine with Lean NOx Trap (LNT) Catalyst After-treatment

A lean NO_x trap operates, in principle, by oxidizing NO to NO2 in the exhaust and storing NO2 on alkali sorbent material. When the control system determines (via mathematical model or a NO_x sensor) that the trap is saturated with NO_x, it switches the engine into a rich operating mode or may in some cases inject fuel directly into the exhaust stream to produce excess hydrocarbons that act as a reducing agent to convert the stored NO_x to N_2 and water, thereby "regenerating" the LNT and opening up more locations for NO_x to be stored. LNTs preferentially store sulfate compounds from the fuel, which can reduce catalytic performance. The system must undergo periodic desulfurization by operating at a net-fuel-rich condition at high temperatures in order to retain NO_x trapping efficiency.

NHTSA and EPA have concluded that diesel engines on small vehicles would be LNT-based. In the proposed rule, we did not include a diesel option for small vehicles because it did not appear to be a cost effective solution. Based on comments received we are including a diesel option for small vehicles in the final rule, and we are allowing the respective models to choose whether to apply the technology.

3.4.2.1.11.2 Diesel Engine with Selective Catalyst Reduction (SCR) After-treatment

An SCR aftertreatment system uses a reductant (typically, ammonia derived from urea) that is injected into the exhaust stream ahead of the SCR catalyst. Ammonia combines with NO_x in the SCR catalyst to form N_2 and water. The hardware configuration for an SCR system is more complicated than that of an LNT, due to the onboard urea storage and delivery system (which requires a urea pump and injector to inject urea into the exhaust stream). While a rich engine-operating mode is not required for NO_x reduction, the urea is typically injected at a rate of approximately 3 percent of the fuel consumed. Manufacturers designing SCR systems intend to align urea tank refills with standard maintenance practices such as oil changes. As is the case with LNT-based diesels, EPA and NHTSA project that SCR-based diesel engines will be available within the next couple of years. Mercedes-Benz recently introduced two 2009 model year vehicles R320 and GL320, both of which are certified to Tier 2, Bin 5 emission standards. Based on public announcements from several other companies, an increased number of product offerings from multiple companies are expected over the next few years.

In order to maintain equivalent performance to comparable gasoline-engine vehicles, an in-line 4-cylinder diesel engine, with displacement varying around 2.0 liters was assumed to replace an I4 gasoline base engine for Subcompact, Compact, and Midsize Passenger Car, Performance Subcompact Car and Small Light Truck. An in-line 4-cylinder diesel engine, with displacement varying around 2.8 liters was assumed to replace a V6 gasoline base engine for Performance Compact, Performance Midsize, Large Passenger Car, Minivan, and Midsize Truck for the CAFE model. A V6 diesel engine, with displacement varying around 4.0 liters to meet vehicle performance requirements, was assumed to replace a V8 gasoline base engine for Large Truck and

Performance Large Car vehicle classes for the CAFE model. It was also assumed that diesel engines for these classes would utilize SCR aftertreatment systems.

Confidential manufacturer and non-confidential comment data submitted in response to NHTSA's past rulemaking for diesel engines showed a fuel consumption reduction in the range of 16.7 to 26.7 percent or a 15 to 23 percent CO_2 emission reduction over a baseline gasoline engine. NHTSA's MY 2011 CAFE final rule, which was supported by confidential manufacturer data, estimated the fuel consumption reduction of a SCR-based diesel engine to be between 19 to 25 percent over a baseline gasoline engine. NHTSA and EPA have revisited these values and found them to be reasonable. EPA estimates a 15 to 26 percent CO_2 reduction for light-duty diesels equipped with SCR.

Diesel engines are more costly than port-injected spark-ignition gasoline engines. These higher costs result from:

- Fuel systems (higher pressures and more responsive injectors);

- Controls and sensors to optimize combustion and emissions performance;

- Engine design (higher cylinder pressures require a more robust engine, but higher torque output means diesel engines can have reduced displacement);

- Turbocharger(s);

- Aftertreatment systems, which tend to be more costly for diesels;

Due to a significant decrease in platinum group metal prices since NHTSA's MY 2011 CAFE final rule analysis, the agencies chose to re-analyze diesel costs. In EPA's 2008 Staff Report, costs were considered for two types of diesel systems: one using a lean-NO_X trap (LNT) along with a diesel particulate filter (DPF); and one using a selective catalytic reduction (SCR) system along with a DPF. In that report, EPA estimated direct manufacturing costs to range from $1,860 for the small car (LNT plus DPF) to $2,710 for the large truck (SCR plus DPF). For comparison, the NESCCAF study showed direct manufacturing costs of $1,500 to $1,950. More recently, NHTSA's MY 2011 CAFE final rule showed direct manufacturing costs of $2,670 for a 4-cylinder engine using a LNT plus DPF system, $3,735 for a 6-cylinder engine using a SCR plus DPF system, and $4,668 for an 8-cylinder engine using a SCR plus DPF system. NHTSA noted that estimates in the MY 2011 CAFE final rule were higher than those shown in this rule due largely to the spike in platinum group metal prices that had occurred in the months just prior to issuing the 2011 CAFE final rule.

The following diesel engine costs were developed by first taking a look back at EPA's 2008 Staff Report, which reveals a couple of factors that resulted in somewhat misleading costs. First, the engine costs estimated there did not take into account the

downsizing that would occur when moving from a gasoline engine to a diesel engine (provided equivalent performance was maintained). Second, the engine costs used in that analysis were actually stated in terms of 2002 dollars rather than 2006 dollars in which the report was meant to be stated. The agencies decided that an update to the engine-related costs would provide a much better cost estimate for converting to diesel. This was done by starting with the source for engine costs in the 2008 staff report which was an October 2005 EPA Interim Report[37] which, in turn, sourced estimates from a 2003 study done by FEV for EPA contained within a 2004 EPA Interim Technical Report.[38] These direct manufacturing costs are reproduced in Table 3-9.

Table 3-9 Diesel Engine Direct Manufacturing Source Costs, Incremental to a Baseline Gasoline Engine (2002 dollars)

Component(s)	Large SUV	Midsize
Gasoline engine (baseline)	5L V8	2.4L I4
Diesel engine	4L V8	2.2L I4
Add high-pressure, common rail diesel fuel injection system	$980	$630
Delete gasoline fuel injection system	-$245	-$165
Add variable geometry turbocharger	$175	$126
Delete gasoline ignition system	-$120	-$75
Delete fuel pump and other changes to fuel system	-$94	-$75
Enhance powertrain mounting system	$87	$107
Other engine changes	$80	$70
Add air intercooler, ducts, and sensor	$80	$55
Larger battery and starter, add glow plugs	$72	$50
Delete exhaust gas oxygen sensor*	-$60	-$30
Add supplemental heater	$50	$15
Modify transmission	$25	$25
Enhance sound insulation package	$25	$10
Smaller radiator	-$13	-$4
Total	$1,042	$739

Note: Table reproduced from EPA420-R-05-012, October 2005

Building on the direct manufacturing costs shown in Table 3-9, the agencies used appropriate scaling to estimate the costs for replacing a baseline gasoline engine with a diesel engine for the following five situations: a small car converted from a 2.4L I4 gasoline to a 2L I4 Diesel; a large car converted from a 4.5L V8 gasoline to a 3L V6 diesel; a medium/large MPV converted from a 3.2L V6 to a 2.8L I4 diesel; a small truck converted from a 3.2L V6 gasoline to a 2.8L I4 diesel; and a large truck converted from a 5.6L V8 gasoline to a 4L V6 diesel. The results for the five base gasoline to diesel conversions are shown in Table 3-10. Values from Table 3-9 have been updated to 2007 dollars using the GDP price deflator factor of 1.15 (see Appendix 3.A). Since the source costs were developed in 2003, this analysis conservatively considers the costs shown in Table 3-10 as being applicable to the 2012 model year.

Table 3-10 Diesel Engine Direct Manufacturing Scaled-Costs in 2012, Incremental to Baseline Gasoline Engine (2007 dollars)

Component(s)	Small car	Large car	Med/large MPV	Small truck	Large truck	Notes (see text below)
Gasoline engine (baseline)	2.4L I4	4.5L V8	3.2L V6	3.2L V6	5.6L V8	
Diesel engine	2.0L I4	3L V6	2.8L I4	2.8L I4	4L V6	
Add high-pressure, common rail diesel fuel injection system	$517	$1,026	$724	$724	$1,026	1
Delete gasoline fuel injection system	-$52	-$89	-$73	-$73	-$89	2
Add variable geometry turbocharger	$145	$173	$145	$145	$201	3
Delete gasoline ignition system	-$69	-$138	-$112	-$112	-$138	4
Delete fuel pump and other changes to fuel system	-$62	-$108	-$86	-$86	-$108	5
Enhance powertrain mounting system	$123	$100	$123	$123	$100	6
Other engine changes	$57	$86	$80	$80	$86	7
Add air intercooler, ducts, and sensor	$45	$78	$63	$63	$92	8
Larger battery and starter, add glow plugs	$57	$70	$57	$57	$70	9
Delete exhaust gas oxygen sensor*	$0	$0	$0	$0	$0	10
Add supplemental heater	$17	$37	$17	$17	$57	11
Modify transmission	$29	$29	$29	$29	$29	12
Enhance sound insulation package	$11	$20	$11	$11	$29	13
Smaller radiator	-$7	-$15	-$10	-$10	-$15	14
Engine downsize credit	$0	-$185	-$390	-$390	-$185	15
Total	$813	$1,085	$580	$580	$1,156	

* Note: Oxygen sensor removals are included in aftertreatment costs.

The costs shown in Table 3-10 were scaled in the following ways:

1. Large car and large truck calculated as 75% the cost of Table 3-9's large SUV and 25% of midsize car; medium/large MPV and small truck calculated as equal to Table 3-9's midsize car; small car calculated using Table 3-10's Med/large MPV value of $724 and applying the ratio of diesel engine sizes (2.0/2.8). Values converted to 2007 dollars using GDP factor of 1.15.

2. The estimates generated by FEV for eliminating the gasoline fuel injection systems were considerably larger than EPA & NHTSA believed was appropriate. Therefore, for a more accurate estimate, these costs were estimated, in 2007 dollars as follows: large car and large truck were calculated using incremental costs of $8/injector, $20/fuel rail, and $5 for a pressure damper or $8x8+$20+$5=$89; medium/large MPV and small truck were calculated using incremental costs of $8/injector, $20/fuel rail, and $5 for a pressure damper or $8x6+$20+$5=$73; small car calculated using Table 3-10's Med/large MPV value of -$73 and applying the ratio of diesel engine sizes (2.0/2.8).

3. Large car calculated as the average of Table 3-9's large SUV and midsize car; medium/large MPV and small truck calculated as equal to Table 3-9's midsize car, and large truck calculated as equal to Table 3-9's large SUV; small car calculated as equal to medium/large MPV. Values converted to 2007 dollars using GDP factor of 1.15.

4. Medium/large MPV and small truck calculated as the average of Table 3-9's large SUV and midsize car; Large car and large truck calculated as equal to Table 3-9's large SUV; small car calculated as equal to half of Table 3-10's large truck value of -$138. Values converted to 2007 dollars using GDP factor of 1.15.

5. Medium/large MPV and small truck calculated as equal to Table 3-9's midsize car; Large car and large truck calculated as equal to Table 3-9's large SUV; small car calculated using Table 3-10's Med/large MPV value of -$86 and applying the ratio of diesel engine sizes (2.0/2.8). Values converted to 2007 dollars using GDP factor of 1.15.

6. Medium/large MPV and small truck calculated as equal to Table 3-9's large SUV; Large car and large truck calculated as equal to Table 3-9's midsize car; small car calculated as equal to medium/large MPV. Values converted to 2007 dollars using GDP factor of 1.15.

7. Medium/large MPV and small truck calculated as equal to Table 3-9's midsize car; Large car and large truck calculated as the average of Table 3-9's large SUV and midsize car; small car calculated using Table 3-10's Med/large MPV value of $80 and applying the ratio of diesel engine sizes (2.0/2.8). Values converted to 2007 dollars using GDP factor of 1.15.

8. Medium/large MPV and small truck calculated as equal to Table 3-9's midsize car; Large car calculated as the average of Table 3-9's large SUV and midsize car; Large truck calculated as equal to Table 3-9's large SUV; small car calculated using Table 3-10's Med/large MPV value of $63 and applying the ratio of diesel engine sizes (2.0/2.8). Values converted to 2007 dollars using GDP factor of 1.15.

9. Medium/large MPV and small truck calculated as equal to Table 3-9's midsize car; Large car and large truck calculated as the average of Table 3-9's large SUV and midsize car; small car calculated as equal to medium/large MPV. Values converted to 2007 dollars using GDP factor of 1.15.

10. Oxygen sensor costs are included in the aftertreatment costs discussed below.

11. Medium/large MPV and small truck calculated as equal to Table 3-9's midsize car; Large car calculated as the average of Table 3-9's large SUV and midsize car; Large truck calculated as equal to Table 3-9's large SUV; small car calculated as equal to medium/large MPV. Values converted to 2007 dollars using GDP factor of 1.15.

12. Values from Table 3-9 converted to 2007 dollars using GDP factor of 1.15.

13. Medium/large MPV and small truck calculated as equal to Table 3-9's midsize car; Large car calculated as the average of Table 3-9's large SUV and midsize car; Large truck calculated as equal to Table 3-9's large SUV; small car calculated as equal to medium/large MPV. Values converted to 2007 dollars using GDP factor of 1.15.

14. Medium/large MPV and small truck calculated as the average of Table 3-9's large SUV and midsize car; Large car and large truck calculated as equal to Table 3-9's large SUV; small car calculated using Table 3-10's Med/large MPV value of -$10 and applying the ratio of diesel engine sizes (2.0/2.8). Values converted to 2007 dollars using GDP factor of 1.15.

15. Based on the approach presented in the turbocharging/downsizing section (see section 3.5.2.1.11), the savings associated with downsizing the gasoline engine were calculated by estimating the cost in 2007 dollars of each cylinder at $51, each valve at $10, and each cam at $103.[m] Therefore, the large car and large truck, which each lose two cylinders (-$102), eight valves (-$82) and no cams realize a $185 savings. The medium/large MPV and small truck would each lose two cylinders (-$102) and eight valves (-$82) and two cams (-$205) for a savings of $390. The small car downsizing credit was left at $0 given the small displacement change and lack of cylinder or valve removals.

For the diesel aftertreatment systems, the approach taken is consistent with the approach taken in EPA's 2007/2010 Highway Diesel rule and EPA's recent locomotive and marine rule.[39] For platinum group metal (PGM) costs, monthly average prices as of March 2009 as reported by Johnson-Matthey were used.[40,n] Those values were $1,085/troy ounce for platinum and $1,169/troy ounce for rhodium. Aftertreatment devices were sized according to the diesel engine displacement with a 1:1 ratio for both the SCR catalyst and the DPF, and a 0.5:1 ratio for the DOC (*i.e.*, the DOC is half the displacement of the engine). The end result for aftertreatment devices, including a urea dosing unit, urea tank and necessary brackets and heaters, are shown in Table 3-11. Also shown in Table 3-11 are the savings associated with removal of the gasoline catalyst. Note that the gasoline catalyst was sized according to the gasoline engine that served as the baseline engine.

---

[m] These are the correct costs for the 2015MY in 2007$. But, they are used here erroneously as 2012MY values. Technically, 3 years of time-based learning should have been backed out to get 2012MY values. So, the 2012MY costs are slightly underestimated by roughly $10. This was true in the proposed analysis and, because it has no meaningful impact on the analysis (1-2% of the estimated diesel costs), continues to be true in the final analysis.

[n] These are the PGM prices used in the NPRM. As precious metals, PGM prices swing widely year-to-year and even month-to-month. Given economic conditions during the past year and the tendency of investors during tough economic times to invest in valuable metals such as gold and PGMs, PGM prices have increased considerably since the NPRM. Were the January 2010 PGM prices used, the diesel costs presented here would increase on the order of 10-20 percent. That would serve to make diesels less cost effective options for improving fuel economy or reducing GHGs. Since diesels comprise such a small percentage of each agency's analysis from a technology penetration standpoint, even using the lower March 2009 PGM prices, the choice of what PGM prices to use is of little consequence to the analytical results for purposes of this rulemaking.

Table 3-11 Diesel Aftertreatment Direct Manufacturing Costs in 2012 (2007 dollars)

Component(s)	Small car	Large car	Med/large MPV	Small truck	Large truck
Gasoline engine (baseline)	2.4L I4	4.5L V8	3.2L V6	3.2L V6	5.6L V8
Diesel engine	2.0L I4	3L V6	2.8L I4	2.8L I4	4L V6
DOC	$216	$277	$257	$257	$339
DPF (includes a $20 pressure sensor for OBD & sensing)	$401	$534	$503	$503	$668
SCR system (includes a $50 NOx sensor for OBD & sensing)	n/a	$904	$904	$914	$996
LNT System includes $50 NOx sensor for OBD and sensing	$442	n/a	n/a	n/a	n/a
Removal of gasoline catalysts & sensors	-$175	-$401	-$288	-$298	-$483
Total	$883	$1,314	$1,376	$1,376	$1,520

The incremental costs to convert from a gasoline to a diesel engine—Table 3-10 and Table 3-11 combined—are shown in Table 3-12.

Table 3-12 Direct Manufacturing Costs to Convert from a Gasoline to Diesel System in 2012 (2007 dollars)

Component(s)	Small car	Large car	Med/large MPV	Small truck	Large truck
Gasoline engine (baseline)	2.4L I4	4.5L V8	3.2L V6	3.2L V6	5.6L V8
Diesel engine	2.0L I4	3L V6	2.8L I4	2.8L I4	4L V6
Engine-related costs	$813	$1,085	$580	$580	$1,156
Aftertreatment	$883	$1,314	$1,376	$1,376	$1,520
Total	$1,697	$2,399	$1,956	$1,956	$2,676

This analysis applies time-based learning to diesel systems and a 1.25 ICM for a medium complexity rating. Therefore, the MY 2012 compliance costs are as shown in Table 3-13.

Table 3-13 Compliance Costs to Convert from a Gasoline to Diesel System in 2012 (2007 dollars)

Component(s)	Small car	Large car	Med/large MPV	Small truck	Large truck
Gasoline engine (baseline)	2.4L I4	4.5L V8	3.2L V6	3.2L V6	5.6L V8
Diesel engine	2.0L I4	3L V6	2.8L I4	2.8L I4	4L V6
Total	$2,121	$2,999	$2,445	$2,445	$3,345

The diesel costs for the 2016 MY, which include 4 years of time-based learning, are shown in section 3.5.2. In the NHTSA analysis, and consistent with the above analysis, diesel costs for a 2.0L in-line 4-cylinder from an I4 gasoline engine were

estimated to be $2,121 in MY 2012. A 2.8L in-line 4-cylinder from a V6 gasoline engine were estimated to be $2,445 in MY 2012. A MY 2012 cost of $3,345 was estimated for a conversion to 4.0L V6 diesel from a V8 gasoline engine. These MY 2012 estimates were obtained using the in-line 4-cylinder 2.0L cost of $1,697, the in-line 4-cylinder 2.8L cost of $1956 and V6 cost of $2,676, from Table 3-12, and multiplying them by the medium complexity ICM markup of 1.25 and are eligible for time-based learning cost reductions.

3.4.2.2   Transmission Technologies

NHTSA and EPA have also reviewed the transmission technology estimates used in the MY 2011 CAFE final rule. In doing so, NHTSA and EPA 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.

3.4.2.2.1   *Improved Automatic Transmission Control (IATC) (Aggressive Shift Logic and Early Torque Converter Lockup)*

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 (NVH). 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. Given that the Aggressive Shift Logic and Early Torque Converter Lockup are best optimized simultaneously due to the fact that adding both of them primarily requires only minor modifications to the transmission or calibration software, these two technologies are combined in the modeling.

3.4.2.2.2   *Aggressive Shift Logic*

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 (ASL) 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.

The agencies have estimated the effectiveness of aggressive shift logic at 1 to 2 percent, as explained below. The agencies have estimated the cost at $32 for a MY 2012

vehicle, regardless of size (2007\$).[o] With time-based learning applied, this cost would be $28 for a MY 2016 vehicle (2007\$) based on the 2002 NAS report.

3.4.2.2.3 *Early Torque Converter Lockup*

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.[p] 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 will 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 is required to successfully implement this technology.

Regarding the effectiveness of Improved Automatic Transmission Control, the MY 2011 CAFE final rule, which was supported by the 2002 NAS and NESCCAF reports as well as confidential manufacturer data, estimated an effectiveness improvement of 1 to 2 percent for aggressive shift logic and 0.5 percent for early torque converter lockup. These estimates are in agreement with the values stated in the NESCCAF report and confidential manufacturer data. For the purpose of this final rule, NHTSA and EPA concluded that the combined estimated effectiveness is 1.5 to 2.5 percent reduction in CO_2 emissions and fuel consumption.

Regarding cost estimates, the agencies estimate the cost at $29, regardless of vehicle size and including a low complexity ICM of 1.11 for a MY 2012 vehicle (2007\$). With time-based learning, this cost would be $25 for a MY 2016 vehicle (2007\$). For IATC (or the combination of aggressive shift logic and early torque converter lockup), the cost, including the 1.11 ICM, would be $60 for a MY 2012 vehicle and $53 for a MY 2016 vehicle after time-based learning (2007\$).

3.4.2.2.4 *Automatic 6-, 7- and 8-Speed Transmissions (NAUTO)*

Manufacturers can also choose to replace 4- and 5-speed transmission with 6-, 7-, or 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

---

[o] This reflects a revisiting of component costs for NHTSA since the MY 2011 CAFE final rule.
[p] Although only modifications to the transmission calibration software are considered as part of this technology, very aggressive early torque converter lock up may require an adjustment to damper stiffness and hysteresis inside the torque converter.

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. Some manufacturers are replacing 4- and 5-speed automatics with 6-speed automatics, and 7- and 8-speed automatics have also entered production, albeit in lower-volume applications in luxury and performance oriented cars.

As discussed in the MY 2011 CAFE final rule, confidential manufacturer data projected that 6-speed transmissions could incrementally reduce fuel consumption by 0 to 5 percent from a baseline 4-speed automatic transmission, while an 8-speed transmission could incrementally reduce fuel consumption by up to 6 percent from a baseline 4-speed automatic transmission. GM has publicly claimed a fuel economy improvement of up to 4 percent for its new 6-speed automatic transmissions.[41] The 2008 EPA Staff Technical Report found a 4.5 to 6.5 percent fuel consumption improvement for a 6-speed over a 4-speed automatic transmission.[42] Based on this information, NHTSA estimated in the MY 2011 rule, that the conversion to a 6-,7- and 8-speed transmission (NAUTO) from a 4 or 5-speed automatic transmission with IATC would have an incremental fuel consumption benefit of 1.4 percent to 3.4 percent, for all vehicle classes. From a baseline 4 or 5 speed transmission without IATC, the incremental fuel consumption benefit would be approximately 3 to 6 percent, which is consistent with the EPA Staff Report estimate.

NHTSA and EPA reviewed these effectiveness estimates and concluded that they remain accurate. While the CAFE model follows the incremental approach discussed above, the GHG model estimates the packaged effectiveness of 4.5 to 6.5 percent.

In the NPRM, NHTSA and EPA reviewed the cost estimates from the MY 2011 CAFE final rule which used cost estimates from 2008 Martec report and the 2008 EPA Staff Report (which assumed use of a Lepelletier gear set) and concluded that some but not all 6-speed automatic transmissions would be equipped with Lepelletier gear set. As such, the estimates were revised to establish the cost for the 6 speed transmission to be equally divided between application using Lepelletier, and application of a standard planetary gear set 6-speed automatic transmission as estimated in the 2008 Martec Report (and the MY 2011 CAFE final rule). The 2008 Martec report estimated a cost of $323 with RPE adjustment and $215 without RPE adjustment for converting a 4-speed to a 6-speed transmission and a cost of $638 with RPE adjustment or $425 without RPE adjustment for converting a 4-speed to an 8-speed transmission. As a result, the final incremental cost estimate in the NPRM was $170, independent of vehicle type and size and including a low complexity 1.11 ICM (2007$). In the CAFE model, due to the structure of the vehicle classes used, an additional $102 (2007$) was included to account for performance vehicle classes and for medium and large trucks. This is because for performance classes, additional gear ratios, such as 7 and 8 speed transmissions may be utilized, and for medium and large trucks heavier duty transmissions are required. These estimates represented MY 2012 vehicle costs

For the final analysis, as noted earlier, the agencies have considered the teardown work done by FEV. In its teardown work, FEV determined the 6 speed automatic transmission to be $106 less costly than a 5 speed automatic transmission (direct manufacturing cost without markups). This is counterintuitive but can be attributed to the type of gear set employed in the 6 speed automatic transmission studied by FEV. That 6 speed auto transmission was equipped with a Lepelletier-like gear set and therefore does not require a 1-way clutch that is essential to other designs. The cost analysis performed in this rule requires that the cost difference between both a 4 speed and 5 speed auto relative to 6 speed auto be established because there are a substantial number of both 4 speed and 5 speed automatic transmissions used in the baseline fleet. This was done using the NPRM analysis for a 4 speed to 5 speed and adding the FEV results for the transition from a 5 speed to a 6 speed. Our analysis resulted in a cost for a 5 speed auto transmission relative to a 4 speed auto of $91 direct manufacturing cost (2007$ in 2012). As done in the NPRM, the agencies averaged the non-Lepelletier gear set cost with the Lepelletier-like gear set cost (FEV tear-down value of -$106). In the 2011 FRM, NHTSA estimated the cost of a 6 speed auto transmission, without a Lepelletier gear set, relative to a 4 speed auto transmission at $215 (2007$). Therefore, we have used the $215 value (4 speed to 6 speed) from NHTSA's 2011 FRM and subtracted $91 from that (4 speed to 5 speed) to arrive at a cost of $124 as the non-Lepelletier cost for a 6 speed auto transmission relative to a 5 speed auto transmission. We have then averaged the $124 value with the FEV value of -$106 (Lepelletier-like cost) to get an end result of $9 (2007$ in 2012). This $9 cost represents the cost for a 6 speed auto transmission relative to a 5 speed auto transmission in the final analysis. This $9 can then be added to the $91 to get a cost of $101 for a 6 speed auto transmission relative to a 4 speed auto transmission. Table 3-14 shows the direct manufacturing costs used in the NPRM and the final analyses. With the low complexity markup of 1.11, the compliance cost for a 6 speed automatic transmission relative to a 4 speed automatic transmission in 2012 is $112 (2007$). With time based learning, the compliance costs in 2016 to move from a 4 speed auto to a 5 speed auto and then from a 5 speed auto to a 6 speed auto transmission would be $90 and $9, respectively (2007$).

Table 3-14 Direct Manufacturing Costs for Automatic Transmissions (2007$ in 2012)

Technology	Non-Lepelletier Cost Used in 2011 CAFE Analysis	NPRM	FEV tear down (Lepelletier-like)	Final Rule	Comments
5s auto relative to 4s auto		$91	n/a	$91	Final rule uses NPRM value
6s auto relative to 5s auto			-$106	$9	$215-$91=$124 [$124+(-$106)]/2=$9
6s auto relative to 4s auto	$215	$153	n/a	$101	$91+$9=$101 (values are rounded)

Notes: Blank cells represent values not considered in this analysis; n/a means that FEV did not conduct a tear down of the technology; refer to text for more detail on the comments.

3.4.2.2.5 Dual Clutch Transmissions / Automated Manual Transmissions (DCTAM)

An Automated Manual Transmission (AMT) is mechanically similar to a conventional manual transmission, but shifting and launch functions are automatically controlled by the electronics. There are two basic types of AMTs, single-clutch and dual-clutch (DCT). A single-clutch AMT is essentially a manual transmission with automated clutch and shifting. Because of shift quality issues with single-clutch designs, DCTs will likely be far more common in the U.S. and are the basis of the estimates that follow. A DCT uses separate clutches (and separate gear shafts) for the even-numbered gears and odd-numbered gears. In this way, the next expected gear is pre-selected, which allows for faster and smoother shifting. For example, if the vehicle is accelerating in third gear, the shaft with gears one, three and five has gear three engaged and is transmitting power. 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 down instead of continuing to accelerate, the transmission will 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.

In addition to single-clutch and dual-clutch AMTs, there are also wet clutch and dry clutch designs which are used for different types of vehicle applications. Wet clutch AMTs offer a higher torque capacity that comes from the use of a hydraulic system that cools the clutches. Wet clutch systems are less efficient than the dry clutch systems due to the losses associated with hydraulic pumping. Additionally, wet AMTs have a higher cost due to the additional hydraulic hardware required.

Overall, DCTs likely offer the greatest potential for effectiveness improvements among the various transmission options presented in this report because they 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 or bands to maintain gear ratios (in automatic transmissions) or hold pulleys in position to maintain gear ratio (in Continuously Variable Transmissions). However, the lack of a torque converter will affect how the vehicle launches from rest, so a DCT will most likely be paired with an engine that offers sufficient torque at low engine speeds to allow for adequate launch performance.

For the MY 2011 CAFE final rule, NHTSA estimated a 5.5 to 9.5 percent improvement in fuel consumption over a baseline 4/5-speed automatic transmission for a wet clutch DCT, which was assumed for all but the smallest of vehicle subclasses, Subcompact and Compact cars and small LT. This results in an incremental effectiveness estimate of 2.7 to 4.1 percent over a 6-speed automatic transmission with IATC. For Subcompact and Compact Cars and small LT, which were assumed to use a dry clutch DCT, NHTSA estimated an 8 to 13 percent fuel consumption improvement over a baseline 4/5-speed automatic transmission, which equates to a 5.5 to 7.5 percent incremental improvement over the 6-speed transmission. This is consistent with the EPA Staff Report, which estimated that these transmissions offer an effectiveness of 9.5 to

14.5 percent over a 4-speed automatic transmission. EPA and NHTSA therefore conclude that 8 to 13 percent effectiveness is appropriate for this rule.

In the NPRM analysis, the agencies estimated costs for 6 speed dual-clutch transmissions relative to 6 speed auto transmissions. For the dry clutch DCT, the agencies estimated a direct manufacturing cost of $59 (2007$ in 2012). For the wet clutch DCT, the estimate was $126 (2007$ in 2012). For the final rule, we have considered the teardown work done by FEV. In that teardown work, FEV found a wet clutch DCT to be $147 less costly than a 6 speed auto transmission. This cost savings is not unexpected when one considers that the DCT is less complex than an auto transmission. However, such a cost savings presumes that capacity exists to produce dual-clutch transmissions at volumes of 450,000 units, an assumption made by FEV. Since such capacity may not currently exist in the US, we have not used the FEV value directly but have instead averaged the FEV value (-$147) with the value used in the NPRM analysis ($126). Therefore, in the final rule, the wet clutch DCT is estimated to save $11 relative to a 6 speed auto transmission (2007$ in 2012). To generate a dry clutch DCT cost for the final analysis, we have applied the same cost difference from the NPRM for wet clutch versus dry clutch. In other words, the NPRM analysis had a cost difference of $67 which was then subtracted from the final wet-clutch DCT cost of -$11 to arrive at a result of -$78 for a dry-clutch DCT relative to a 6 speed auto transmission (2007$ in 2012). Table 3-15 shows the direct manufacturing costs used in the NPRM and final rule for dual clutch transmissions. Applying the medium complexity ICM of 1.25 results in costs of -$59 for the wet-clutch DCT and -$8 for the dry clutch DCT (2007$ in 2012), both relative to a 6 speed auto transmission. With time based learning, these costs become -$52 and -$7, respectively, in 2016 (2007$).

Table 3-15 Direct Manufacturing Costs for Dual-Clutch Transmissions (2007$ in 2012)

Technology	NPRM	FEV tear down	Final Rule	Comments
6s wet DCT relative to 6s auto	$126	-$147	-$11	[$126+(-$147)]/2=-$11
6s dry DCT relative to 6s auto	$59	n/a	-$78	-$11-($126-$59) = -$78

Notes: n/a means that FEV did not conduct a tear down of the technology; refer to text for more detail on the comments.

3.4.2.2.6 Continuously Variable Transmission (CVT)

A Continuously Variable Transmission (CVT) is unique in that it does not use gears to provide ratios for operation. Instead, the most common CVT design uses two V-shaped pulleys connected by a metal belt. Each pulley is split in half and a hydraulic actuator moves the pulley halves together or apart. This causes the belt to ride on either a larger or smaller diameter section of the pulley which changes the effective ratio of the input to the output shafts. Advantages of the CVT are that the engine can operate at its most efficient speed-load point more of the time, since there are no fixed ratios. However, CVTs are limited by engine power and cannot be applied to high torque applications. Also, CVTs often have a wider range of ratios compared to conventional automatic transmissions which can provide for more options in engine optimization.

While CVTs by definition are fully continuous, some automakers choose to emulate conventional stepped automatic operation because some drivers are not used to the sensation of the engine speed operating independently of vehicle speed.

Considering the confidential data together with independent review, NHTSA has estimated the fuel consumption effectiveness for CVTs at 2.2 to 4.5 percent over a 4/5-speed automatic transmission, which translates into a 0.7 to 2.0 incremental effectiveness improvement over an automatic transmission with the IATC technology. EPA and NHTSA reviewed these estimates and found them to be accurate.

The agencies adjusted the original estimates used in the MY 2011 CAFE final rule to account for medium complexity ICM of 1.25. This resulted in estimated incremental compliance cost of $250 for the MY 2012 vehicles. In the Volpe model, this technology was only applied to vehicles manufactured with unibody construction methods. CVTs are an established and readily available technology, so time based learning is applied.

3.4.2.2.7 *6-Speed Manual Transmissions (6MAN)*
Manual transmissions are entirely dependent upon driver input to shift gears: the driver selects when to perform the shift and which gear to select. This is the most efficient transfer of energy of all transmission layouts, because it has the lowest internal gear losses, with a minimal hydraulic system, and the driver provides the energy to actuate the clutch. From a systems viewpoint, however, vehicles with manual transmissions have the drawback that the driver may not always select the optimum gear ratio for fuel economy. Nonetheless, increasing the number of available ratios in a manual transmission can improve fuel economy by allowing the driver to select a ratio that optimizes engine operation more often. Typically, this is achieved through adding overdrive ratios to reduce engine speed at cruising velocities (which saves fuel through reduced engine pumping losses) and pushing the torque required of the engine towards the optimum level. However, if the gear ratio steps are not properly designed, this may require the driver to change gears more often in city driving, resulting in customer dissatisfaction. Additionally, if gear ratios are selected to achieve improved launch performance instead of to improve fuel economy, then no fuel saving effectiveness is realized.

NHTSA's MY 2011 CAFE final rule estimated an effectiveness increase of 0.5 percent for replacing a 5-speed manual with a 6-speed manual transmission, which was derived from confidential manufacturer data. NHTSA and EPA have found no evidence to dispute this estimate and chosen to use 0.5 percent reduction in CO_2 emissions and fuel consumption for replacing a 5-speed manual with a 6-speed manual transmission for this rule.

NHTSA updated costs to reflect the ICM low complexity markup of 1.11 which resulted in a incremental compliance cost of $250 as compared to $338 for MY 2012, with lower costs in later MYs due to the application of time-based learning factors. In the 2008 Staff Report, EPA estimated this RPE (1.5 RPE factor) at $107 (2006$) relative to a 5-speed manual transmission and for a MY 2015 vehicle. EPA updated this value to

2007$ and used a 1.11 ICM to get costs of $89 for a MY 2012 vehicle and $69 for a MY 2016 vehicle, both relative to a 5-speed manual transmission (2007$).

3.4.2.3 Hybrid and Electrification/Accessory Technologies

A Hybrid is a vehicle that combines two or more 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 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. A fourth mechanism to reduce petroleum fuel consumption, available only to plug-in hybrids, is by substituting the petroleum fuel energy with energy from another source, such as the electric grid. 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. While this approach has been used in cars such as the Honda Accord Hybrid (now discontinued), it is more likely to be used for vehicles like trucks where towing and/or hauling is 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 with a low battery, and therefore engines are traditionally not downsized for these vehicles.

Although hybrid vehicles using other energy storage concepts (flywheel, hydraulic) have been developed, the systems currently in production in the U.S. for passenger cars and light trucks use battery storage and electric drive systems. Hybrid

electric vehicles (HEV) are part of a continuum of vehicles using systems with differing levels of electric drive and electric energy storage. This range of vehicles includes relatively basic engine start/stop systems, HEV systems with varying degrees of electric storage and electric drive system capability, plug-in hybrid electric vehicles (PHEV) with differing degrees of all electric range and battery electric vehicles (EV) that rely entirely on electric drive and battery electric energy storage.

Different HEV, PHEV and EV concepts utilize these mechanisms differently, so they are treated separately for the purposes of this analysis. Below is a discussion of battery energy storage and the major hybrid concepts that were determined to be available in the near term. In many applications, particularly with PHEV and EV, the battery represents the most costly and system-limiting sub-component of the hybrid system. Currently, there are many battery chemistries being developed and refined for hybrid applications that are expected to enhance the performance of future hybrid vehicles.

3.4.2.3.1 *Batteries for MHEV, HEV, PHEV and EV Applications*

The design of battery secondary cells can vary considerably between MHEV, HEV, PHEV and EV applications.

MHEV batteries: Due to their lower voltage (12-42 VDC) and reduced power and energy requirements, MHEV systems will likely continue to use lead-acid batteries. MHEV battery designs differ from those of current starved-electrolyte (typical maintenance free batteries) or flooded-electrolyte (the older style lead-acid batteries requiring water "top-off") batteries used for starting, lighting and ignition (SLI) in automotive applications. Standard SLI batteries are primarily designed to provide high-current for engine start-up and then recharge immediately after startup via the vehicle's charging system. Deeply discharging a standard SLI battery will greatly shorten its life. MHEV applications are expected to use:

- Extended-cycle-life flooded (ELF) lead-acid batteries
- Absorptive glass matt, valve-regulated lead-acid (AGM/VRLA) batteries – or –
- Asymmetric lead-acid battery/capacitor hybrids (*e.g.*, flooded ultrabatteries)

MHEV systems using electrolytic double-layer capacitors are also under development.

HEV batteries: HEV applications operate in a narrow, short-cycling, charge-sustaining state of charge (SOC). Energy capacity in HEV applications is somewhat limited by the ability of the battery and power electronics to accept charge and by space and weight constraints within the vehicle design. HEV battery designs tend to be optimized for high power density rather than high energy density, with thinner cathode and anode layers and more numerous current collectors and separators (Figure 3-1).

EV batteries: EV batteries tend to be optimized for high energy density and are considerably larger than HEV batteries. PHEV battery designs are intermediate between power-optimized HEV and energy-optimized EV battery cell designs.

PHEV batteries: PHEV batteries must provide both charge depleting operation similar to an EV and charge sustaining operation similar to an HEV. Unlike HEV applications, charge-sustaining operation with PHEVs occurs at a relatively low battery state of charge (SOC) which can pose a significant challenge with respect to attaining acceptable battery cycle life. In the case of the GM Volt, this limits charge depleting operation to a minimum SOC of approximately 30 percent.[43] An alternative approach for PHEV applications that has potential to allow extension of charge depletion to a lower battery SOC is using energy-optimized lithium-ion batteries for charge depleting operation in combination with the use of supercapacitors for charge sustaining operation.[44]

Figure 3-1: Schematic representation of power and energy optimized prismatic-layered battery cells
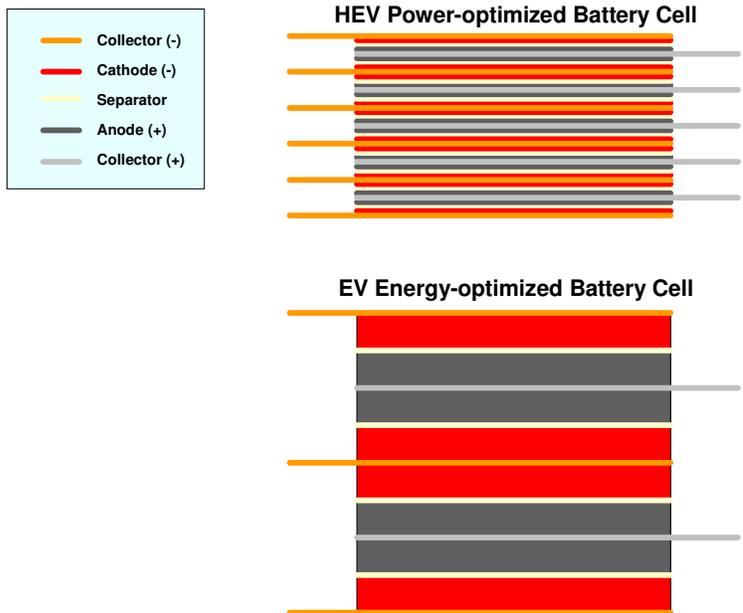
Power-split hybrid vehicles from Toyota, Ford and Nissan, integrated motor assist hybrid vehicles from Honda and the GM 2-mode hybrid vehicles currently use nickel-metal hydride (NiMH) batteries. Lithium-ion (Li-ion) batteries offer the potential to approximately double both the energy and power density relative to current NiMH batteries, enabling much more electrical-energy-intensive automotive applications such as PHEVs and EVs. Li-ion batteries for high-volume automotive applications differ substantially from those used in consumer electronics applications with respect to cathode chemistry, construction and cell size. Li-ion battery designs currently under

development by CPI (LG-Chem) for the GM Volt PHEV and by AESC, GS-Yuasa and A123 Systems (respectively) for the upcoming Nissan, Mitsubishi and Chrysler EVs use large-format, layered-prismatic cells assembled into battery modules. The modules are then combined into battery packs.

Cathodes for large-format, automotive Li-ion batteries are becoming increasingly focused on two chemistries – LiMn2O4-spinel (CPI, GS-Yuasa, AESC) and LiFePO4 (A123 Systems).

In addition to the purely hybrid technologies, which decrease 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. These steps, together with the hybrid technologies, are collectively referred to as "vehicle electrification" because they generally use electricity instead of engine power. In order to achieve consistency between the two modeling techniques, and to improve the number and range of technology offerings, the CAFE model was revised to include one additional mild hybrid technology. The high voltage or improved efficiency alternator (HVIA) technology, which was used in the MY 2011 CAFE final rule, is no longer represented as a separate technology and has instead been incorporated into this new mild hybrid technology, as discussed further below.

3.4.2.3.2 *Hybrid System Sizing and Cost Estimating Methodology*

NHTSA and EPA reviewed estimates of cost and effectiveness for hybrid and related electrical technologies and adjusted them as appropriate. Both agencies found the hybrid technology cost estimating methodology that Ricardo and NHTSA developed during the MY 2011 CAFE final rule to be reasonable and used it to estimate hybrid systems costs and account for variation in component sizing across both the hybrid types and vehicle subclasses. That method utilizes four pieces of data: (1) key component sizes for a midsize car by hybrid system type; (2) normalized costs for each key component; (3) component scaling factors that are applied to each vehicle class/subclass by hybrid system type; and (4) vehicle characteristics for the subclasses which are used as the basis for the scaling factors. During development of the methodology, NHTSA and Ricardo made several assumptions:

1) Hybrid controls hardware varies with the level of functionality offered by the hybrid technology. Assumed hybrid controls complexity for a 12V micro hybrid (MHEV) and belt integrated starter generator (BISG) was 25 percent of a strong hybrid controls system and the complexity for a Crank Integrated Starter Generator (CISG) was 50 percent. These ratios were estimates based on the directional need for increased functionality as system complexity increases.
2) Li-ion batteries for hybrid electric vehicles are currently entering production, including a 2010 MY Mercedes and Hyundai. One estimate from Anderman indicates that Li-ion market penetration will achieve 35 percent by 2015.[45]

However, as was discussed above, significant development effort is underway by a number of battery producers which could impact cost and overcome other technical concerns. Therefore it was assumed that mild hybrids (MHEV, BISG, CISG) and strong hybrids (PSHEV, 2MHEV, PHEV) will use either Li-ion or NiMH batteries, depending on cost considerations. However, plug-in hybrids will use Li-ion batteries only. Battery usage is discussed further below.

3) The plug-in hybrid battery pack was sized for a mid-sized car by assuming: the vehicle has a 20 mile all electric range and consumes an average of 300 W-hr per mile; the battery pack can be discharged down to 30 percent depth of discharge;[q] and the capacity of a new battery pack is 20 percent greater than at end of life (*i.e.*, range on a new battery pack is 24 miles).

4) All hybrid systems included a DC/DC converter which was sized to accommodate vehicle electrical loads appropriate for increased vehicle electrification in the time frame considered.

5) High voltage wiring scaled with hybrid vehicle functionality and could be represented as a fraction of strong hybrid wiring. These ratios were estimates based on the directional need for increased functionality as system complexity increases.

6) All hybrid systems included a supplemental heater to provide vehicle heating when the engine is stopped; however, in this analysis, it is assumed that only half of the vehicles will adapt this technology, as discussed further below. Only the strong hybrids included electric air conditioning to enable engine stop/start when vehicle air conditioning was requested by the operator.

Furthermore, NHTSA and Ricardo recognized that some strong hybrid systems replaced a conventional transmission with a hybrid-specific transmission, resulting in a cost offset (*i.e.*, a cost credit) for the removal of a portion of the clutches and gear sets within the transmission. In the MY 2011 CAFE final rule, the transmission cost in Table 3-16 below expressed hybrid transmission costs as a percentage of traditional automatic transmission cost, as described in the 2008 Martec Report, at $850 direct manufacturing costs (non-RPE/ICM). The method assumed that the mechanical aspect of a power-split transmission with a reduced number of gear sets and clutches resulted in a cost savings of 50 percent ($425) over a conventional transmission with torque converter. For a 2-mode hybrid, the mechanical aspects of the transmission are similar in complexity to a conventional transmission, so no cost savings was appropriate. The plug-in hybrid assumed a highly simplified transmission for electric motor drive, thus 25 percent of the base vehicle transmission cost was applied (resulting in a $638 credit).

The NHTSA MY 2011 CAFE final rule discusses in detail how the hybrid cost estimating methodology uses the information provided in the tables below to calculate costs for each of the strong hybrid systems used in this analysis. It also includes a step-by-step example for the midsize vehicle mild hybrid systems used in the MY 2011 CAFE

---

[q] The GM Volt operates between 30% DOD and 85% DOD. So there is 55% useable DOD, but charge sustaining operation starts at 30% and cycles between 30 and 35% DOD.

final rule.[46] As in that analysis, it is important to understand that the CISG technology replaces existing mild hybrid systems.[r]

NHTSA and EPA in reviewing the above made the following revisions. First, NHTSA and EPA revalidated the component sizes that were estimated for a midsize car for each type of hybrid system as shown in Table 3-16. However, NHTSA and EPA added an additional component, front engine accessory drive (FEAD), because hybridization often involves revision to the FEAD design such that certain devices (belts, pulleys, idlers, etc.) as well as other engine components (alternator, A/C compressor, and starter) may no longer be needed and can thus be eliminated, or may be de-specified to lower cost alternatives. This is applicable to CISG and the strong hybrid technologies, and is intended to account for cost savings associated with items that changed or are no longer required as a result of these technology applications.

Table 3-16. Component Sizes by Hybrid Type for a Midsize Car

Component	Hybrid Type				
	MHEV BISG	CISG	PSHEV	2MHEV	PHEV
Primary Motor power, continuous (kW)	3	11	45	45	45
Secondary Motor power, continuous (kW)	na	na	30	45	30
Primary Inverter power, continuous (kW)	3	11	45	45	45
Secondary Inverter power, continuous (kW)	na	na	30	45	30
Controls complexity (relative to strong hybrid)	25%	50%	100%	100%	100%
NiMH Battery Pack capacity (kW-hr)[1]	na	1	2	2	na
Li-Ion Battery Pack capacity (kW-hr)[1]	na	1	2	2	15
DC/DC Converter power (kW)	0.7	2	2	2	2
High Voltage Wiring (relative to strong hybrid)	na	50%	100%	100%	100%
Supplemental heating[2]	50%	50%	50%	50%	50%
Mechanical Transmission (relative to baseline vehicle)	100%	100%	50%	100%	25%
Electric AC	No	No	Yes	Yes	Yes
Blended Brakes	No	Yes	Yes	Yes	Yes
FEAD Credit	No	Yes	Yes	Yes	Yes
Charger power, continuous (kW)	na	na	na	na	3
1 - Assumes the use of either NiMH or Li-Ion, and not both.					
2 - Implemented through a reduction in component cost (50%)					

Second, the costs estimates of the key components were revised. The MY 2011 CAFE final rule was developed at a time when economic conditions were significantly different than those that currently exist, a time when many of the commodity materials used in the hybrid systems were more expensive than today. These changes in economic conditions were one of the factors leading to some of the cost revisions EPA and NHTSA jointly discussed and made. Differences in estimates provided by confidential sources to either EPA or NHTSA also played a part in the revisions. In addition, the agencies applied the new ICM mark-up factors instead of the RPE that was used previously. An appropriate ICM factor (1.45 for most mild and strong hybrid technologies) replaces the

---

[r] For the incremental CAFE model, before CISG is applied, the costs for MHEV and BISG are subtracted if they were previously applied.

previous RPE factor (1.5), as discussed in section 3.3.2.2.2. Specifically, the primary and secondary inverter cost per kilowatt were revised downward from $10 to $7, the controls cost was revised upward from $100 to $115, the DC/DC converter costs were revised from $100 to $88, the blended brake system that was revised from $400 to $310, and finally the fully learned, high volume production, cost per kilowatt hour (kW-hr) for NiMH batteries was revised from $350 to $320 to match the updated costs for Li-ion batteries discussed below.[s]

The cost for Li-ion batteries was also revised. As previously stated, Li-ion batteries are being implemented in series production in model year 2010. Battery technology is changing rapidly in the marketplace today, as discussed above, and is expected to continue along this path throughout the rulemaking period. OEMs are now forming relationships with battery manufacturers in an effort to research and develop not only new and improved battery technology, but also more efficient manufacturing processes capable of supporting high volume production. Accordingly, as shown in Table 3-17, the $600 per kW-hr used in the MY 2011 CAFE final rule was revised downward to $320 per kW-hr. The revision downward from $600/kW-hr in the MY 2011 CAFE final rule to $320/kW-hr in this analysis was done based a study by Deutsche Bank that estimated Li-ion battery costs at 300-400 €/kW-hr.[47] This was converted to $500/kW-hr then learned twice using volume-based learning to arrive at the $320/kW-hr applicable in the 2015 timeframe.

Li-ion batteries were originally restricted to plug-in hybrids only. Recent vehicle introductions confirm either battery technology can be used in any mild or strong HEV application. However, manufacturers are likely to consider cost highly in their selection of battery technology. If Li-ion battery prices remain high, NiMH would be the default battery technology for all hybrid electric vehicles. For plug-in hybrids Li-ion would continue to be required because plug-in hybrids demand higher energy density than NiMH can provide. Neither the CAFE nor OMEGA model predicts a high penetration of plug-in technology in achieving the standards.

Finally, the agencies assessed the cost savings associated with the FEAD credit discussed above. This cost was not previously represented in the hybrid cost model. As shown in Table 3-17 below, a $100 credit is shown which offsets directly the costs of the other components specified. This is the best approximation of the value of these items, based on NHTSA and EPA engineering assessment.

Estimates of each key component are shown in Table 3-17 below along with the sources of those estimates. The cost basis estimates assume fully learned, high-volume (greater than 1.2 million units per annum) production, and the costs shown are direct manufacturing costs that are not RPE or ICM adjusted. This table does not show a cost applicable to the belt integrated starter generator system (BISG) since it is a fixed cost that, like the automatic transmission pump cost, is not scaled by subclass as described later.

---

[s] In the MY 2011 final rule NHTSA had misstated this $350 per kW-hr cost as $50 per kW-hr due to a typographical error.

Table 3-17. Component Cost Basis at High Volumes and Data Sources stated in 2015 (2007 dollars)

COMPONENT	COST BASIS	DATA SOURCE
Primary Motor ($/kW)	$15	Martec 2008
Secondary Motor ($/kW)	$15	
Primary Inverter ($/kW)	$7	Confidential Business Information
Secondary Inverter ($/kW)	$7	
Controls	$115	
NiMH Battery Pack ($/kW-hr.)	$320	2011 CAFE FRM (with revision)
Li-ion Battery Pack ($/kW-hr.)	$320	Deutsche Bank 2008
DC/DC Converter (Size: 2kW)	$88	Confidential Business Information
High Voltage Wiring	$200	Martec 2008
Supplemental Heating	$42	
Mechanical Transmission	$850	Martec 2008 (to 4-spd auto)
Electric Air Conditioning	$450	Confidential Business Information
Blended Brakes	$310	
Charger	$100	
Automatic Transmission Pump	$75	Martec 2008
FEAD Credit	$(100)	Confidential Business Information

Third, NHTSA and EPA also revised component size/scaling assumptions for some vehicles (*i.e.*, large trucks). NHTSA and EPA recognized that some manufacturers may choose not to use supplemental cabin heating, opting instead to continue engine operation in the event heat demand occurs; therefore supplemental heating is specified for only half of the vehicles. Table 3-17 above indicates the 50 percent application rate implemented in the hybrid cost estimating methodology reducing the component cost from $84 to $42.

EPA and NHTSA also reviewed the choice of a 3 kW DC/DC converter as a component size input for a midsize vehicle, which represented a 250 amp current capability. In retrospect this is a high specification for a midsize vehicle, so the agencies revised the estimate to a 2 kW DC/DC converter, as shown in Table 3-17 above, which would represent a more reasonable 150 amp current capacity.

The scaling factor used for the primary and secondary motors and invertors on the large truck and SUV vehicles was revised. As in the MY 2011 CAFE final rule, a linear extrapolation was used from the midsize vehicle and extended it out to the largest of vehicles, the large truck class. This resulted in projected component sizes that are larger than those used on a commercially realized truck in this vehicle class, the Chevrolet Tahoe two-mode HEV. Accordingly, the scaling factors have been revised for this class (and the agencies have verified scaling factors for the other classes). This more closely approximates the motor and inverter sizes specified in the Tahoe application. For future

analysis, the agencies are considering whether it may be more accurate to use one set of scaling for passenger cars and another different set for light trucks.

Another revision involves the addition of a stand-alone higher voltage Start-Stop/ BISG mild hybrid system. NHTSA and EPA determined that by applying a cost increase to the MHEV technology to allow for a voltage increase (lead acid batteries) and efficiency improvements to the alternator, the system would then approximate the higher voltage Start-Stop/BISG applied by EPA. Based on confidential sources, the estimates provided were first converted to 2007 dollars and then reverse-learned through two cycles, since volume learning is applicable, to arrive at a non-RPE/ICM incremental compliance cost of $229. This cost is applicable to all classes that use higher voltage Start-Stop/BISG, and is not scaled by any vehicle attribute.

Component scaling factors for each type of hybrid system are as shown in Table 3-18 below.

Table 3-18. Component Scaling Factors applied to Vehicle Class for each Hybrid System

Component	Hybrid Type				
	MHEV	**CISG**	**PSHEV**	**2MHEV**	**PHEV**
Primary Motor	Engine displacement	Curb weight	Curb weight[1]		Engine power
Secondary Motor	na	na	Engine displacement		Curb weight[2]
Primary Inverter	Primary motor power				
Secondary Inverter	na	na	Secondary motor power		
Controls	Complexity				
NiMH Battery Pack	na	Curb weight			na
Li-Ion Battery Pack	na				Curb weight
DC/DC Converter	Curb weight[3]				
High Voltage Wiring	na	Vehicle footprint			
Supplemental heating	Vehicle footprint				
Mechanical Transmission	Same for all vehicle classes				
Electric AC	na	na	Vehicle footprint		
Blended Brakes	na	Same for all vehicle classes			
Charger	na	na	na	na	Same for all vehicle classes

[1] For all vehicle classes except for performance classes which use Engine Torque

[2] Curb weight used as surrogate for vehicle road load

[3] Curb weight used as surrogate for vehicle electrical load

Regarding the market data file from the MY 2011 CAFE final rule, NHTSA and EPA did not make any revisions to the average vehicle characteristics for each vehicle subclass as shown in Table 3-19, which defines the average vehicle characteristics for each vehicle subclass. These characteristics were used as the basis of the scaling factors in the CAFE and OMEGA models. EPA used these vehicle specifications solely for the purpose of scaling hybrid vehicle attributes in order to remain consistent with the NHTSA methodology.

Table 3-19. **Key Vehicle Characteristics For Each Vehicle Subclass for CAFE Model**

Vehicle Subclass	Curb Weight (lbs)	Footprint (ft2)	Engine Disp. (L)	Engine Power (hp)	Torque (ft-lb)
Subcompact Car	2795	41	1.9	134	133
Compact Car	3359	44	2.2	166	167
Midsize Car	3725	47	2.9	205	206
Large Car	4110	50	3.4	258	248
Performance Subcompact Car	3054	40	2.7	260	260
Performance Compact Car	3516	44	3.0	269	260
Performance Midsize Car	3822	47	3.9	337	318
Performance Large Car	4189	51	4.8	394	388
Minivan	4090	50	3.3	247	242
Small Truck	3413	45	2.6	178	185
Medium Truck	4260	50	3.6	250	256
Large Truck	5366	63	5.0	323	352

3.4.2.3.3 *Electrical 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 may require a higher voltage system which may add cost and complexity.

In the MY 2011 CAFE final rule, NHTSA estimated a 1 to 2 percent effectiveness based on the 2002 NAS report, a Sierra Research report, and confidential manufacturer

data. NHTSA and EPA reviewed these effectiveness estimates and found them to be accurate, thus they have been retained for this final rule.

Regarding costs, in the MY 2011 CAFE final rule, NHTSA estimated EPS at $105-120 at 1.5 RPE mark-up factor. NHTSA and EPA adjusted the EPS cost for the current rulemaking based on a review of the specification of the system. Adjustments were made to include potentially higher voltage or heavier duty system operation, such as would be required on some hybrid trucks. Accordingly, higher costs were estimated for systems with higher capability. After accounting for the differences in system capability and applying the ICM markup of low complexity technology of 1.11, the estimated costs for this rulemaking are $106 for a MY 2012 vehicle (2007$). With time-based learning, this cost would be $94 for a MY 2016 vehicle (2007$). As EPS systems are in widespread usage today, time-based learning is deemed applicable.

3.4.2.3.4 *Improved Accessories (IACC)*

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 starting of the engine. Further benefit may be obtained when electrification is combined with an improved, higher efficiency engine alternator. 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.[t]

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 for this rulemaking.

NHTSA and EPA jointly reviewed the estimates of 1 to 2 percent effectiveness estimates used in the MY 2011 CAFE final rule and found them to be accurate for Improved Electrical Accessories. For its analysis, NHTSA simply adjusted the MY 2011 CAFE final rule costs to reflect the new ICM markup of low complexity value of 1.11, resulting in a cost estimate for this rulemaking of $128 at MY 2012 (2007$). Improved

---

[t] In the CAFE model, IACC 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.

accessory systems are in production currently and thus time-based learning is applied. For its analysis, EPA considered both an accessory upgrade to a 12 Volt system and a combined accessory upgrade with conversion to a 42 Volt system. The accessory upgrade itself is estimated to cost $86 in MY 2012 and $76 in MY 2016 (with time-based learning; both in 2007$). The conversion to a 42 Volt electrical system is estimated to cost $97 for a MY 2012 vehicle and $86 for a MY 2016 vehicle (again with time-based learning; both in 2007$).

3.4.2.3.5 *12V Micro Hybrid (MHEV)*

12V Micro-Hybrid (MHEV) systems are the most basic of hybrid systems and offer only the ability to turn the engine off when the vehicle is stopped or potentially during deceleration (*i.e.*, idle stop). Their low cost and adaptability to existing powertrains and platforms can make them attractive for some applications. The conventional belt-driven alternator is replaced with a belt-driven, enhanced power starter-alternator and a redesigned front-end accessory drive system. A conventional 12V gear-reduction starter is retained to ensure reliable cold-weather starting. Also, during idle-stop, some functions such as power steering and automatic transmission hydraulic pressure are lost, so electric power steering and an auxiliary transmission pump are needed.

Although EPA does not use the 12 V version of this stop-start technology, NHTSA and EPA jointly reviewed the assumptions. The effectiveness estimates for this technology ranged from 2.0 to 4.0 percent, depending on whether the vehicle is equipped with a 4-, 6- or 8-cylinder engine, with the 4-cylinder engine having the lowest range and the 8-cylinder having the highest. The estimates reflect the limited capability of 12 volt systems; sources citing higher estimates typically involve higher voltage systems that have increased capability.

For this final rule, the system specifications assumed in the MY 2011 CAFE final rule were applied (*i.e.*, use of a 3 kW motor and a DC/DC converter) and the hybrid technology cost method produced costs like those in MY 2011 final rule; however, the use of new ICM markups resulted in costs ranging from $288 for Subcompact subclass to $410 for the Large Performance subclass. This technology is not applied to the Large Truck and SUV subclass due to the heavy duty utility requirements of these vehicles. Time-based learning is considered applicable, and a schematic of the MHEV system is shown in Figure 3-2.

Figure 3-2 Schematic of MHEV type System [Husted, 2003]
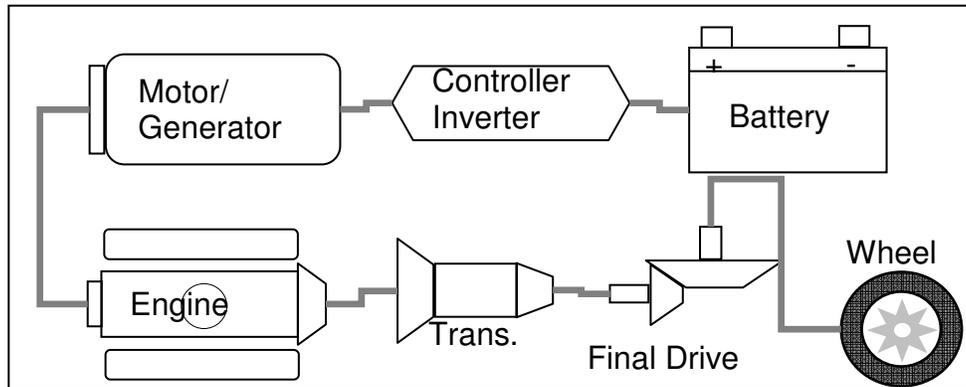
3.4.2.3.6 Higher Voltage Stop-Start/Belt Integrated Starter Generator (BISG)

Higher Voltage Stop-Start and Belt Mounted Integrated Starter Generator (BISG) systems are similar to a micro-hybrid system, offering idle-stop functionality, except that they utilize larger electric machine and a higher capacity battery, typically 42 volts or above, thus enabling a limited level of regenerative braking which is generally not applicable to 12 volt systems. The larger electric machine and battery also enables a limited degree of power assist, which MHEV cannot provide. However, because of the limited torque capacity of the belt-driven design, these systems have a smaller electric machine, and thus less capability than crank-integrated or stronger hybrid systems. These systems replace the conventional alternator with a belt-driven starter/alternator and may add 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.

The effectiveness estimates used for these technologies range from 3.0 to 7.5 percent depending on vehicle subclass. The CAFE model, which applies this effectiveness incrementally to the prior 12 Volt technology, uses estimates of 4 to 6 percent. The estimates are based on those found in the 2002 NAS and 2004 NESCCAF reports, and confidential manufacturer data.

EPA estimates an incremental compliance cost range of $549 (small car) to $682 (large truck) for a MY 2012 vehicle and including a medium complexity ICM of 1.25 (2007$). With volume-based learning applied, these become $351 (small car) and $437 (large truck) for a MY 2016 vehicle (2007$). The cost estimate in the CAFE model is incremental to the 12 Volt micro hybrid systems as noted above, and therefore is adjusted upwards to $286 to reflect the additional battery capacity, wiring upgrades, and a larger optimized electric machine only. The $286 reflects volume-based learning factors and the ICM medium-complexity markup of 1.25.

3.4.2.3.7 *Integrated Motor Assist (IMA)/Crank Integrated Starter Generator (CISG)*

IMA is a system developed and marketed by Honda[48] and is similar to CISG. They both utilize a thin axial electric motor bolted to the engine's crankshaft and connected to the transmission through a torque converter or clutch. The axial motor is motor/generator that typically operates above 100 volts (but lower than the stronger hybrid systems discussed below, which typically operate at around 300 volts) and can provide sufficient torque for launch as well as generate sufficient current to provide significant levels of brake energy recovery. The motor/generator also acts as the starter for the engine and can replace a typical accessory-driven alternator. Current IMA/CISG systems typically do not launch the vehicle on electric power alone, although some commercially available systems can cruise on electric power and dual-clutch IMA/CISG systems capable of all-electric drive are under development. IMA and CISG could be applied to all classes of vehicles. A schematic of the Honda IMA system is shown in Figure 3-3.

Figure 3-3 Schematic of Honda IMA System [Husted, 2003]
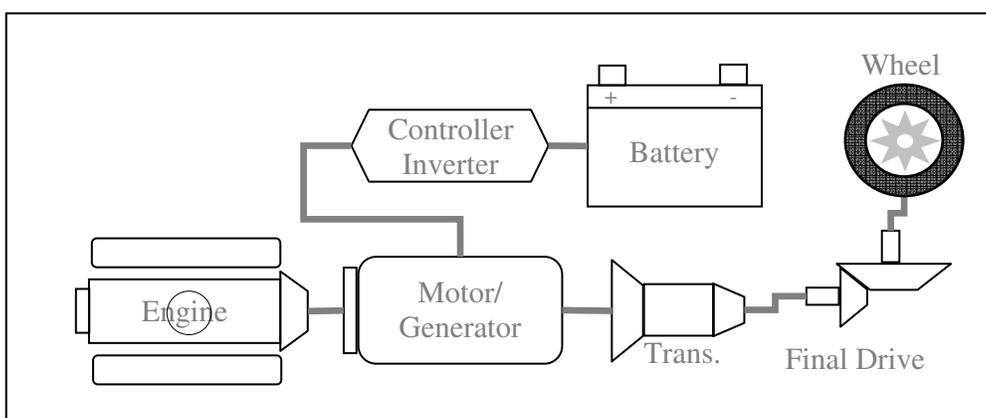
NHTSA did not have an equivalent technology to CISG in the MY 2011 CAFE final rule (the ISG technology used in the MY 2011 final rule was envisioned to be less capable than the CISG technology defined here). For the CISG technology, NHTSA estimated a net effectiveness range of 16 to 20 percent, relative to the baseline vehicle and across all vehicle subclasses in this analysis. The CAFE model therefore applies an incremental effectiveness of approximately 8.6 to 8.9 percent relative to the BISG technology and dependent on vehicle subclass, except for large truck and SUV in which case BISG does not apply. Note that the net effectiveness assumptions used in this rule do not include engine downsizing, or any other effectiveness gains from engine, transmission, or vehicle technologies added to the vehicle by the modeling process.

EPA relied on a combination of certification data (comparing vehicles available with and without a hybrid system and backing out other components where appropriate) and manufacturer-supplied information to determine that the effectiveness of these systems in terms of CO_2 reduction is 30 percent for small cars, 25 percent for large cars,

and 20 percent for minivans and small trucks similar to the range estimated by NHTSA for the respective vehicle classes. The effectiveness for small cars assumes engine downsizing to maintain approximately equivalent performance. The large car, minivan, and small truck effectiveness values assume less engine downsizing in order to improve vehicle performance and/or maintain towing and hauling performance.

EPA has estimated these costs, relative to a base engine/transmission, as $4,459 (small car) to $6,924 (large truck) for a MY 2012 vehicle and including a high complexity ICM of 1.45 (2007$). With volume-based learning, these costs become $2,854 and $4,431, respectively, for a MY 2016 vehicle (2007$). NHTSA has estimated the MY 2012 compliance cost, relative to a BISG baseline, to range from $2,791 for Subcompact vehicles to $3,611 for Midsize Light Truck and Minivan vehicles. These include a high complexity ICM markup factor of 1.45 for this technology. As this technology is still in limited production use, volume-based learning is applied, resulting in lower costs in later years.

3.4.2.3.8 *Power Split Hybrid*

The Power Split hybrid (PSHEV) has the ability to move the vehicle on electric power only. It replaces the vehicle's transmission with a single planetary gear and a motor/generator. A second, more powerful motor/generator is directly connected to the vehicle's final drive. The planetary gear splits engine power between the first motor/generator and the final drive. The first motor/generator uses power from the engine to either charge the battery or supply power to the wheels. The speed of the first motor/generator determines the relative speed of the engine to the wheels. In this way, the planetary gear allows the engine to operate independently of vehicle speed, much like a CVT. The Toyota Prius and the Ford Hybrid Escape are two examples of power split hybrid vehicles.

In addition to providing the functions of idle engine stop, subsequent restart and regenerative braking, this hybrid system allows for pure EV operation. The power split system provides very good fuel consumption in city driving. During highway cycles, the hybrid functions of regenerative braking, engine start/stop and optimal engine operation cannot be applied as often as in city driving, and so the effectiveness in fuel consumption is less. Additionally, it is less efficient at highway speeds due to the fact that the first motor/generator must be spinning at a relatively high speed and therefore incurs losses. Newer designs incorporate a gear-reduction motor to provide improved high speed efficiency and improved matching of motor torque to engine torque.

The Power Split hybrid also reduces the cost of the transmission, replacing a conventional multi-speed unit with a single planetary gear. The electric components are bigger than those in mild hybrid and IMA/CISG configurations so the costs are correspondingly higher.

EPA and NHTSA used a combination of manufacturer-supplied information and a comparison of vehicles available with and without a hybrid system from EPA's fuel economy test data to determine that the effectiveness is 19 to 36 percent for the classes to

which it is applied. The estimate would depend on whether engine downsizing is also assumed. As an example, See Table 3-20 and Table 3-21, which assume some level of engine downsizing. In the CAFE incremental model, the range of effectiveness used was 23 to 33 percent as engine downsizing is not assumed (and accounted for elsewhere).

Table 3-20 Large Car Power Split Certification Data

		Tailpipe CO_2		
		City	Hwy	55/45 comb.
Nissan Altima				
	3.5L CVT	444	306	386
	HEV 2.5L PS	317	254	286
	Net % difference			-26%
Toyota Camry				
	3.0L 5-auto	404	286	355
	HEV 2.4L PS	222	234	228
	Net % difference			-36%
Lexus GS				
	4.3L 6-auto	493	355	423
	HEV 3.5L PS	355	317	341
	Net % difference			-19%

Table 3-21 Small Truck Power Split Certification Data

		Tailpipe CO_2		
		City	Hwy	55/45 comb.
Ford Escape 4X4				
	3.0L 4-auto	467	386	423
	HEV 2.3L PS	277	306	286
	Net % difference			-32%
Ford Escape 4X2				
	3.0L 4-auto	444	370	404
	HEV 2.3L PS	247	286	261
	Net % difference			-35%
Toyota Highlander 4X4				
	3.3L 5-auto	493	370	423
	HEV 3.3L PS	286	329	306
	Net % difference			-28%

Using the hybrid cost estimating methodology with updated component costs, EPA established a compliance cost range of $4,481 (small cars) to $8,145 (large trucks) relative to the base engine and transmission for a MY 2012 vehicle (all in 2007$). With time-based learning, these costs become $3,967 and $7,210, respectively, for a MY 2016 vehicle (2007$). Using the same methodology, NHTSA established overall PSHEV system costs with electric power steering (EPS) and improved accessories (IACC) ranging from $5,509 to $11,534 for MY 2012, which leads to incremental costs in the CAFE model ranging from $1,600 to $6,723 depending on the subclass (all in 2007$). The estimates were determined with a 1.45 ICM for a high complexity technology.

Based on Toyota Prius and Ford Escape/Mariner market sales, PSHEV technology with NiMH battery is considered mature from the perspective of cost learning, and time-based learning is applicable. However, the Li-ion battery technology is undergoing rapid development and it is expected that some manufacturers may choose to use Li-ion batteries on PSHEV applications during this rulemaking period. Because this combination of technology is new, volume-based learning would be appropriate for such applications. For cost analysis in the NPRM and final rule, volume-based learning is used for PSHEV which assumes use of Li-ion batteries. This volume-based learning for Li-ion is supported by the 2008 Deutsche Bank study.

3.4.2.3.9   2-Mode Hybrid

The 2-Mode Hybrid (2MHEV) uses an adaptation of a conventional stepped-ratio automatic transmission which replaces some of the transmission clutches with two electric motor/generators, allowing the transmission to act like a CVT. The motor/generators control the ratio of engine speed to vehicle speed. The clutches allow the motors to be bypassed improving the transmission's torque capacity and the efficiency for improved fuel economy at highway speeds. This type of system is used in the Chevrolet Tahoe Hybrid.

In addition to providing the hybrid functions of engine stop and subsequent restart and regenerative braking, the 2MHEV allows for pure EV operation. The two motor/generators allow the engine to be run in efficient operating zones. The 2-mode system provides significantly reduced CO_2 emissions and fuel consumption. The primary motor/generator is comparable in size to that in the PSHEV system, but the secondary motor/generator is larger. The 2-mode system cost is greater than that for the power split system due to the additional transmission complexity and secondary motor sizing.

The battery pack for 2MHEV is assumed to be 300V NiMH as is used in current 2MHEV systems today, however GM recently announced an agreement with Hitachi to provide Li-ion battery packs for 2012 and later 2MHEVs.

For this rule the CAFE model considered a range of 23 to 33 percent with a midpoint of 28 percent, assuming no engine downsizing to preserve the utility nature of medium and large trucks (*e.g.*, maintaining full towing capability even in situations with low battery charge) and EPA estimates CO_2 emissions reduction effectiveness to be 25 percent for large trucks (LDT3 and LDT4 categories) based on vehicle certification data. EPA estimates an effectiveness of 40 percent for smaller vehicles.

EPA and NHTSA estimated MY 2012 costs using the updated component costs and scaling factors in the hybrid cost estimating methodology discussed above. EPA estimated the compliance cost to range from $5,469 for large car to $7,236 for large truck/SUV relative to the base engine/transmission (all in 2007$). NHTSA determined incremental cost estimates ranging from $3,521 to $5,779 for light-duty truck applications in the CAFE model. These include the 1.45 ICM markup value for high complexity technology. Given that the CAFE and OMEGA models classify vehicles

differently, these numbers varied slightly in the modeling to reflect the different classification methods of the OMEGA and CAFE models, as described in the individual NHTSA and EPA FRIAs. Volume-based learning is applicable to this technology.

3.4.2.3.10 Plug-In Hybrid

Plug-In Hybrid Electric Vehicles (PHEVs) are very similar to Hybrid Electric Vehicles, but with three significant functional differences. The first is the addition of a means to charge the battery pack from an outside source of electricity (*e.g.*, the electric grid). Second, a PHEV would have a larger battery pack with more energy storage, and a greater capability to be discharged. Finally, a PHEV would have a control system that allows the battery pack to be significantly depleted during normal operation.

Table 3-22 below, illustrates how PHEVs compare functionally to both hybrid electric vehicles (HEV) and electric vehicles (EV). These characteristics can change significantly within each class/subclass, so this is simply meant as an illustration of the general characteristics. In reality, the design options are so varied that all these vehicles exist on a continuum with HEVs on one end and EVs on the other.

Table 3-22 Conventional, HEVs, PHEVs, and EVs Compared

	Increasing Electrification			
Attribute	Conventional	HEV	PHEV	EV
Drive Power	Engine	Blended Engine/Electric	Blended Engine/Electric	Electric
Engine Size	Full Size	Full Size or Smaller	Smaller or Much Smaller	No Engine
Electric Range	None	None to Very Short	Short to Medium	Medium to Long
Battery Charging	None	On-Board	Grid/On-Board	Grid Only

Deriving some of their propulsion energy from the electric grid provides several advantages for PHEVs. PHEVs offer a significant opportunity to replace petroleum used for transportation energy with domestically-produced electricity. The reduction in petroleum usage does, of course, depend on the amount of electric drive the vehicle is capable of under its duty cycle. PHEVs also provide electric utilities the possibility to increase electric generation during "off-peak" periods overnight when there is excess generation capacity and electricity prices are lower. Utilities like to increase this "base load" because it increases overall system efficiency and lowers average costs. Utilities are also investigating the use of PHEV and EV batteries as a source of grid storage capacity to provide ancillary services for grid stabilization purposes. PHEVs can lower localized emissions of criteria pollutants and air toxics especially in urban areas by operating on electric power. The emissions from the power generation occur outside the urban area at the power generation plant which provides health benefits for residents of the more densely populated urban areas by moving emissions of ozone precursors out of the urban air shed. Unlike most other alternative fuel technologies, PHEVs can initially use an existing infrastructure for refueling (charging and liquid refueling) so investments in infrastructure may be reduced.

In analyzing the impacts of grid-connected vehicles like PHEVs and EVs, the emissions from the electrical generation can be accounted for if a full upstream and downstream analysis is desired. While this issue is being studied on an on-going basis, upstream CO_2 emissions are not unique to grid-connected technologies and so are not included in this analysis.

PHEVs will be considerably more costly than conventional vehicles and some other advanced technologies. To take advantage of their capability, consumers would have to be willing to charge the vehicles nightly, and would need access to electric power where they park their vehicles. For many urban dwellers who may park on the street, or in private or public lots or garages, charging may not be practical. Charging may be possible at an owner's place of work, but that would increase grid loading during peak hours which would eliminate some of the benefits to utilities of off-peak charging versus on-peak. Oil savings will still be the same in this case assuming the vehicle can be charged fully.

The effectiveness potential of PHEVs depends on many factors, the most important being the energy storage capacity designed into the battery pack. To estimate the fuel consumption and tailpipe CO_2 reduction potential of PHEVs, EPA has developed an in-house vehicle energy model (PEREGRIN) to estimate the fuel consumption/CO_2 emissions reductions of PHEVs. This model is based on the PERE (Physical Emission Rate Estimator) physics-based model used as a fuel consumption input for EPA's MOVES mobile source emissions model.

The PHEV small car, large car, minivan and small trucks were modeled using parameters from a midsize car similar to today's hybrids and scaled to each vehicle's weight. The large truck PHEV was modeled separately assuming no engine downsizing. PHEVs can have a wide variation in the All Electric Range (AER) that they offer. Some PHEVs are of the "blended" type where the engine is on during most of the vehicle operation, but the proportion of electric energy that is used to propel the vehicle is significantly higher than that used in a PSHEV or 2MHEV. Each PHEV was modeled with enough battery capacity for a 20-mile-equivalent AER and a power requirement to provide similar performance to a hybrid vehicle. 20 miles was selected because it offers a good compromise for vehicle performance, weight, battery packaging and cost. Given expected near-term battery capability, a 20 mile range represents the likely capability that will be seen in PHEVs in the near-to-mid term.

To calculate the total energy use of a PHEV, the PHEV can be thought of as operating in two distinct modes, electric (EV) mode, and hybrid (HEV) mode. At the tailpipe, the CO_2 emissions during EV operation are zero. The EV mode fuel economy can then be combined with the HEV mode fuel economy using the Utility Factor calculation in SAE J1711 to determine a total MPG value for the vehicle. (See Table 3-23)

Table 3-23 Sample Calculation of PHEV Gasoline-Equivalent CO_2 Reduction

	Midsize Car	Large Truck
EV energy comb (0.55 city / 0.45 hwy)	0.252 kwh/mi	0.429 kwh/mi
EV range (from PEREGRIN)	20 miles	20 miles
SAE J1711 utility factor	0.30	0.30
HEV mode comb FE (0.55 city / 0.45 hwy)	49.1 mpg	25.6 mpg
Total UF-adjusted FE (UF*FCEV + (1-UF)*FCHEV)	70.1 mpg	36.6 mpg
Baseline FE	29.3 mpg	19.2 mpg
Percent FE gain	139%	90%
Percent CO_2 reduction	-58%	-47%

Calculating a total fuel consumption and tailpipe CO_2 reduction based on model outputs and the Utility Factor calculations results in a 58 percent reduction for small cars, large cars, minivans, and small trucks. For large trucks, the result is a 47 percent reduction. The lower improvement is due to less engine downsizing in the large truck class. The CAFE model does not apply this technology to medium and large trucks and SUVs.

Using the hybrid cost estimating model and updated component costs, EPA and NHTSA determined MY 2012 incremental cost estimates for the CAFE model ranging from $11,527 for a subcompact car to $19,265 for a midsize performance car. This includes the 1.64 ICM markup value for very high complexity technology. In the OMEGA model, and relative to a IMA/ISA/BSG, these values range from $6,922 for small car to $12,467 for a large truck, and relative to power-split hybrid, these values range from $5,423 for small car to $9,643 for large truck (all values for MY 2016 in 2007$). Volume-based learning is applied to plug-in hybrid costs since this is a newly emerging technology.

3.4.2.4 Vehicle Technologies

3.4.2.4.1 Mass Reduction

Reducing a vehicle's mass, or down-weighting the vehicle, decreases fuel consumption by reducing the energy demand needed to overcome forces resisting motion, and rolling resistance. 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 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. For example, use of a smaller, lighter engine with lower torque-output subsequently allows the use of a smaller, lighter-weight transmission and drive line components. Likewise, the compounded weight reductions of the body, engine and drivetrain reduce stresses on the suspension components, steering components, wheels, tires and brakes, allowing further reductions in the mass of these subsystems. The reductions in unsprung masses such as brakes, control arms, wheels and tires further reduce stresses in the suspension mounting points. This produces a compounding effect of mass reductions.

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."[49] 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.[50] 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.

Mass reduction is broadly applicable across all vehicle subsystems including the engine, exhaust system, transmission, chassis, suspension, brakes, body, closure panels, glazing, seats and other interior components, engine cooling systems and HVAC systems. It is estimated that up to 1.25 kilograms of secondary weight savings can be achieved for every kilogram of weight saved on a vehicle when all subsystems are redesigned to take into account the initial primary weight savings.[51,52]

Mass reduction can be accomplished by proven methods such as:

- Smart Design: Computer aided engineering (CAE) tools can be used to better optimize load paths within structures by reducing stresses and bending moments applied to structures (Figure 3-4 through Figure 3-6). This allows better optimization of the sectional thicknesses of structural components to reduce mass while maintaining or improving the function of the component. Smart designs also integrate separate parts in a manner that reduces mass by combining functions or the reduced use of separate fasteners. In addition, some "body on frame" vehicles are redesigned with a lighter "unibody" construction.

- Material Substitution: Substitution of lower density and/or higher strength materials into a design in a manner that preserves or improves the function of the component. This includes substitution of high-strength steels, aluminum, magnesium or composite materials for components currently fabricated from mild steel.

- Reduced Powertrain Requirements: Reducing vehicle weight sufficiently allows for the use of a smaller, lighter and more efficient engine while maintaining or increasing performance. Approximately half of the reduction is due to these reduced powertrain output requirements from reduced engine power output and/or

displacement, changes to transmission and final drive gear ratios. The subsequent reduced rotating mass (*e.g.*, transmission, driveshafts/halfshafts, wheels and tires) via weight and/or size reduction of components are made possible by reduced torque output requirements.

Using smart design, material substitution and space efficient designs have already been integrated into vehicles as new platforms cycle into production although net vehicle weight and performance has continued to increase (Figure 3-4).
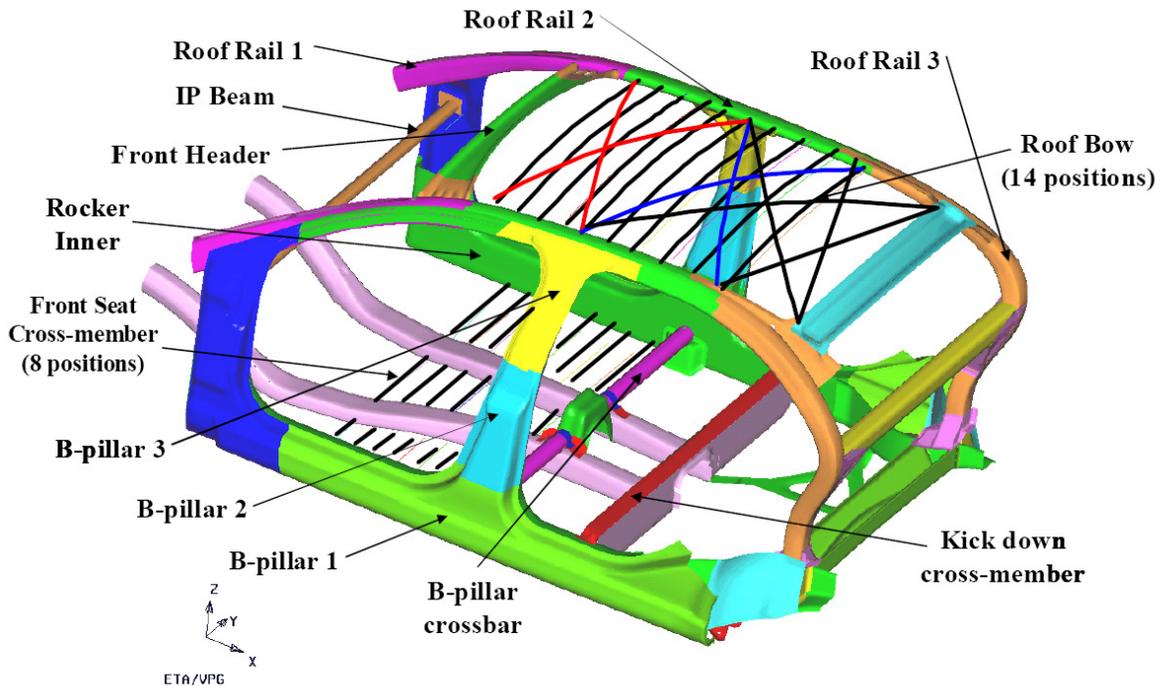
Figure 3-4: Example of CAE optimization of the design and position of the roof rails and front seat cross-member for the "Future Generation Passenger Compartment."[53] The thin lines represent relative positions for roof bows and front cross-members considered during iterations of the CAE analysis of the vehicle structure. The different colors given to the structural components represent differences in sectional material thickness within this particular CAE modeling run.

Material = 500800
Thickness= 1.0mm

Material = 500800
Thickness= 0.6mm

Thickness= 0.7mm

Thickness= 0.8mm

| Baseline Design Mass = 13.9 kg | Optimized Design Mass = 8.2 kg |

41%
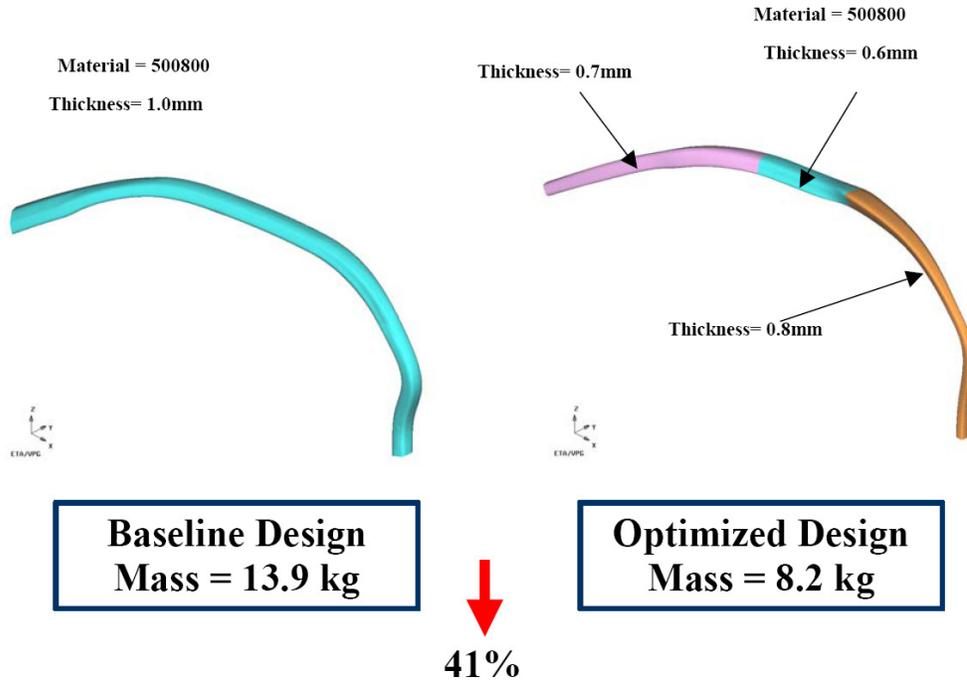
Figure 3-5: Example of CAE optimization of a roof-rail design for the "Future Generation Passenger Compartment" that reduces component mass by 41%.[53]

| Baseline Design Mass = 12.58 kg | Optimized Design Mass = 5.38 kg |

57%
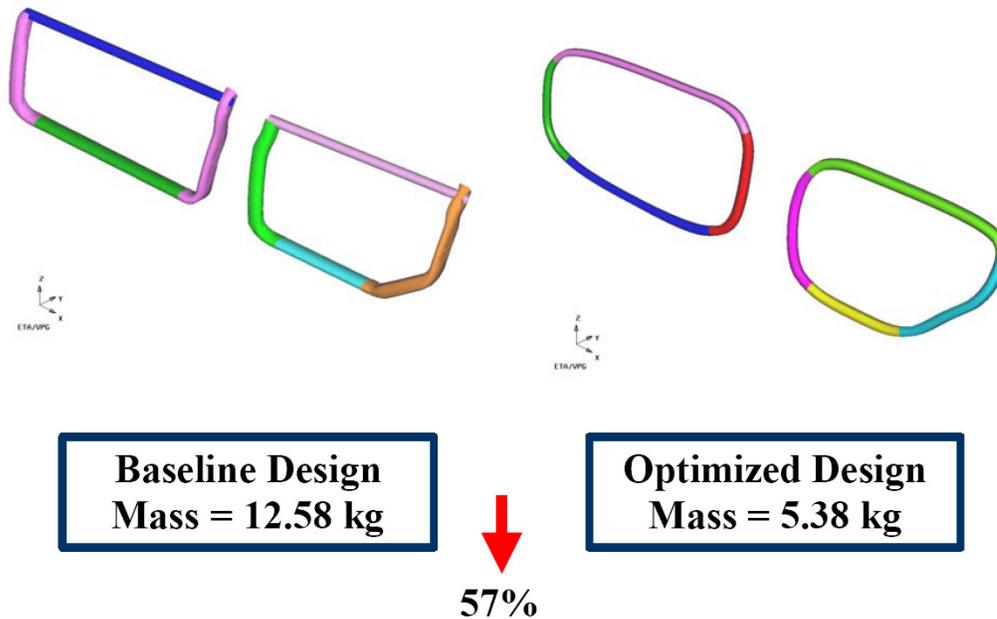
Figure 3-6: Example of CAE optimization of a door-beam design for the "Future Generation Passenger Compartment" that reduces component mass by 57% and reduces part count and assemby.[53]

Figure 3-7: Lightweight, tubular front door intrusion beams (2007 Civic)

- Automotive companies have largely used weight savings in some vehicle subsystems to offset or mitigate weight gains in other subsystems from increased feature content (sound insulation, entertainment systems, improved climate control, panoramic roof, etc.).

- Lightweight designs have also been used to improve vehicle performance parameters by increased acceleration performance or superior vehicle handling and braking.

Many manufacturers have already announced proposed future products plans reducing the weight of a vehicle body through the use of high strength steel body-in-white, composite body panels, magnesium alloy front and rear energy absorbing structures reducing vehicle weight sufficiently to allow a smaller, lighter and more efficient engine. Nissan will be reducing average vehicle curb weight by 15% by 2015.[54] Ford has identified weight reductions of 250 to 750 lbs per vehicle as part of its implementation of known technology within its sustainability strategy between 2011 and 2020.[55] Mazda plans to reduce vehicle weight by 220 pounds per vehicle or more as models are redesigned.[56,57] Ducker International estimates that the average curb weight of light duty vehicle fleet will decrease approximately 2.8% from 2009 to 2015 and approximately 6.5% from 2009 to 2020 via changes in automotive materials and increased change-over from previously used body-on-frame automobile and light-truck designs to newer unibody designs.[54]

NHTSA in the CAFE model has used a tiered approach in material substitution to reduce mass without considering other means of vehicle mass reduction. MS1, a 1.5 percent mass reduction, is applicable in any year at refresh or redesign. MS2, a 3.5 to 8.5 percent mass reduction incremental to MS1, is only available in MY 2014 and beyond in an attempt to mimic manufacturers' planned applications of mass reduction/material substitution in later years. For smaller vehicles, MS2 was limited to a 3.5 percent mass reduction of mass reduction/material substitution, but for larger cars and trucks up to 8.5 percent mass reduction was allowed.

In the CAFE model, MS2 is cumulative to MS1, as it is only applied after MS1; therefore the maximum weight reduction that can occur for smaller subclass vehicles is 5 percent, while large cars, truck, and SUVs could experience up to a 10 percent weight reduction. Making the MS2 technology unavailable until MY 2014 is intended to recognize the lead time required to implement platform redesigns that would be necessary for these levels of weight reduction.

NHTSA and EPA estimate that a 10 percent mass reduction with engine downsizing results in a 6.5 percent reduction in fuel consumption while maintaining equivalent vehicle performance (*i.e.*, 0-60 mph time, towing capacity, etc.) which is consistent with estimates in the 2002 NAS report. For small amounts of mass reduction, such as the 1.5 percent used at vehicle refresh in NHTSA's modeling, no engine downsizing will be used and a 10 percent mass reduction without engine downsizing will result in a 3.5 percent reduction in fuel consumption.[58,59,60]

NHTSA and EPA have reviewed three studies of mass reduction/material substitution and the associated cost. The 2002 NAS,Report estimated that vehicle weight could be reduced for approximately $1.50 per pound, along with 3 to 4 percent reductions in fuel consumption, without engine downsizing, from a 5 percent reduction in vehicle weight, at a cost of $210-$350. This translates into $1.50 per pound, assuming a 3,800 pound base vehicle and using the midpoint cost. Additionally, Sierra Research estimated that a 10 percent reduction, with compounding, could be accomplished for a cost of $1.01 per pound.[61] Finally, an MIT study[62] estimated that the weight of a vehicle could be reduced by 14 percent, with no compounding, for a cost of $1.36 per pound. The final cost estimate is $1.32 per pound and is based on the average of the three referenced studies. Applying an ICM factor of 1.11 for a low complexity technology results in a compliance cost of $1.48 per pound. For the vehicle mass reduction technologies, neither volume-based nor time-based cost reductions are applied, since many of the materials under consideration are commodity based.

3.4.2.4.2 Low Drag Brakes (LDB)

Low drag brakes reduce the sliding friction of disc brake pads on rotors when the brakes are not engaged because the brake pads are pulled away from the rotating disc either by mechanical or electric methods. While most passenger cars have already adopted this technology with the standardization of electronic brake control, there are indications that this technology is still available for body-on-frame trucks and for some large passenger cars.

NHTSA's MY 2011 CAFE final rule estimated the effectiveness of LDB to be as much as 1 percent, based on confidential manufacturer data. NHTSA and EPA have reviewed this estimate and believe it to be applicable for this final rule.

NHTSA and EPA have reviewed the cost estimates from the MY 2011 CAFE final rule and have not found any evidence to suggest that this cost is not a valid cost and have chosen to maintain this estimate. However, the agencies adjusted the costs to apply the ICM of 1.11, for a low-complexity technology. The compliance cost for LDB is estimated to be $63 for MY 2012 through MY 2016 vehicles as no learning effects are applied to this technology.

3.4.2.4.3 Low Rolling Resistance Tires (ROLL)

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 economy 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 low rolling resistance tire's attributes would 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 would generally be accompanied with additional changes to suspension tuning and/or suspension design.

EPA and NHTSA estimated a 1 to 2 percent increase in effectiveness with a 10 percent reduction in rolling resistance, which was based on the 2002 NAS report findings and consistent with NHTSA's MY 2011 CAFE final rule estimate. NHTSA and EPA still believe that this NAS effectiveness estimate is valid for this final rule. Lower rolling resistance tires are widely available today.

Based on NHTSA' MY 2011 CAFE final rule and the 2006 NAS/NRC report, the agencies have estimated the cost for low rolling resistance tires to be $6 per vehicle.[63] This is based on a cost of $1 per tire as estimated by NAS/NRC 2006 report, which is $5 per vehicle, including the spare tire. When applying the ICM low complexity markup factor, of 1.11, results in compliance cost of $6 per vehicle for MY 2012 through MY 2016 vehicles (2007$).[u] Due to the commodity-based nature of this technology, cost learning is not applied.

3.4.2.4.4 Front or Secondary Axle Disconnect for Four-Wheel Drive Systems (SAX)

Energy is required to continually drive the front, or secondary, axle in a four-wheel drive system even when the system is not required during most operating conditions. This energy loss directly results in increased fuel consumption and CO_2 emissions. Many part-time four-wheel drive systems use some type of front axle disconnect to provide shift-on-the-fly capabilities. The front axle disconnect is normally part of the front differential assembly. As part of a shift-on-the-fly four-wheel drive

---

[u] Note that the costs developed for low rolling resistance tires for this analysis do not include the increase in lifetime costs that would be expected at each tire replacement. Instead, the analysis includes only the upfront increase in costs.

system, the front axle disconnect serves two basic purposes. First, in two-wheel drive mode, it disengages the front axle from the front driveline so the front wheels do not turn the front driveline at road speed, saving wear and tear. Second, when shifting from two- to four-wheel drive "on the fly" (while moving), the front axle disconnect couples the front axle to the front differential side gear only when the transfer case's synchronizing mechanism has spun the front driveshaft up to the same speed as the rear driveshaft. Four-wheel drive systems that have a front axle disconnect typically do not have either manual- or automatic-locking hubs. To isolate the front wheels from the rest of the front driveline, front axle disconnects use a sliding sleeve to connect or disconnect an axle shaft from the front differential side gear. NHTSA and EPA are not aware of any manufacturer offering this technology in the U.S. today on unibody frame vehicles; however, it is possible this technology could be introduced by manufacturers within the rulemaking time period.

Based on confidential manufacturer data, NHTSA's MY 2011 CAFE final rule estimated an effectiveness improvement of 1.0 to 1.5 percent for axle disconnect. NHTSA and EPA believe this to still be an accurate estimate for this rulemaking.

Regarding costs, the agencies believe that the incremental compliance cost from NHTSA's MY 2011 final rule is an accurate estimate. However, for this final rule, this estimate was revised by applying the new ICM factor markup, for a low complexity technology, of 1.11. Thus, the compliance cost estimate for this final rule, is $87 for a MY 2012 vehicle (2007$). With time-based learning this cost would be $84 for a MY 2016 vehicle (2007$).

3.4.2.4.5 *Aerodynamic Drag Reduction (AERO)*

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 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.

The MY 2011 CAFE final rule estimated that a fleet average of 10 to 20 percent total aerodynamic drag reduction is attainable (with a caveat for "high-performance" vehicles described below) which equates to incremental reductions in fuel consumption and CO_2 emissions of 2 to 3 percent for both cars and trucks. These numbers are generally supported by confidential manufacturer data and public technical literature and

therefore NHTSA and EPA are retaining these estimates, as confirmed by joint review, for the purposes of this final rule.

In the MY 2011 CAFE final rule, NHTSA estimated a range from $60 to $116 (1.5 RPE); $40 to $75 (without RPE). NHTSA and EPA reviewed these estimates and updated these estimates to reflect the new ICM markup factor of 1.11 for a low complexity technology. In addition, given its low complexity and the facility of its implementation during design and refresh cycles, NHTSA and EPA believe that a cost estimate at the lower end of the range is more appropriate. Thus, the cost estimate used in this rulemaking is $48, including the 1.11 ICM markup value, for a low complexity technology (2007$). This compliance cost is for a MY 2012 vehicle. With time-based learning, this cost would be $42 for a MY 2016 vehicle (2007$)

3.4.2.5 Technologies considered but not included in the final rule analysis

NHTSA and EPA have identified six technologies that will not be available in the time frame considered under this rulemaking. These technologies while considered were not made available in the CAFE and OMEGA models. They are: electric vehicles, camless valve actuation (CVA), lean burn gasoline direct injection (LBDI), homogeneous charge compression ignition (HCCI), and electric assist turbocharging and full series hydraulic hybrids (HHV). While electric vehicles are likely become available in small numbers in the near future, the costs for this technology (as estimated by the agencies) are non-competitive with the more conventional technologies listed above. Therefore, the OMEGA and Volpe model analysis would preclude their selection, when estimating the costs of the rule. Lean Burn direct injection engines are currently available in Europe, however, these vehicles cannot be designed at this time to be both efficient and meet the NOx standards in the United States with the current sulfur levels in the fuels. The other technologies listed are still in the research phase of development. NHTSA and EPA will continue to monitor the industry and system suppliers for progress on these technologies, and should they become more available, consider them for use in future rulemaking activity. More details are described below.

3.4.2.5.1 Electric Vehicles

The recent intense interest in Hybrid vehicles and the development of Hybrid vehicle battery and motor technology has helped make Electric Vehicle technology more viable than it has ever been. Electric Vehicles (EVs) require much larger batteries than either HEVs or PHEVs, but the batteries must be of a high-energy and lower-power design to deliver an appropriate amount of power over the useful charge of the battery. These high-energy batteries are generally less expensive per kilowatt-hour than high-power batteries required for hybrids, but the size of the battery pack still incurs a considerable cost.

Electric motor and power electronics designs are very similar to HEV and PHEV designs, but they must be larger, more powerful, and more robust since they provide the only motive power for the vehicle. On the other hand, the internal combustion engine, fuel system, and possibly the transmission can all be removed for significant weight, complexity and cost savings.

As for PHEVs, two electric vehicles were modeled, a small car and a large car, using the same model (PEREGRIN) and similar assumptions. EVs are only considered for these two classes because the larger, heavier vehicles would require too much battery capacity to be practical in the short-to-mid term and the agencies do not see any serious development activities for these vehicle types in the market.

We chose to model the EVs with a range of 150 miles on the urban driving cycle because this range offers a good compromise in capability and battery cost, weight and size with expected technology in the near- to mid-term. Using the same methodology as used for PHEVs to calculate gasoline-equivalent fuel consumption, the results obtained are shown in Table 3-24, below.

Table 3-24 Electric Vehicle Gasoline-Equivalent CO_2 Reduction (excluding A/C)

	Small Car	Large Car
EV energy comb (0.55 city / 0.45 hwy)	0.202 kwh/mi	0.244 kwh/mi
City cycle EV range	150 miles	150 miles
Highway cycle EV range	166 miles	162 miles
Baseline FE	35.5	25.3 mpg
Tailpipe CO_2 reduction	100%	100%

3.4.2.5.2 Camless Valve Actuation

Camless valve actuation relies on electromechanical actuators instead of camshafts to open and close the cylinder valves. When electromechanical actuators are used to replace cams and coupled with sensors and microprocessor controls, valve timing and lift can be optimized over all conditions. An engine valvetrain that operates independently of any mechanical means provides the increased flexibility for intake and exhaust timing and lift optimization. With it comes increased ability to vary valve overlap, the rapid response required to change between combustion operating modes (such as HCCI and GDI), intake valve throttling, cylinder deactivation, and elimination of the camshafts (reduced friction and rotating mass). This level of control can enable even further incremental reductions in fuel consumption and CO_2 emissions.

This technology has been under research for many decades and although progress is being made, NHTSA and EPA have not found evidence to support that the technology can be successfully implemented within the 2012 through 2016 timeframe of these regulations. Thus NHTSA and EPA have not estimated cost or effectiveness for this technology at this time.

3.4.2.5.3 *Lean-Burn Gasoline Direct Injection Technology*

Direct injection, especially with diesel-like "spray-guided" injection systems, enables operation with excess air in a stratified or partially-stratified fuel-air mixture, as a way of reducing the amount of intake throttling. Also, with higher-pressure fuel injection systems, the fuel may be added late enough during the compression stroke so as to delay the onset of autoignition, even with higher engine compression ratios or with boosted intake pressure. Taken together, an optimized "lean-burn" direct injection gasoline engine may achieve high engine thermal efficiency which approaches that of a diesel engine. European gasoline direct-injection engines have implemented stratified-charge lean-burn GDI, although at higher NOx emissions levels than are allowed at under U.S. Federal Tier 2 emissions standards. Fuel system improvements, changes in combustion chamber design and repositioning of the injectors have allowed for better air/fuel mixing and combustion efficiency. There is currently a shift from wall-guided injection to spray guided injection, which improves injection precision and targeting towards the spark plug, increasing lean combustion stability. Combined with advances in NO_x after-treatment, lean-burn GDI engines may eventually be a possibility in North America.

EPA and NHTSA's current assessment is that the availability of ultra-low sulfur (ULS less than 15 ppm sulfur) gasoline is a key technical requirement for lean-burn GDI engines to meet EPA's Tier 2 NO_x emissions standards. Since we do not believe that ULS gasoline will be available during the model years applicable to these rules, the technology was not applied in EPA or NHTSA analyses.

3.4.2.5.4 *Homogeneous Charge Compression Ignition*

Gasoline homogeneous charge compression ignition (HCCI), also referred to as controlled autoignition (CAI), is an alternate engine operating mode that does not rely on a spark event to initiate combustion. The principles are more closely aligned with a diesel combustion cycle, in which the compressed charge exceeds a temperature and pressure necessary for spontaneous autoignition although it differs from diesel by having a homogenous fuel/air charge rather than being a diffusion-controlled combustion event. The subsequent combustion event is much shorter in duration with higher thermal efficiency.

An HCCI engine has inherent advantages in its overall efficiency for two main reasons:

- The engine is operated with a higher compression ratio, and with a shorter combustion duration, resulting in a higher thermodynamic efficiency, and

- The engine can be operated virtually unthrottled, even at light loads,

Combined, these effects have shown an increase in engine brake efficiency (typically 25 to 28 percent) to greater than 35 percent at the high end of the HCCI operating range.[64]

Criteria pollutant emissions are very favorable during HCCI operation. Lower peak in-cylinder temperatures (due to high dilution) keep engine-out NOx emissions to a minimum – realistically below Tier 2 levels without aftertreatment – and particulates are low due to the homogeneous nature of the premixed charge.

Due to the inherent difficulty in maintaining combustion stability without encountering engine knock, HCCI is difficult to control, requiring feedback from in-cylinder pressure sensors and rapid engine control logic to optimize combustion timing, especially considering the transient nature of operating conditions seen in a vehicle. Due to the highly dilute conditions under which gasoline-HCCI combustion is stable, the range of engine loads achievable in a naturally-aspirated engine is somewhat limited. Because of this, it is likely that any commercial application would operate in a "dual-mode" strategy between HCCI and spark ignition combustion modes, in which HCCI would be utilized for best efficiency at light engine loads and spark ignition would be used at higher loads and at idle. This type of dual-mode strategy has already been employed in diesel HCCI engines in Europe and Asia (notably the Toyota Avensis D-Cat and the Nissan light-duty "MK" combustion diesels).

Until recently, gasoline-HCCI technology was considered to still be in the research phase. However, most manufacturers have made public statements about the viability of incorporating HCCI into light-duty passenger vehicles, and have significant vehicle demonstration programs aimed at producing a viable product within the next 5-10 years.

There is widespread optimism as to the CO_2 reduction potential for HCCI in the literature. Based on confidential manufacturer information, EPA and NHTSA believe that a gasoline HCCI / GDI dual-mode engine might achieve 10 to 12 percent reduction in CO_2, compared to a comparable SI engine. Despite its promise, application of HCCI in light duty vehicles is not yet ready for the market. It is not anticipated to be seen in volume for at least the next 5-10 years, which is concurrent with many manufacturers' public estimates. NHTSA also noted in its MY 2011 CAFE final rule that the technology will not be available within the time frame considered based on a review of confidential product plan information.

3.4.2.5.5 *Electric Assist Turbocharging*

The Alliance commented in NHTSA's previous rulemaking that global development of electric assist turbocharging has not demonstrated the fuel efficiency effectiveness of a 12V EAT up to 2kW power levels since the 2004 NESCCAF study, and stated that it saw remote probability of its application over the next decade. While hybrid vehicles lower the incremental hardware requirements for higher-voltage, higher-power EAT systems, NHTSA and EPA agree that significant developmental work is required to demonstrate effective systems and that implementation in significant volumes will not occur in the 2012 to 2016 time frame considered in this rulemaking. Thus, this technology was not included in the final rule.

3.4.2.5.6 Full Series Hydraulic Hybrid

A Full Series Hydraulic Hybrid Vehicle (HHV) is somewhat similar in concept to a full series electric hybrid vehicle, except that the energy is stored in the form of compressed nitrogen gas and the power is transmitted in the form of hydraulic fluid. Series HHV technology currently under development by EPA is capable of a 40 percent decrease in tailpipe CO_2 emissions in the small car, large car, minivan, and small truck classes. In the large truck class, a 30 percent CO_2 reduction is possible. The large truck benefit is somewhat lower than the other classes because it is assumed that a large truck requires a larger engine to maintain towing and hauling performance after the energy in the high pressure hydraulic accumulator is exhausted. This technology is still under development and not yet commercialized, however there are technology demonstration vehicles in service with UPS in daily package delivery service.

3.5 Cost and effectiveness tables

The tables representing the Volpe model input files for incremental technology costs by vehicle subclass are presented below. The tables have been divided into passenger cars, performance passenger cars, and light trucks to make them easier to read. It should be noted that the Volpe model input files define costs for MY 2012 and learn down costs for subsequent years.

3.5.1 NHTSA cost and effectiveness tables

Table 3-25 Technology Incremental Cost Estimates for Volpe model, Passenger Cars in 2012

VEHICLE TECHNOLOGY ICM COSTS PER VEHICLE (2007$) BY VEHICLE SUBCLASS - PASSENGER CARS		Subcompact Car	Compact Car	Midsize Car	Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	Inline 4	Inline 4	V6
Low Friction Lubricants		3	3	3	3
Engine Friction Reduction	EFR	50	50	50	75
VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	45	45	45	90
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	142	142	142	205
Cylinder Deactivation on SOHC	DEACS	n.a.	n.a.	n.a.	0 - 56
VVT - Intake Cam Phasing (ICP)	ICP	45	45	45	90
VVT - Dual Cam Phasing (DCP)	DCP	38	38	38	83
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	142	142	142	205
Continuously Variable Valve Lift (CVVL)	CVVL	277	277	277	509
Cylinder Deactivation on DOHC	DEACD	n.a.	n.a.	n.a.	0 - 56
Cylinder Deactivation on OHV	DEACO	n.a.	n.a.	n.a.	170
VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	45	45	45	45
Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	142	142	142	0 - 56
Conversion to DOHC with DCP	CDOHC	276	276	276	436

Stoichiometric Gasoline Direct Injection (GDI)	SGDI	236	236	236	341
Combustion Restart	CBRST	118	118	118	118
Turbocharging and Downsizing	TRBDS	445	445	445	325
Exhaust Gas Recirculation (EGR) Boost	EGRB	144	144	144	144
Conversion to Diesel following CBRST	DSLC	1,527.	1,527	1,527	1,556 - 1,612
Conversion to Diesel following TRBDS	DSLT	938.	938	938	1,088- 1,143
6-Speed Manual/Improved Internals	6MAN	250	250	250	250
Improved Auto. Trans. Controls/Externals	IATC	60	60	60	60
Continuously Variable Transmission	CVT	250	250	250	250
6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	112	112	112	112
Dual Clutch or Automated Manual Transmission	DCTAM	(59)	(59)	(8)	(8)
Electric Power Steering	EPS	106	106	106	106
Improved Accessories	IACC	128	128	128	128
12V Micro-Hybrid	MHEV	288	311	342	367
Belt mounted Integrated Starter Generator	BISG	286	286	286	286
Crank mounted Integrated Starter Generator	CISG	2,791	3,107	3,319	3,547
Power Split Hybrid	PSHEV	1,600	2,133	2,742	3,261
2-Mode Hybrid	2MHEV	n.a.	n.a.	n.a.	n.a.
Plug-in Hybrid	PHEV	11,520	14,135	16,215	n.a.
Mass Reduction (1.5%)	MS1	1.5	1.5	1.5	1.5
Mass Reduction (3.5 to 8.5%)	MS2	1.5	1.5	1.5	1.5
Low Rolling Resistance Tires	ROLL	6	6	6	6
Low Drag Brakes	LDB	n.a.	n.a.	n.a.	63
Secondary Axle Disconnect	SAX	87	87	87	87
Aero Drag Reduction	AERO	48	48	48	48

Table 3-26. **Technology Incremental Cost Estimates for Volpe model, Performance Passenger Cars in 2012**

VEHICLE TECHNOLOGY ICM COSTS PER VEHICLE (2007$) BY VEHICLE SUBCLASS - PERFORMANCE PASSENGER CARS					
		Perform. Subcomp. Car	Perform. Compact Car	Perform. Midsize Car	Perform. Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	V6	V6	V8
Low Friction Lubricants	LUB	3	3	3	3
Engine Friction Reduction	EFR	50	75	75	101
VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	45	90	90	90
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	142	205	205	293
Cylinder Deactivation on SOHC	DEACS	n.a.	0 - 56	0 - 56	0 – 56
VVT - Intake Cam Phasing	ICP	45	90	90	90

(ICP)					
VVT - Dual Cam Phasing (DCP)	DCP	38	83	83	82
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	142	205	205	293
Continuously Variable Valve Lift (CVVL)	CVVL	277	509	509	555
Cylinder Deactivation on DOHC	DEACD	n.a.	0 - 56	0 - 56	0 – 56
Cylinder Deactivation on OHV	DEACO	n.a.	170	170	190
VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	45	45	45	45
Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	142	0 - 56	0 - 56	0 – 56
Conversion to DOHC with DCP	CDOHC	276	436	436	552
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	236	341	341	552
Combustion Restart	CBRST	118	118	118	118
Turbocharging and Downsizing	TRBDS	445	325	325	919
Exhaust Gas Recirculation (EGR) Boost	EGRB	144	144	144	144
Conversion to Diesel following CBRST	DSLC	1,527	1,556 – 1,612	1,556 – 1,612	2,294 – 2,349
Conversion to Diesel following TRBDS	DSLT	938	1,088 – 1,143	1,088 – 1,143	1,231 – 1,287
6-Speed Manual/Improved Internals	6MAN	250	250	250	250
Improved Auto. Trans. Controls/Externals	IATC	60	60	60	60
Continuously Variable Transmission	CVT	250	250	250	250
6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	112 – 214	112 – 214	112 – 214	112 - 214
Dual Clutch or Automated Manual Transmission	DCTAM	(8)	(8)	(8)	(8)
Electric Power Steering	EPS	106	106	106	106
Improved Accessories	IACC	128	128	128	128
12V Micro-Hybrid	MHEV	314	337	372	410
Belt mounted Integrated Starter Generator	BISG	286	286	286	286
Crank mounted Integrated Starter Generator	CISG	2,839	3,149	3,335	3,571
Power Split Hybrid	PSHEV	3,661	4,018	5,287	6,723
2-Mode Hybrid	2MHEV	n.a.	n.a.	n.a.	n.a.
Plug-in Hybrid	PHEV	14,987	16,792	19,265	n.a.
Mass Reduction (1.5%)	MS1	1.5	1.5	1.5	1.5
Mass Reduction (3.5 to 8.5%)	MS2	1.5	1.5	1.5	1.5
Low Rolling Resistance Tires	ROLL	n.a.	n.a.	n.a.	n.a.
Low Drag Brakes	LDB	n.a.	n.a.	n.a.	63

Secondary Axle Disconnect	SAX	87	87	87	87
Aero Drag Reduction	AERO	n.a.	n.a.	n.a.	n.a.

Table 3-27 . Technology Incremental Cost Estimates for Volpe model, Light Trucks in 2012

VEHICLE TECHNOLOGY ICM COSTS PER VEHICLE (2007$) BY VEHICLE SUBCLASS - LIGHT TRUCKS					
		Minivan LT	Small LT	Midsize LT	Large LT
Nominal Baseline Engine (For Cost Basis)		V6	Inline 4	V6	V8
Low Friction Lubricants	LUB	3	3	3	3
Engine Friction Reduction	EFR	75	50	75	101
VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	90	45	90	90
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	205	142	205	293
Cylinder Deactivation on SOHC	DEACS	0 - 56	n.a.	0 - 56	0 – 56
VVT - Intake Cam Phasing (ICP)	ICP	90	45	90	90
VVT - Dual Cam Phasing (DCP)	DCP	83	38	83	83
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	205	142	205	293
Continuously Variable Valve Lift (CVVL)	CVVL	509	277	509	555
Cylinder Deactivation on DOHC	DEACD	0 - 56	n.a.	0 - 56	0 – 56
Cylinder Deactivation on OHV	DEACO	170	n.a.	170	190
VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	45	45	45	45
Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	0 - 56	142	0 - 56	0 – 56
Conversion to DOHC with DCP	CDOHC	436	276	436	552
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	341	236	341	391
Combustion Restart	CBRST	118	118	118	118
Turbocharging and Downsizing	TRBDS	325	445	325	919
Exhaust Gas Recirculation (EGR) Boost	EGRB	144	144	144	144
Conversion to Diesel following CBRST	DSLC	1,556 - 1,612	1,527	1,556 -1,612	2,294 – 2,349
Conversion to Diesel following TRBDS	DSLT	1,088-1,143	938	1,088 – 1,143	1,231 – 1,287
6-Speed Manual/Improved Internals	6MAN	250	250	250	250
Improved Auto. Trans. Controls/Externals	IATC	60	60	60	60
Continuously Variable Transmission	CVT	250	250	250	n.a.
6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	112	112	112 - 214	112 - 214

Dual Clutch or Automated Manual Transmission	DCTAM	(8)	(8)	(8)	(8)
Electric Power Steering	EPS	106	106	106	106
Improved Accessories	IACC	128	128	128	n.a.
12V Micro-Hybrid	MHEV	367	325	376	n.a.
Belt mounted Integrated Starter Generator	BISG	286	286	286	n.a.
Crank mounted Integrated Starter Generator	CISG	3,547	3,141	3,611	5,124
Power Split Hybrid	PSHEV	3,261	2,377	3,462	n.a.
2-Mode Hybrid	2MHEV	n.a.	3,661	4,887 - 4,989	5,902 – 6,004
Plug-in Hybrid	PHEV	n.a.	14,721	n.a.	n.a.
Mass Reduction (1.5%)	MS1	1.5	1.5	1.5	1.5
Mass Reduction (3.5 to 8.5%)	MS2	1.5	1.5	1.5	1.5
Low Rolling Resistance Tires	ROLL	6	6	6	6
Low Drag Brakes	LDB	63	n.a.	63	63
Secondary Axle Disconnect	SAX	87	87	87	87
Aero Drag Reduction	AERO	48	48	48	48

Table 3-28. Technology Incremental Effectiveness Estimates for Volpe model, Passenger Cars in 2012

VEHICLE TECHNOLOGY INCREMENTAL FUEL CONSUMPTION REDUCTION (-%) BY VEHICLE SUBCLASS - PASSENGER CAR					
		Subcompact Car	Compact Car	Midsize Car	Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	Inline 4	Inline 4	V6
Low Friction Lubricants	LUB	0.5	0.5	0.5	0.5
Engine Friction Reduction	EFR	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Cylinder Deactivation on SOHC	DEACS	n.a.	n.a.	n.a.	2.5 - 3.0
VVT - Intake Cam Phasing (ICP)	ICP	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
VVT - Dual Cam Phasing (DCP)	DCP	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Continuously Variable Valve Lift (CVVL)	CVVL	1.5 - 3.5	1.5 - 3.5	1.5 - 3.5	1.5 - 3.5
Cylinder Deactivation on DOHC	DEACD	n.a.	n.a.	n.a.	0 - 0.5
Cylinder Deactivation on OHV	DEACO	n.a.	n.a.	n.a.	3.9 - 5.5
VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5
Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	0.5 - 2.5	0.5 - 2.5	0.5 - 2.5	0.5 - 2.5

Conversion to DOHC with DCP	CDOHC	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
Combustion Restart	CBRST	2.0 - 2.5	2.0 - 2.5	2.0 - 2.5	2.0 - 2.5
Turbocharging and Downsizing	TRBDS	4.2 - 4.8	4.2 - 4.8	4.2 - 4.8	1.8 - 1.9
Exhaust Gas Recirculation (EGR) Boost	EGRB	3.5 - 4.0	3.5 - 4.0	3.5 - 4.0	3.5 - 4.0
Conversion to Diesel following CBRST	DSLC	13.5 – 13.9	13.5 – 13.9	13.5 – 13.9	10.8 - 11.7
Conversion to Diesel following TRBDS	DSLT	5.3 – 6.9	5.3 – 6.9	5.3 – 6.9	5.3 - 6.9
6-Speed Manual/Improved Internals	6MAN	0.5	0.5	0.5	0.5
Improved Auto. Trans. Controls/Externals	IATC	1.5 - 2.5	1.5 - 2.5	1.5 - 2.5	1.5 - 2.5
Continuously Variable Transmission	CVT	0.7 - 2.0	0.7 - 2.0	0.7 - 2.0	0.7 - 2.0
6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	1.4 - 3.4	1.4 - 3.4	1.4 - 3.4	1.4 - 3.4
Dual Clutch or Automated Manual Transmission	DCTAM	5.5 – 7.5	5.5 – 7.5	2.7 - 4.1	2.7 - 4.1
Electric Power Steering	EPS	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
Improved Accessories	IACC	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
12V Micro-Hybrid	MHEV	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.5 - 3.5
Belt mounted Integrated Starter Generator	BISG	4.0 - 6.0	4.0 - 6.0	4.0 - 6.0	3.5 - 5.5
Crank mounted Integrated Starter Generator	CISG	8.6 - 8.9	8.6 - 8.9	8.6 - 8.9	8.7 - 8.9
Power Split Hybrid	PSHEV	6.3 - 12.4	6.3 - 12.4	6.3 - 12.4	6.3 - 12.4
2-Mode Hybrid	2MHEV	n.a.	n.a.	n.a.	n.a.
Plug-in Hybrid	PHEV	45.2 - 47.7	45.2 - 47.7	45.2 - 47.7	n.a.
Mass Reduction (1.5%)	MS1	0.5	0.5	0.5	0.5
Mass Reduction (3.5 to 8.5%)	MS2	2.7	2.7	4.4	6.0
Low Rolling Resistance Tires	ROLL	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
Low Drag Brakes	LDB	n.a.	n.a.	n.a.	0.5 - 1.0
Secondary Axle Disconnect	SAX	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5
Aero Drag Reduction	AERO	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0

Table 3-29. Component Technology Incremental Effectiveness Estimates for Volpe model, Performance Cars in 2012

VEHICLE TECHNOLOGY INCREMENTAL FUEL CONSUMPTION REDUCTION (-%) BY VEHICLE SUBCLASS - PERFORMANCE PASSENGER CAR		Perform. Subcomp. Car	Perform. Compact Car	Perform. Midsize Car	Perform. Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	V6	V6	V8
Low Friction Lubricants	LUB	0.5	0.5	0.5	0.5
Engine Friction Reduction	EFR	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Cylinder Deactivation on SOHC	DEACS	n.a.	2.5 - 3.0	2.5 - 3.0	2.5 - 3.0
VVT - Intake Cam Phasing (ICP)	ICP	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
VVT - Dual Cam Phasing (DCP)	DCP	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Continuously Variable Valve Lift (CVVL)	CVVL	1.5 - 3.5	1.5 - 3.5	1.5 - 3.5	1.5 - 3.5
Cylinder Deactivation on DOHC	DEACD	n.a.	0.0 - 0.5	0.0 - 0.5	0.0 - 0.5
Cylinder Deactivation on OHV	DEACO	n.a.	3.9 - 5.5	3.9 - 5.5	3.9 - 5.5
VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5
Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	0.5 - 2.5	0.5 - 2.5	0.5 - 2.5	0.5 - 2.5
Conversion to DOHC with DCP	CDOHC	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
Combustion Restart	CBRST	2.0 - 2.5	2.0 - 2.5	2.0 - 2.5	2.0 - 2.5
Turbocharging and Downsizing	TRBDS	4.2 - 4.8	1.8 - 1.9	1.8 - 1.9	1.8 - 1.9
Exhaust Gas Recirculation (EGR) Boost	EGRB	3.5 - 4.0	3.5 - 4.0	3.5 - 4.0	3.5 - 4.0
Conversion to Diesel following CBRST	DSLC	13.5 – 13.9	10.8 - 11.7	10.8 - 11.7	10.8 - 11.7
Conversion to Diesel following TRBDS	DSLT	5.3 – 6.9	5.3 - 6.9	5.3 - 6.9	5.3 - 6.9
6-Speed Manual/Improved Internals	6MAN	0.5	0.5	0.5	0.5
Improved Auto. Trans. Controls/Externals	IATC	1.5 - 2.5	1.5 - 2.5	1.5 - 2.5	1.5 - 2.5
Continuously Variable Transmission	CVT	0.7 - 2.0	0.7 - 2.0	0.7 - 2.0	n.a.
6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	1.4 - 3.4	1.4 - 3.4	1.4 - 3.4	1.4 - 3.4
Dual Clutch or Automated Manual Transmission	DCTAM	2.7 - 4.1	2.7 - 4.1	2.7 - 4.1	2.7 - 4.1
Electric Power Steering	EPS	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
Improved Accessories	IACC	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
12V Micro-Hybrid	MHEV	2.0 - 3.0	2.5 - 3.5	2.5 - 3.5	3.0 - 4.0
Belt mounted Integrated Starter Generator	BISG	4.0 - 6.0	3.5 - 5.5	3.5 - 5.5	3.0 - 5.0
Crank mounted Integrated Starter Generator	CISG	8.6 - 8.9	8.7 - 8.9	8.7 - 8.9	8.7 - 8.9
Power Split Hybrid	PSHEV	6.3 - 12.4	6.3 - 12.4	6.3 - 12.4	6.3 - 12.4

		Minivan LT	Small LT	Midsize LT	Large LT
2-Mode Hybrid	2MHEV	n.a.	n.a.	n.a.	n.a.
Plug-in Hybrid	PHEV	45.2 - 47.7	45.2 - 47.7	45.2 - 47.7	n.a.
Mass Reduction (1.5%)	MS1	0.5	0.5	0.5	0.5
Mass Reduction (3.5 to 8.5%)	MS2	2.7	2.7	4.4	6.0
Low Rolling Resistance Tires	ROLL	n.a.	n.a.	n.a.	n.a.
Low Drag Brakes	LDB	n.a.	n.a.	n.a.	0.5 - 1.0
Secondary Axle Disconnect	SAX	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5
Aero Drag Reduction	AERO	n.a.	n.a.	n.a.	n.a.

Table 3-30. Component Technology Incremental Effectiveness Estimates for Volpe model, Light Trucks in 2012

VEHICLE TECHNOLOGY INCREMENTAL FUEL CONSUMPTION REDUCTION (-%) BY VEHICLE SUBCLASS - LIGHT TRUCKS		Minivan LT	Small LT	Midsize LT	Large LT
Nominal Baseline Engine (For Cost Basis)		V6	Inline 4	V6	V8
Low Friction Lubricants	LUB	0.5	0.5	0.5	0.5
Engine Friction Reduction	EFR	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
VVT - Coupled Cam Phasing (CCP) on SOHC	CCPS	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Cylinder Deactivation on SOHC	DEACS	2.5 - 3.0	n.a.	2.5 - 3.0	2.5 - 3.0
VVT - Intake Cam Phasing (ICP)	ICP	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0
VVT - Dual Cam Phasing (DCP)	DCP	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0	1.0 - 3.0
Continuously Variable Valve Lift (CVVL)	CVVL	1.5 - 3.5	1.5 - 3.5	1.5 - 3.5	1.5 - 3.5
Cylinder Deactivation on DOHC	DEACD	0 - 0.5	n.a.	0.0 - 0.5	0.0 - 0.5
Cylinder Deactivation on OHV	DEACO	3.9 - 5.5	n.a.	3.9 - 5.5	3.9 - 5.5
VVT - Coupled Cam Phasing (CCP) on OHV	CCPO	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5
Discrete Variable Valve Lift (DVVL) on OHV	DVVLO	0.5 - 2.5	0.5 - 2.5	0.5 - 2.5	0.5 - 2.5
Conversion to DOHC with DCP	CDOHC	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5	1.0 - 2.5
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0
Combustion Restart	CBRST	2.0 - 2.5	2.0 - 2.5	2.0 - 2.5	2.0 - 2.5
Turbocharging and Downsizing	TRBDS	1.8 - 1.9	4.2 - 4.8	1.8 - 1.9	1.8 - 1.9
Exhaust Gas Recirculation (EGR) Boost	EGRB	3.5 - 4.0	3.5 - 4.0	3.5 - 4.0	3.5 - 4.0
Conversion to Diesel following CBRST	DSLC	10.8 - 11.7	13.5 – 13.9.	10.8 - 11.7	10.8 - 11.7
Conversion to Diesel following TRBDS	DSLT	5.3 - 6.9	n.a.	5.3 - 6.9	5.3 - 6.9
6-Speed Manual/Improved Internals	6MAN	0.5	0.5	0.5	0.5

Improved Auto. Trans. Controls/Externals	IATC	1.5 - 2.5	1.5 - 2.5	1.5 - 2.5	1.5 - 2.5	
Continuously Variable Transmission	CVT	0.7 - 2.0	0.7 - 2.0	0.7 - 2.0	n.a.	
6/7/8-Speed Auto. Trans with Improved Internals	NAUTO	1.4 - 3.4	1.4 - 3.4	1.4 - 3.4	1.4 - 3.4	
Dual Clutch or Automated Manual Transmission	DCTAM	2.7 - 4.1	2.7 -4.1	2.7 - 4.1	2.7 - 4.1	
Electric Power Steering	EPS	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	
Improved Accessories	IACC	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	n.a.	
12V Micro-Hybrid	MHEV	2.5 - 3.5	2.0 - 3.0	2.5 - 3.5	n.a.	
Belt mounted Integrated Starter Generator	BISG	3.5 - 5.5	4.0 - 6.0	3.5 - 5.5	n.a.	
Crank mounted Integrated Starter Generator	CISG	8.7 - 8.9	8.6 - 8.9	8.7 - 8.9	14.1 - 16.3	
Power Split Hybrid	PSHEV	6.3 - 12.4	6.3 - 12.4	6.3 - 12.4	n.a.	
2-Mode Hybrid	2MHEV	n.a.	3.0 - 7.3	3.0 - 7.3	4.1 - 9.5	
Plug-in Hybrid	PHEV	n.a.	45.2 - 47.7	n.a.	n.a.	
Mass Reduction (1.5%)	MS1	0.5	0.5	0.5	0.5	
Mass Reduction (3.5 to 8.5%)	MS2	6.0	4.4	4.4	6.0	
Low Rolling Resistance Tires	ROLL	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	1.0 - 2.0	
Low Drag Brakes	LDB	0.5 - 1.0	n.a.	0.5 - 1.0	0.5 - 1.0	
Secondary Axle Disconnect	SAX	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5	1.0 - 1.5	
Aero Drag Reduction	AERO	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	2.0 - 3.0	

3.5.2 EPA cost and effectiveness tables

The tables below show costs and effectiveness values for each particular technology described throughout this chapter (those considered by EPA in its model). The costs are shown as incremental to a particular baseline as noted in the tables. In general, the costs are meant to reflect the cost of a given technology relative to a baseline vehicle or engine with fixed timing 4 valves per cylinder, port fuel injection and a 4 speed automatic transmission. Where this is not the case is made clear in the tables. The same is true of the effectiveness tables below. As such, the costs and effectiveness values shown in the tables below will differ from the values contained in the NHTSA tables due to the different ways that the agency's models handles them. However, the underlying cost and effectiveness values used by each agency in their respective analyses are consistent.

Table 3-31 EPA's Incremental Piece Costs for Engine Technologies Marked up to include both Direct and Indirect Costs in 2016 (2007 Dollars per Vehicle)

	TECHNOLOGY	INCREMENTAL TO	VEHICLE CLASS				
			Small Car	Large Car	Minivan	Small Truck	Large Truck
	Low friction lubricants	Base engine	$3	$3	$3	$3	$3
	Engine friction reduction	Base engine	$50	$75	$75	$75	$100
OHC Engines	VVT – intake cam phasing	Base engine	$40	$80	$80	$80	$80
	VVT – coupled cam phasing	Base engine	$40	$80	$80	$80	$80
	VVT – dual cam phasing	Base engine	$73	$157	$157	$157	$157
	Cylinder deactivation	Base engine	n/a	$150	$150	$150	$169

	Discrete VVLT	Base engine	$125	$181	$181	$181	$259
	Continuous VVLT	Base engine	$245	$449	$449	$449	$489
OHV Engines	Cylinder deactivation	Base engine	n/a	$150	$150	$150	$169
	VVT – coupled cam phasing	Base engine	$40	$40	$40	$40	$40
	Discrete VVLT	Base engine	$141	$204	$204	$204	$291
	Continuous VVLT (includes conversion to Overhead Cam)	Base engine w/ VVT-coupled	$497	$1,048	$1,048	$1,048	$1,146
	Camless valvetrain (electromagnetic)	Base engine	$501	$501	$501	$501	$501
	GDI – stoichiometric I4	Base I4	$209	209	$209	209	209
	GDI – stoichiometric V6	Base V6	n/a	$301	$301	$301	$301
	GDI – stoichiometric V8	Base V8	n/a	$346	$346	n/a	$346
	GDI – lean burn	GDI - stoich	$623	$623	$623	$623	$623
Turbo w/o downsize Downsize w/o turbo	Turbocharge (single)	Base I4	$397	n/a	$397	n/a	n/a
	Turbocharge (single)	Base V6	n/a	$420	$420	$420	$420
	Turbocharge (twin)	Base engine	$666	$666	$666	$666	$666
	Downsize to I4 DOHC	V6 DOHC	n/a	-$384	-$384	-$384	-$384
	Downsize to I4 DOHC	V6 SOHC	n/a	-$177	-$177	-$177	-$177
	Downsize to I4 DOHC	V6 OHV	n/a	$265	$265	$265	$265
	Downsize to I4 DOHC	I4 DOHC (larger)	-$67	-$67	-$67	-$67	-$67
	Downsize to I3 DOHC	I4 DOHC	-$116	n/a	n/a	n/a	n/a
	Downsize to V6 DOHC	V8 DOHC	n/a	-$188	-$188	-$188	-$188
	Downsize to V6 DOHC	V8 SOHC 2V	n/a	$59	$59	$59	$59
	Downsize to V6 DOHC	V8 SOHC 3V	n/a	-$17	-$17	-$17	-$17
	Downsize to V6 DOHC	V8 OHV	n/a	$310	$310	$310	$310
Turbo with downsize	Downsize to I4 DOHC & add turbo	V6 DOHC w/o turbo	n/a	$149	$149	$149	$149
	Downsize to I4 DOHC & add turbo	V6 SOHC w/o turbo	n/a	$323	$323	$323	$323
	Downsize to I4 DOHC & add turbo	V6 OHV w/o turbo	$771	$771	$771	$771	$771
	Downsize to I4 DOHC & add turbo	I4 DOHC (larger) w/o turbo	$391	n/a	$391	n/a	n/a
	Downsize to I3 DOHC & add turbo	I4 DOHC w/o turbo	$349	n/a	n/a	n/a	n/a
	Downsize to V6 DOHC & add twin turbo	V8 DOHC w/o turbo	n/a	$592	$592	$592	$592
	Downsize to V6 DOHC & add twin turbo	V8 SOHC 2V w/o turbo	n/a	$816	$816	$816	$816
	Downsize to V6 DOHC & add twin turbo	V8 SOHC 3V w/o turbo	n/a	$736	$736	$736	$736
	Downsize to V6 DOHC & add twin turbo	V8 OHV w/o turbo	n/a	$1,099	$1,099	$1,099	$1,099
	Convert to V6 DOHC	V6 SOHC	n/a	$258	$258	$258	$258
	Convert to V6 DOHC	V6 OHV	n/a	$464	$464	$464	$464
	Convert to V8 DOHC	V8 SOHC 2V	n/a	$292	$292	$292	$292
	Convert to V8 DOHC	V8 SOHC 3V	n/a	$213	$213	$213	$213
	Convert to V8 DOHC	V8 OHV	n/a	$509	$509	$509	$509
	Gasoline HCCI dual-mode	GDI - stoich	$253	$375	$375	$375	$659
	Diesel – Lean NOx trap	Base gasoline engine	$1,877				
	Diesel – urea SCR	Base gasoline engine		$2,655	$2,164	$2,164	$2,961

Table 3-32 EPA's Incremental Piece Costs for Transmission Technologies Marked up to include both Direct and Indirect Costs in 2016 (2007 Dollars per Vehicle)

TECHNOLOGY	INCREMENTAL TO	VEHICLE CLASS				
		Small Car	Large Car	Minivan	Small Truck	Large Truck
Aggressive shift logic	Base trans	$28	$28	$28	$28	$28
Early torque converter lockup	Base trans	$25	$25	$25	$25	$25
5-speed automatic	4-speed auto trans	$90	$90	$90	$90	$90
6-speed automatic	4-speed auto trans	$99	$99	$99	$99	$99
6-speed DCT – dry clutch	6-speed auto trans	-$52	-$52	-$52	-$52	-$52
6-speed DCT – wet clutch	6-speed auto trans	-$7	-$7	-$7	-$7	-$7
6-speed manual	5-speed manual trans	$79	$79	$79	$79	$79
CVT	4-speed auto trans	$192	$224	$224	n/a	n/a

Table 3-33 EPA's Incremental Piece Costs for Hybrid Technologies Marked up to include both Direct and Indirect Costs in 2016 (2007 Dollars per Vehicle)

TECHNOLOGY	INCREMENTAL TO	VEHICLE CLASS				
		Small Car	Large Car	Minivan	Small Truck	Large Truck
Stop-Start	Base engine & trans	$351	$398	$398	$398	$437
IMA/ISA/BSG (includes engine downsize)	Base engine & trans	$2,854	$3,612	$3,627	$3,423	$4,431
2-Mode hybrid electric vehicle	Base engine & trans	$4,232	$5,469	$5,451	$4,943	$7,236
Power-split hybrid electric vehicle	Base engine & trans	$3,967	$5,377	$5,378	$4,856	$7,210
Plug-in hybrid electric vehicle	IMA/ISA/BSG hybrid	$6,922	$9,519	$9,598	$9,083	$12,467
Plug-in hybrid electric vehicle	Power-split hybrid	$5,423	$7,431	$7,351	$7,128	$9,643
Full electric vehicle	Base engine & trans	$27,628	n/a	n/a	n/a	n/a

Table 3-34 EPA's Incremental Piece Costs for Accessory Technologies Marked up to include both Direct and Indirect Costs in 2016 (2007 Dollars per Vehicle)

TECHNOLOGY	INCREMENTAL TO	VEHICLE CLASS				
		Small Car	Large Car	Minivan	Small Truck	Large Truck
Improved high efficiency alternator & electrification of accessories	Base accessories	$76	$76	$76	$76	$76
Upgrade to 42 volt electrical system	12 volt electrical system	$86	$86	$86	$86	$86
Electric power steering (12 or 42 volt)	Base power steering	$94	$94	$94	$94	$94

Table 3-35 EPA's Incremental Piece Costs for Vehicle Technologies Marked up to include both Direct and Indirect Costs in 2016 (2007 Dollars per Vehicle)

TECHNOLOGY	INCREMENTAL TO	VEHICLE CLASS				
		Small Car	Large Car	Minivan	Small Truck	Large Truck
Aero drag reduction (20% on cars, 10% on trucks)	Base vehicle	$42	$42	$42	$42	$42
Low rolling resistance tires	Base tires	$6	$6	$6	$6	$6
Low drag brakes (ladder frame only)	Base brakes	n/a	n/a	n/a	$63	$63
Secondary axle disconnect (unibody only)	Base vehicle	$514	$514	$514	$514	n/a
Front axle disconnect (ladder frame only)	Base vehicle	n/a	n/a	n/a	$84	$84

Table 3-36 through Table 3-40 summarize the estimates for the CO_2 reduction estimates of various technologies which can be applied to cars and light-duty trucks.

Table 3-36 Engine Technology Effectiveness

Technology	Absolute CO_2 Reduction (% from baseline vehicle)				
	Small Car	Large Car	Minivan	Small Truck	Large Truck
Low friction lubricants – incremental to base engine	0.5	0.5	0.5	0.5	0.5
Engine friction reduction – incremental to base engine	1-3	1-3	1-3	1-3	1-3
Overhead Cam Branch					
VVT – intake cam phasing	2	1	1	1	2
VVT – coupled cam phasing	3	4	2	3	4
VVT – dual cam phasing	3	4	2	2	4
Cylinder deactivation (includes imp. oil pump, if applicable)	n.a.	6	6	6	6
Discrete VVLT	4	3	3	4	4
Continuous VVLT	5	6	4	5	5
Overhead Valve Branch					
Cylinder deactivation (includes imp. oil pump, if applicable)	n.a.	6	6	6	6
VVT – coupled cam phasing	3	4	2	3	4
Discrete VVLT	4	4	3	4	4
Continuous VVLT (includes conversion to Overhead Cam)	5	6	4	5	5
Camless valvetrain (electromagnetic)	5-15	5-15	5-15	5-15	5-15
Gasoline Direct Injection–stoichiometric (GDI-S)	1-2	1-2	1-2	1-2	1-2
Gasoline Direct Injection–lean burn (incremental to GDI-S)	8-10	9-12	9-12	9-12	10-14
Gasoline HCCI dual-mode (incremental to GDI-S)	10-12	10-12	10-12	10-12	10-12
Turbo+downsize (incremental to GDI-S)	5-7	5-7	5-7	5-7	5-7
Diesel – Lean NOx trap[]*	15-26	15-26	15-26	15-26	15-26
Diesel – urea SCR []*	15-26	15-26	15-26	15-26	15-26

Table 3-37 Transmission Technology Effectiveness

Technology	Absolute CO_2 Reduction (% from baseline vehicle)				
	Small Car	Large Car	Minivan	Small Truck	Large Truck
5-speed automatic (from 4-speed auto)	2.5	2.5	2.5	2.5	2.5
Aggressive shift logic	1-2	1-2	1-2	1-2	1-2
Early torque converter lockup	0.5	0.5	0.5	0.5	0.5
6-speed automatic (from 4-speed auto)	4.5-6.5	4.5-6.5	4.5-6.5	4.5-6.5	4.5-6.5
6-speed AMT (from 4-speed auto)	9.5-14.5	9.5-14.5	9.5-14.5	9.5-14.5	9.5-14.5
6-speed manual (from 5-speed manual)	0.5	0.5	0.5	0.5	0.5
CVT (from 4-speed auto)	6	6	6	n.a.	n.a.

Table 3-38 Hybrid Technology Effectiveness

Technology	Absolute CO_2 Reduction (% from baseline vehicle)				
	Small Car	Large Car	Minivan	Small Truck	Large Truck
Stop-Start with 42 volt system	7.5	7.5	7.5	7.5	7.5
IMA/ISA/BSG (includes engine downsize)	30	25	20	20	20
2-Mode hybrid electric vehicle	n.a.	40	40	40	25
Power-split hybrid electric vehicle	35	35	35	35	n.a.
Full-Series hydraulic hybrid	40	40	40	40	30
Plug-in hybrid electric vehicle	58	58	58	58	47
Full electric vehicle (EV)	100	100	n.a.	n.a.	n.a.

Table 3-39 Accessory Technology Effectiveness

Technology	Absolute CO_2 Reduction (% from baseline vehicle)				
	Small Car	Large Car	Minivan	Small Truck	Large Truck
Improved high efficiency alternator & electrification of accessories (12 volt)	1-2	1-2	1-2	1-2	1-2
Electric power steering (12 or 42 volt)	1.5	1.5-2	2	2	2
Improved high efficiency alternator & electrification of accessories (42 volt)	2-4	2-4	2-4	2-4	2-4

Table 3-40 Other Vehicle Technology Effectiveness

Technology	Absolute CO_2 Reduction (% from baseline vehicle)				
	Small Car	Large Car	Minivan	Small Truck	Large Truck
Aero drag reduction (20% on cars, 10% on trucks)	3	3	3	2	2
Low rolling resistance tires (10%)	1-2	1-2	1-2	1-2	n.a.
Low drag brakes (ladder frame only)	n.a.	n.a.	n.a.	1	1
Secondary axle disconnect (unibody only)	1	1	1	1	n.a.
Front axle disconnect (ladder frame only)	n.a.	n.a.	n.a.	1.5	1.5

Appendix 3.A

Gross Domestic Product Adjustments Used to Adjust 2002-2006 Dollars to 2007 Dollars

Throughout this analysis, the incremental cost estimates have been presented in terms of 2007 dollars. However, most of the data sources relied upon as the basis for the estimates have presented costs in terms of 2006 dollars. To convert the 2006 dollars to 2007 dollars, the "chain-type" Gross Domestic Product (GDP) deflator was used.   Table 3.A-1 shows the GDP deflator data used for this analysis.

Table 3.A-1 Price Indexes for Gross Domestic Product

LINE		2002	2003	2004	2005	2006	2007	2008
1	Gross domestic product	104.193	106.409	109.462	113.039	116.676	119.819	122.5
2	Personal consumption expenditures	103.542	105.597	108.392	111.581	114.675	117.659	121.596
3	Durable goods	95.766	92.366	90.696	89.984	88.772	87.154	86.071
4	Nondurable goods	102.089	104.145	107.626	111.606	114.984	118.407	124.666
5	Services	106.018	109.379	112.929	116.7	120.752	124.712	128.752
6	Gross private domestic investment	101.64	103.191	106.686	111.381	116.102	117.735	118.509
7	Fixed investment	101.66	103.313	106.845	111.638	116.38	117.995	118.727
8	Nonresidential	99.513	99.591	100.896	103.829	107.277	108.739	110.513
9	Structures	110.03	113.872	120.912	135.177	151.822	157.662	163.298
10	Equipment and software	95.956	94.912	94.6	94.534	94.594	94.87	95.485
11	Residential	107.24	112.372	120.587	129.268	136.897	138.884	135.587
12	Change in private inventories							
13	Net exports of goods and services							
14	Exports	99.273	101.429	104.997	108.814	112.618	116.586	122.788
15	Goods	98.661	100.64	104.323	107.536	111.131	115.062	121.147
16	Services	100.762	103.333	106.632	111.855	116.156	120.211	126.684
17	Imports	96.341	99.685	104.526	111.154	115.932	120.168	132.698
18	Goods	95.288	98.063	102.915	109.568	114.171	118.326	131.408
19	Services	101.878	108.291	113.049	119.496	125.257	129.928	139.217
20	Government consumption expenditures and gross investment	105.507	109.849	114.754	121.47	127.239	132.941	139.234
21	Federal	105.631	110.094	115.322	120.834	125.806	130.076	134.289
22	National defense	105.792	110.751	115.932	121.944	127.381	131.874	136.574
23	Nondefense	105.345	108.898	114.218	118.744	122.803	126.636	129.869
24	State and local	105.435	109.712	114.431	121.862	128.109	134.671	142.219

Source: Bureau of Economic Analysis, U.S. Department of Commerce,
http://www.bea.gov/national/nipaweb/TableView.asp?SelectedTable=4

Using Line 1 in the table, 2006 dollars can be adjusted to 2007 dollars by multiplying the ratio 119.8/116.7, or 1.027, by any value expressed in 2006 dollars. For example, $1 in 2006 dollars would be $1 x 1.027, or $1.03 in 2007 dollars.

References

[1] "EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-duty Vehicle Carbon Dioxide Emissions," EPA420-R-08-008, March 2008, Docket EPA-HQ-OAR-2009-0472-0132.

[2] "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards," National Research Council, National Academy of Sciences, 2002, Docket EPA-HQ-OAR-2009-0472-0147.

[3] "Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles," Northeast States Center for a Clean Air Future, September 2004, Docket EPA-HQ-OAR-2009-0472-0148.

[4] "Staff Report: Initial Statement of Reasons for Proposed Rulemaking," California Environmental Protection Agency, Air Resources Board, Regulations to Control Greenhouse Gas Emissions from Motor Vehicles, August 6, 2004, Docket EPA-HQ-OAR-2009-0472-0134.

[5] "Technology to Improve the Fuel Economy of Light Duty Trucks to 2015," Energy and Environmental Analysis, Inc., May 2006, Docket EPA-HQ-OAR-2009-0472-0136.

[6] "Variable Costs of Fuel Economy Technologies," prepared for The Alliance of Automobile Manufacturers, June 1, 2008, Docket EPA-HQ-OAR-2009-0472-0144; and, "Variable Costs of Fuel Economy Technologies," prepared for The Alliance of Automobile Manufacturers, June 1, 2008, Amended December 10, 2008, Docket EPA-HQ-OAR-2009-0472-0145.

[7] National Highway Traffic Safety Administration, Request for Product Plan Information, 74 FR 48192, September 22, 2009.

[8] Memorandum from Don Kopinski, U.S. EPA, Docket No. EPA-HQ-OAR-2009-0472-0217, dated September 11, 2009.

[9] 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, Docket EPA-HQ-OAR-2009-0472-0149; EPA-420-R-09-020, EPA docket number EPA-HQ-OAR-2009-0472-11282.

[10] "Light-duty Technology Cost Analysis – Report on Additional Case Studies," EPA-420-R-10-010.

[11] U.S. Environmental Protection Agency, "Light-Duty Technology Cost Analysis Pilot Study," Contract No. EP-C-07-069, Work Assignment 1-3, December 2009, EPA-420-R-09-020, Docket EPA-HQ-OAR-2009-0472-0149; peer review report dated November 6, 2009, is at EPA-HQ-OAR-2009-0472-11285; "Light-duty Technology Cost Analysis – Report on Additional Case Studies," EPA-420-R-10-010..

[12] NHTSA's 2011 CAFE final rule at 74 FR 14196.

[13] National Income and Product Accounts Table 1.1.4: Price Indexes for Gross Domestic Product; downloaded on 6/25/2009 At 12:00:25 PM, Last Revised June 25, 2009; Bureau of Economic Analysis, U.S. Department of Commerce, www.bea.gov.

[14] The 2002 NAS Report, Docket EPA-HQ-OAR-2009-0472-0147; the 2004 study done by NESCCAF, Docket EPA-HQ-OAR-2009-0472-0148; the California Air Resources Board (CARB) Initial Statement of Reasons in support of their carbon rulemaking, Docket EPA-HQ-OAR-2009-0472-0134; a 2006 study done

by Energy and Environmental Analysis (EEA) for the Department of Energy, Docket EPA-HQ-OAR-2009-0472-0136; a study done by Martec for the Alliance of Automobile Manufacturers, Docket EPA-HQ-OAR-2009-0472-0144, and the 2008 Martec Report which updated that study, Docket EPA-HQ-OAR-2009-0472-0145; and vehicle fuel economy certification data, and confidential data submitted by manufacturers in response to the March and November 2009 requests for product plans.

[15] 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, Docket EPA-HQ-OAR-2009-0472-0149.

[16] Rogozhin, Alex, Michael Gallaher, and Walter McManus, "Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers," EPA 420-R-09-003, Docket EPA Docket EPA-HQ-OAR-2009-0472-0142, February 2009, http://epa.gov/otaq/ld-hwy/420r09003.pdf.

[17] "Memorandum: Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies," Gloria Helfand and Todd Sherwood, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, August 2009, Docket EPA-HQ-OAR-2009-0472-0158.

[18] "Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines," EPA420-R-04-007, May 2004, Docket EPA-HQ-OAR-2009-0472-0140; "Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder," EPA420-D-08-001a, May 2008, Docket EPA-HQ-OAR-2009-0472-0139; NHTSA 2011 CAFE final rule at 74 FR 14196.

[19] "Learning Curves in Manufacturing," Linda Argote and Dennis Epple, Science, February 23, 1990, Vol. 247, pp. 920-924, Docket EPA-HQ-OAR-2009-0472-0143.

[20] NHTSA 2011 CAFE final rule at 74 FR 14196; "EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-Duty Vehicle Carbon Dioxide Emissions," EPA420-R-08-008, March 2008, Docket EPA-HQ-OAR-2009-0472-0132; "Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines," EPA420-R-04-007, May 2004, Docket EPA-HQ-OAR-2009-0472-0140; "Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression-Ignition Engines Less than 30 Liters per Cylinder," EPA420-D-08-001a, May 2008, Docket EPA-HQ-OAR-2009-0472-0139.

[21] "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).

[22] "Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2007", EPA420-S-07-001, September 2007, Docket EPA-HQ-OAR-2009-0472-0137. Available at http://www.epa.gov/oms/cert/mpg/fetrends/fetrends-archive.htm (last accessed July 9, 2009).

[23] Paul Whitaker, Ricardo, Inc., "Gasoline Engine Performance And Emissions – Future Technologies and Optimization," ERC Symposium, Low Emission Combustion Technologies for Future IC Engines, Madison, WI, June 8-9, 2005, Docket EPA-HQ-OAR-2009-0472-0155. Available at http://www.erc.wisc.edu/symposiums/2005_Symposium/June%208%20PM/Whitaker_Ricardo.pdf (last accessed Nov. 9, 2008).

[24] Stefan Trampert, FEV Motorentechnik GmbH, "Engine and Transmission Development Trends - Rising Fuel Cost Pushes Technology," Symposium on International Automotive Technology, Pune, India, January 2007.

[25] "Binning of FEV Costs to GDI, Turbo-charging, and Engine Downsizing," memorandum to Docket EPA-HQ-OAR-2009-0472, from Michael Olechiw, U.S. EPA, dated March 25, 2010.

[26] "Binning of FEV Costs to GDI, Turbo-charging, and Engine Downsizing," memorandum to Docket EPA-HQ-OAR-2009-0472, from Michael Olechiw, U.S. EPA, dated March 25, 2010.

[27] Stefan Wolff, Dirk Abendroth, Werner Weigl, Claus-Peter Linner, Rupert Neudecker, Michael Schneider, Wolfgang Huber, and Andreas Rau, BMW, "Introducing The Automatic Start-Stop (ASS) Function In Series Models," 7th Stuttgart Automotive Vehicle and Engine Symposium, Organised by FKFS, Mar 2007, Vol. 1.

[28] G.K. Fraidl, P.E. Kapus, and H. Friedl, AVL List GmbH, "Future Gasoline Engine Technologies for 130 g/Km CO2," VKM-THD 11th Symposium on the Working Process of Combustion Engines, TU Graz, Sept. 2007.

[29] "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.

[30] 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)

[31] 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.

[32] 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.

[33] 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, Docket EPA-HQ-OAR-2009-0472-0149.

[34] Docket No. NHTSA-2008-0089-0193.1

[35] Cairns *et al.*, Lotus, "Low Cost Solutions for Improved Fuel Economy in Gasoline Engines," Global Powertrain Congress September 27-29, 2005, vol. 33. *Available at* http://www.gpc-icpem.org/pages/publications.html (last accessed Nov. 9, 2008).

[36] Tim Lake, John Stokes, Richard Murphy, and Richard Osborne of Ricardo and Andreas Schamel of Ford-Werke, "Turbocharging Concepts for Downsized DI Gasoline Engines," VKA/ika Aachen Colloquium 2003. *Available at* http://cat.inist.fr/?aModele=afficheN&cpsidt=16973598 (last accessed Nov. 9, 2008).

[37] "Interim Report: New Powertrain Technologies and Their Projected Costs," October 2005, EPA420-R-05-012, Docket EPA-HQ-OAR-2009-0472-0138.

[38] "Cost and Fuel Economy Comparison of Diesel and Gasoline Powertrains in Passenger Cars and Light Trucks," submitted by FEV Engine Technology, Inc., April 23, 2003, contained as Appendix I within EPA Interim Technical Report EPA420-R-04-002, Docket EPA-HQ-OAR-2009-0472-0141.

[39] EPA's 2007/2010 diesel heavy-duty highway final rule at66 FR 5002; EPA's Locomotive and Marine final rule at 73 FR 37096.

[40] http://www.platinum.matthey.com/ (web page printout is contained in Docket EPA-HQ-OAR-2009-0472 as "Johnson-Matthey PGM data for March 2009.pdf").

[41] General Motors, news release, "From Hybrids to Six-Speeds, Direct Injection And More, GM's 2008 Global Powertrain Lineup Provides More Miles with Less Fuel" (released Mar. 6, 2007). *Available at http://www.gm.com/experience/fuel_economy/news/2007/adv_engines/2008-powertrain-lineup-082707.jsp* (last accessed Sept. 18, 2008).

[42] "EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-duty Vehicle Carbon Dioxide Emissions" Environmental Protection Agency, EPA420-R-08-008, March 2008, at page 17, Docket EPA-HQ-OAR-2009-0472-0132.

[43] "Latest Chevrolet Volt Battery Pack and Generator Details and Clarifications." Lyle Dennis interview of Rob Peterson (GM) regarding the all-electric drive range of the GM Volt, August 29, 2007. Accessed on the Internet on June 30, 2009 at: http://gm-volt.com/2007/08/29/latest-Chevrolet-volt-battery-pack-and-generator-details-and-clarifications/

[44] "Active Combination of Ultracapacitorsand Batteries for PHEV ESS." Bohn, T. U.S. Department of Energy 2009 Vehicle Technologies Merit Review, May 20, 2009, Docket EPA-HQ-OAR-2009-0472-0163.

[45] Anderman, Advanced Automotive Battery Conference, May 2008. Proceedings available for purchase at http://www.advancedautobat.com/Proceedings/index.html (last accessed October 17, 2008).

[46] 74 FR 14291 (Mar. 30, 2009)

[47] "Electric Cars: Plugged In, Batteries must be included," Deutsche Bank Global Markets Research Company, June 9, 2008, Docket EPA-HQ-OAR-2009-0472-0154.

[48] http://automobiles.honda.com/insight-hybrid/features.aspx?Feature=ima (last accessed on March 29, 2010; web page printout is contained in Docket EPA-HQ-OAR-2009-0472 as "Honda IMA webpage.pdf").

[49] "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

[50] "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

[51] "Future Generation Passenger Compartment-Validation (ASP 241)" Villano, P.J., Shaw, J.R., Polewarczyk, J., Morgans, S., Carpenter, J.A., Yocum, A.D., in "Lightweighting Materials – FY 2008 Progress Report," U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Vehicle Technologies Program, May 2009, Docket EPA-HQ-OAR-2009-0472-0190.

[52] "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

[53] "Future Generation Passenger Compartment – Final Report," Auto-Steel Partnership Report, June 2007. Accessed on the Internet on May 30, 2009 at: http://www.a-sp.org/database/custom/FGPC%20Phase %201%20Final%20Report.pdf

[54] "Lighten Up!," Brooke, L., Evans, H. Automive Engineering International, Vol. 117, No. 3, March 2009.

[55] "2008/9 Blueprint for Sustainability," Ford Motor Company. Available at: http:// www.ford.com/go/sustainability (last accessed February 8, 2010).

[56] "Mazda to cut vehicle fuel consumption 30 percent by 2015," Mazda press release, June 23, 2009. Available at: http://www.mazda.com/publicity/release/2008/200806/080623.html (last accessed February 8, 2010).

[57] "Mazda: Don't believe hot air being emitted by hybrid hype," Greimel, H. Automotive News, March 30, 2009.

[58] "Factor of Two: Halving the Fuel Consumption of New U.S. Automobiles by 2035," Cheah, L., Evans, C., Bandivadekar, A., Heywood, J., Massachusetts Institute of Technology, Publication No. LFEE 2007-04 RP, October 2007, Docket EPA-HQ-OAR-2009-0472-0174.

[59] "FY 2007 Progress Report for Lightweighting Materials", Davis, P., Sullivan, R., Carpenter, J., U.S. Department of Energy Office of Vehicle Technologies, December 2008, Docket EPA-HQ-OAR-2009-0472-0165. Accessed on the Internet on April 30, 2009 at: http://www1.eere.energy.gov/vehiclesandfuels/resources/vt_lm_fy07.html

[60] "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

[61] "Basic Analysis of the Cost and Long-Term Impact of the Energy Independence and Security Act Fuel Economy Standards" Sierra Research Report No. SR2008-04-01, Docket EPA-HQ-OAR-2009-0472-0173.

[62] "Factor of Two: Halving the Fuel Consumption of New U.S. Automobiles by 2035" L. Cheah, C. Evans, A. Bandivadekar and J. Heywood, Publication No. LFEE 2007-04 RP, October 2007, Docket EPA-HQ-OAR-2009-0472-0174.

[63] "Tires and Passenger Vehicle Fuel Economy," Transportation Research Board Special Report 286, National Research Council of the National Academies, 2006, Docket EPA-HQ-OAR-2009-0472-0146.

[64] "An HCCI Engine Power Plant for a Hybrid Vehicle," Sun, R., R. Thomas and C. Gray, Jr., SAE Technical Paper No. 2004-01-0933, 2004.

CHAPTER 4: Economic Assumptions Used in the Agencies' Analysis

4.1 How the agencies use the economic assumptions in their analyses

Improving new vehicles' fuel efficiency and reducing greenhouse gas (GHG) emissions provides direct benefits to their buyers and users by reducing fuel consumption and fuel costs throughout those vehicles' lifetimes, stimulating increased vehicle use through the fuel economy rebound effect, and increasing vehicles' driving range so that they require less frequent refueling. At the same time, the reduction in fuel use that results from requiring higher fuel economy and reducing GHGs also produces wider benefits to the U.S. economy by lowering the cost of economic externalities that result from U.S. petroleum consumption and imports, including reducing the price of petroleum, lowering the potential costs from disruption in the flow of oil imports, and possibly reducing federal outlays to secure imported oil supplies and cushion the U.S. economy against their potential interruption. Reducing fuel consumption and GHGs also lowers the economic costs of environmental externalities resulting from fuel production and use, including reducing the impacts on human health from emissions of criteria air pollutants, and reducing future economic damages from potential changes in the global climate caused by greenhouse gas emissions.

These benefits are partly offset by the increase in fuel use that results from added vehicle use due to the fuel economy rebound effect, as well as by added costs from the increased congestion, crashes, and noise caused by increased vehicle use. They might also be offset by any loss in the utility that new vehicles provide to their buyers (and subsequent owners) if manufacturers include reductions in vehicles' performance, carrying capacity, or comfort as part of their strategies to comply with higher fuel economy requirements and GHG standards. Nevertheless, the total economic benefits from requiring higher fuel economy and reducing GHGs are likely to be substantial, and the EPA and NHTSA have attempted to develop detailed estimates of the economic benefits from adopting more stringent standards.

This section discusses the common economic values used by both NHTSA and EPA. These economic inputs incorporate a range of forecast information, economic estimates, and input parameters. This section describes the sources that EPA and NHTSA have relied upon for this information, the rationale underlying each assumption, and the agencies' estimates of specific parameter values. These common economic values are then used as inputs into each Agencies' respective modeling and other analyses of the economic benefits and costs of the EPA and NHTSA programs. While the underlying economic input values are common to both Agencies, it is the differences in the way each Agency assesses its program that result in differing benefits estimates. This issue is discussed further in Section I.C of the preamble to the joint rulemaking.

4.2   What economic assumptions do the agencies use?

4.2.1 The on-road fuel economy "gap"

Actual fuel economy levels achieved by vehicles in on-road driving fall significantly short of their levels measured under the laboratory-like test conditions used under the CAFE program to establish its published fuel economy ratings for different models. In analyzing the fuel savings from passenger car and light truck fuel efficiency and GHG standards, the agency adjusts the actual fuel economy performance of each passenger car and light truck model downward from its rated value to reflect the expected size of this on-road fuel economy "gap." In December 2006, EPA adopted changes to its regulations on fuel economy labeling, which were intended to bring vehicles' rated fuel economy levels closer to their actual on-road fuel economy levels.[1]

Comparisons of on-road and CAFE fuel economy levels developed by EPA as part of its Final Rule implementing new fuel economy labeling requirements for new vehicles indicate that actual on-road fuel economy for light-duty vehicles averages 20 percent lower than published fuel economy levels.[2] While there is great heterogeneity between individual drivers, as discussed in the referenced material, 20% represents an accurate average for modeling a fleet. For example, if the overall EPA fuel economy rating of a light truck is 20 mpg, the on-road fuel economy actually achieved by a typical driver of that vehicle is expected to be 16 mpg (20*.80). In its analysis supporting the Final Rule establishing CAFE standards for MY 2011, NHTSA employed EPA's revised estimate of this on-road fuel economy gap in its analysis of the fuel savings resulting from alternative fuel efficiency standards.

An analysis conducted by NHTSA confirmed that EPA's estimate of a 20 percent gap between test and on-road fuel economy is well-founded. The agency used data on the number of passenger cars and light trucks of each model year that were in service (registered for use) during each calendar year from 2000 through 2006, average fuel economy for passenger cars and light trucks produced during each model year, and estimates of average miles driven per year by cars and light trucks of different ages during each calendar year over that period. These data were combined to develop estimates of the usage-weighted average fuel economy that the U.S. passenger car and light truck fleets would have achieved during each year from 2000 through 2006 under test conditions.

Table 4-1 compares NHTSA's estimates of fleet-wide average fuel economy under test conditions for 2000 through 2006 to the Federal Highway Administration's (FHWA) published estimates of actual on-road fuel economy achieved by passenger cars and light trucks during each of those years. As it shows, FHWA's estimates of actual fuel economy for passenger cars ranged from 21 percent to 23 percent lower than NHTSA's estimates of its fleet-wide average value under test conditions over this period. Similarly, FHWA's estimates of actual fuel economy for light trucks ranged from 16 percent to 18 percent lower than NHTSA's estimates of average light truck fuel economy under test conditions. Thus, these results appear to confirm that the 20 percent on-road fuel economy discount or gap represents a reasonable estimate for use in evaluating the fuel savings likely to result from alternative fuel efficiency standards for MY 2012-2016 vehicles.

We are aware of two potential issues involved in these estimates. One, the estimates of total annual car and truck VMT are developed by the states and submitted to FHWA. Each state uses its own definition of a car and a truck. For example, some states classify minivans as cars and some as trucks. Thus, there are known inconsistencies with these estimates when evaluated separately for cars and trucks. Also, total gasoline consumption can be reasonably estimated from excise tax receipts, but separate estimates for cars and trucks are not available. We are not aware of the precise methodology used to develop the distinct on-road fuel economy estimates for cars and trucks developed by FHWA. We do not believe that they are based on direct measurements from substantial numbers of vehicles, as no such test programs were found by EPA during its fuel economy labeling rule in 2006. Also, the year-to-year consistency for both car and truck fuel economy implies some methodology other than direct measurement. For this reason, NHTSA and EPA are not using distinct on-road fuel economy gaps for cars and trucks, but one common value of 20 percent for both vehicle classes for purposes of estimating the fuel savings of the standards.

Table 4-1 Estimated Fleet-Wide Fuel Economy of Passenger Cars and Light Trucks Compared to Reported Fuel Economy

YEAR	PASSENGER CARS			LIGHT-DUTY TRUCKS		
	NHTSA Estimated Test MPG	FHWA Reported Actual MPG	Percent Difference	NHTSA Estimated Test MPG	FHWA Reported Actual MPG	Percent Difference
2000	28.2	21.9	-22.2%	20.8	17.4	-16.3%
2001	28.2	22.1	-21.7%	20.8	17.6	-15.5%
2002	28.3	22.0	-22.3%	20.9	17.5	-16.2%
2003	28.4	22.2	-21.9%	21.0	17.2	-18.0%
2004	28.5	22.5	-21.1%	21.0	17.2	-18.3%
2005	28.6	22.1	-22.8%	21.1	17.7	-16.3%
2006	28.8	22.5	-21.8%	21.2	17.8	-16.2%
Avg., 2000-2006	28.4	22.2	-22.0%	21.0	17.5	-16.7%

4.2.2 Fuel prices and the value of saving fuel

Projected future fuel prices are a critical input into the preliminary economic analysis of alternative fuel efficiency and GHG standards, because they determine the value of fuel savings both to new vehicle buyers and to society. As in the proposal, EPA and NHTSA relied on the most recent fuel price projections from the U.S. Energy Information Administration's (EIA) *Annual Energy Outlook* (AEO) for this analysis. In the proposal, we used the AEO 2009 (April 2009 release). For the final rulemaking presented here, we updated to the more recent AEO 2010 Early Release.[3] The Reference Case forecasts inflation-adjusted (constant-dollar) retail gasoline and diesel fuel prices and represents the EIA's most up-to-date estimate of the most likely course of future prices for petroleum products.[4]

AEO 2010 also reflects the provisions of the Energy Independence and Security Act of 2007 (EISA), including the requirement that the combined mpg level of U.S. cars and light trucks reach 35 miles per gallon by model year 2020. Because this provision would be expected to reduce future U.S. demand for gasoline and other fuels, the agencies conducted analysis whether AEO 2010 is suitable for valuing the projected reductions in fuel use. In response to this concern, the agencies note that EIA issued a revised version of AEO 2008 in June 2008, which modified its previous December 2007 Early Release of AEO 2008 to reflect the effects of the recently-passed EISA legislation. The fuel price forecasts reported in EIA's Revised Release of AEO 2008 differed by less than one cent per gallon over the entire forecast period (2008–2030) from those previously issued as part of its initial release of AEO 2008. Thus, the agencies are reasonably confident that the fuel price forecasts presented in AEO 2010 and used to analyze the value of fuel savings projected to result from this rule are not unduly affected by the CAFE provisions of EISA, and therefore do not cause a baseline problem. For more detail, please see the docket memo.[5]

As compared to the gasoline prices used in the proposal, AEO 2010 Early Release fuel prices are generally lower (in absolute 2007 dollars). A comparison table is presented below, Table 4-2. In broad strokes, future projections of fuel price are generally lower in AEO 2010 than in AEO 2009.

Table 4-2 Gasoline Prices for Selected Years in AEO 2009 and 2010

(Presented in constant 2007$ and including all taxes)

	2015	2020	2030
AEO 2010	$3.00	$3.27	$3.60
AEO 2009	$3.16	$3.62	$3.82

Federal government agencies generally use EIA's projections in their assessments of future energy-related policies. The retail fuel price forecasts presented in AEO 2010 span the period from 2007 through 2035. Measured in constant 2007 dollars, the AEO 2010 Reference Case forecast of retail gasoline prices during calendar year 2020 is $3.27 per gallon, rising gradually to $3.83 by the year 2035 (these values include federal, state and local taxes). However, valuing fuel savings over the maximum lifetimes of passenger cars and light trucks used in this analysis requires fuel price forecasts that extend through 2050, approximately the last year during which a significant number of MY 2016 vehicles will remain in service.[a] To obtain fuel price forecasts for the years 2036 through 2050, the agency assumes that retail fuel prices will continue to increase after 2035 at the average annual rates projected for 2020-2035 in the AEO 2010 Reference Case.[b] This assumption results in a projected retail price of gasoline that reaches $4.49 in 2050.

---

[a] The agency defines the maximum lifetime of vehicles as the highest age at which more than 2 percent of those originally produced during a model year remain in service. In the case of light-duty trucks, for example, this age has typically been 36 years for recent model years.

[b] This projection uses the rate of increase in fuel prices for 2020-2030 rather than that over the complete forecast period (2009-2030) because there is extreme volatility in the forecasts for the years 2009 through approximately

The value of fuel savings resulting from improved fuel economy and GHG emissions to buyers of light-duty vehicles is determined by the retail price of fuel, which includes federal, state, and any local taxes imposed on fuel sales. Total taxes on gasoline, including federal, state, and local levies averaged $0.42 per gallon during 2008, while those levied on diesel averaged $0.50. Because fuel taxes represent transfers of resources from fuel buyers to government agencies, however, rather than real resources that are consumed in the process of supplying or using fuel, their value must be deducted from retail fuel prices to determine the value of fuel savings resulting from more stringent fuel efficiency and GHG standards to the U.S. economy as a whole.

In estimating the economy-wide value of fuel savings from improved fuel efficiency standards and GHG emission standards, EPA and NHTSA follow the assumptions used by EIA in AEO 2010 that state and local gasoline taxes will keep pace with inflation in nominal terms, and thus remain constant when expressed in constant 2007 dollars.[c] In contrast, EIA assumes that federal gasoline taxes will remain unchanged in *nominal* terms, and thus decline throughout the forecast period when expressed in constant 2007 dollars. These differing assumptions about the likely future behavior of federal and state/local fuel taxes are consistent with recent historical experience, which reflects the fact that federal as well as most state motor fuel taxes are specified on a cents-per-gallon basis, and typically require legislation to change. The projected value of total taxes is deducted from each future year's forecast of retail gasoline and diesel prices reported in AEO 2010 to determine the economic value of each gallon of fuel saved during that year as a result of improved fuel economy. Subtracting fuel taxes results in a projected value for saving gasoline of $2.89 per gallon during 2020, rising to $3.48 per gallon by the year 2035.

EIA is widely-recognized as an impartial and authoritative source of analysis and forecasts of U.S. energy production, consumption, and prices. The agency has published annual forecasts of energy prices and consumption levels for the U.S. economy since 1982 in its AEOs. These forecasts have been widely relied upon by federal agencies for use in regulatory analysis and for other purposes. Since 1994, EIA's annual forecasts have been based upon the agency's National Energy Modeling System (NEMS), which includes detailed representation of supply pathways, sources of demand, and their interaction to determine prices for different forms of energy.

From 1982 through 1993, EIA's forecasts of world oil prices – the primary determinant of prices for gasoline, diesel, and other transportation fuels derived from petroleum – consistently overestimated actual prices during future years, often very significantly. Of the total of 119 forecasts of future world oil prices for the years 1985 through 2005 that EIA reported in its 1982-1993 editions of AEO, 109 overestimated the subsequent actual values for those years, on average exceeding their corresponding actual values by 75 percent.

2020. Using the average rate of change over the complete 2009-2030 forecast period would result in projections of declining fuel prices after 2030.

[c] To calculate economy-wide impacts, the agencies value fuel savings at pre-tax prices, since this measures the value of the resources that are saved when less fuel is produced and consumed. The economy-wide value of saving fuel includes this plus the reductions in economic and environmental externalities that result from consuming less fuel, importing less petroleum, and so on.

Since that time, however, EIA's forecasts of future world oil prices show a more mixed record for accuracy. The 1994-2005 editions of AEO reported 91 separate forecasts of world oil prices for the years 1995-2005, of which 33 have subsequently proven too high while the remaining 58 have underestimated actual prices. The average absolute error (*i.e.*, regardless of its direction) of these forecasts has been 21 percent, but over- and underestimates have tended to offset one another, so that on average EIA's more recent forecasts have underestimated actual world oil prices by 7 percent. Although both its overestimates and underestimates of future world oil prices for recent years have often been large, the most recent editions of AEO have significantly underestimated petroleum prices during those years for which actual prices are now available.

However, EPA and NHTSA does not regard EIA's recent tendency to underestimate future prices for petroleum and refined products or the high level of current fuel prices as adequate justification to employ forecasts that differ from the Reference Case forecast presented in the AEO 2010 Reference Case. This is particularly the case because both the AEO 2009 and AEO 2010 Reference Cases forecast significantly higher future prices than those projected in the initial release of AEO 2008, which in turn represented a major upward revision from EIA's fuel price forecast reported previously in AEO 2007. Comparing recent forecasts of world oil prices also shows that EIA's Reference Case forecast reported in AEO 2009 is among the *highest* of all six publicly-available forecasts of world oil prices over the 2010-30 time horizon.[6] Because world petroleum prices are the primary determinant of retail prices for refined petroleum products such as transportation fuels, this suggests that the Reference Case forecast of U.S. fuel prices reported in AEO 2010 is likely to be the highest of those projected by major forecasting services.

In the estimates of costs and benefits presented in the Preamble and the agencies' RIAs, the agencies have included the full fuel savings over vehicles' expected lifetimes, discounted to their present values using both 3 and 7 percent discount rates. More detailed discussion of this approach can be found in Preamble Sections III.H.1 and IV.G.6, in Section 8.1 of EPA's RIA, and in Chapter VIII of NHTSA's RIA.

4.2.3 Vehicle survival and use assumptions

The agencies' analyses of fuel savings and related benefits from adopting higher fuel efficiency standards and establishing GHG emission standards for MY 2012-2016 passenger cars and light trucks begin by estimating the resulting changes in fuel use over the entire lifetimes of these vehicles. The change in total fuel consumption by vehicles produced during each of these model years is calculated as the difference in their lifetime fuel use under the baseline assumption that the CAFE standard previously established for model year 2011 remains in effect, and under the alternative assumption that CAFE and GHG emissions standards improve for each model year from 2012-2016.

The first step in estimating lifetime fuel consumption by vehicles produced during a model year is to calculate the number of those vehicles that is expected to remain in service

during each future calendar year after they are produced and sold.[d] This number is calculated by multiplying the number of vehicles originally produced during a model year by the proportion expected to remain in service at the age they will have reached during each subsequent calendar year, often referred to as a "survival rate."

NHTSA previously updated its estimates of car and light truck survival rates using 2008 registration data (the most recent available) for passenger cars and light trucks produced during recent model years, in order to ensure that its forecasts of age-specific survival rates reflect recent increases in the durability and expected life spans of cars and light trucks.[7] Both agencies used these updated survival estimates in their analyses of fuel savings and other benefits from adopting improved fuel efficiency and GHG standards for MY 2012-2106 cars and light trucks. The proportions of passenger cars and light trucks expected to remain in service at each age up to their maximum lifetimes (26 and 36 years, respectively) are shown in Table 4-3 and Table 4-4.[e]

The next step in estimating lifetime fuel use by the cars or light trucks produced during a future model year is to calculate the total number of miles that they will be driven during each year of their expected lifetimes. To estimate total miles driven, the number of cars and light trucks projected to remain in use during each future calendar year calculated in the previous step is multiplied by the average number of miles a surviving car or light truck is expected to be driven at the age it will have reached in that year.

Updated estimates of average annual miles driven by cars and light trucks at each age were developed by NHTSA from the Federal Highway Administration's 2001 National Household Transportation Survey. These updated estimates, differ from those employed in past NHTSA analyses, were used previously by NHTSA to analyze the effects of the previously-established CAFE standards for MY 2011 cars and light trucks.[f]

Table 4-3 and Table 4-4 report NHTSA's updated estimates of average car and light truck use which were used in the analyses for the MY 2011 final rule. As these tables show, the

---

[d] Vehicles are defined to be of age 1 during the calendar year corresponding to the model year in which they are produced; thus for example, model year 2000 vehicles are considered to be of age 1 during calendar year 2000, age 1 during calendar year 2001, and to reach their maximum age of 26 years during calendar year 2025. NHTSA considers the maximum lifetime of vehicles to be the age after which less than 2 percent of the vehicles originally produced during a model year remain in service. Applying these conventions to vehicle registration data indicates that passenger cars have a maximum age of 26 years, while light trucks have a maximum lifetime of 36 years. *See* Lu, S., NHTSA, Regulatory Analysis and Evaluation Division, "Vehicle Survivability and Travel Mileage Schedules," DOT HS 809 952, 8-11 (January 2006). *Available at* http://www-nrd.nhtsa.dot.gov/Pubs/809952.pdf (last accessed Feb. 15, 2010).

[e] The maximum age of cars and light trucks was defined as the age when the number remaining in service has declined to approximately two percent of those originally produced. Based on an examination of recent registration data for previous model years, typical maximum ages appear to be 26 years for passenger cars and 36 years for light trucks.

[f] See also NHTSA, "Vehicle Survival and Travel Mileage Schedules," Office of Regulatory Analysis and Evaluation, January 2006, pp. 15-17. The original source of information on annual use of passenger cars and light trucks by age used in this analysis is the 2001 National Household Travel Survey (NHTS), jointly sponsored by the Federal Highway Administration, Bureau of Transportation Statistics, and National Highway Traffic Safety Administration.

resulting survival-weighted mileages calculated for that rule over the 26-year maximum lifetime of passenger cars is 161,847 miles, while that over the 36-year maximum lifetime of light trucks is 190,066 miles. It should be noted, however, that survival-weighted mileage is extremely low (less than 1,000 miles per year) after age 20 for cars and after age 25 for light trucks, and thus has little impact on lifetime fuel savings or other benefits from higher fuel economy, particularly after discounting those benefits to their present values.

The survival and annual mileage estimates reported in the tables reflect the convention that vehicles are defined to be of age 1 during the calendar year that coincides with their model year   Thus for example, model year 2012 vehicles will be considered to be of age 1 during calendar year 2012. This convention is used in order to account for the fact that vehicles produced during a model year typical are first offered for sale in June through September of the preceding calendar year (for example, sales of a model year typically begin in June through September of the previous calendar year, depending on manufacturer). Thus virtually all of the vehicles produced during a model year will be in use for some or all of the calendar year coinciding with their model year, and they are considered to be of age 1 during that year.[g]

---

[g] As an illustration, virtually the entire production of model year 2012 cars and light trucks will have been sold by the end of calendar year 2012, so those vehicles are defined to be of age 1 during calendar year 2012. Model year 2012 vehicles are subsequently defined to be of age 2 during calendar year 2013, age 3 during calendar year 2014, and so on. One complication arises because registration data are typically collected for July 1 of each calendar year, so not all vehicles produced during a model year will appear in registration data until the calendar year when they have reached age 2 (and sometimes age 3) under this convention.

Table 4-3 Survival Rates and Unadjusted Annual Miles Traveled (VMT) by Age for Passenger Cars (calculated from 2001 NHTS) Used in MY 2011 Final Rule

Vehicle Age	Estimated Survival Fraction	Estimated Annual VMT	Survival-Weighted Annual VMT
1	0.9950	14,231	14,160
2	0.9900	13,961	13,821
3	0.9831	13,669	13,438
4	0.9731	13,357	12,998
5	0.9593	13,028	12,497
6	0.9413	12,683	11,938
7	0.9188	12,325	11,324
8	0.8918	11,956	10,662
9	0.8604	11,578	9,961
10	0.8252	11,193	9,237
11	0.7866	10,804	8,499
12	0.7170	10,413	7,466
13	0.6125	10,022	6,138
14	0.5094	9,633	4,907
15	0.4142	9,249	3,831
16	0.3308	8,871	2,934
17	0.2604	8,502	2,214
18	0.2028	8,144	1,652
19	0.1565	7,799	1,220
20	0.1200	7,469	896
21	0.0916	7,157	656
22	0.0696	6,866	478
23	0.0527	6,596	348
24	0.0399	6,350	253
25	0.0301	6,131	185
26	0.0227	5,940	135
Estimated Passenger Car Lifetime VMT			161,847

**Table 4-4 Survival Rates and Unadjusted Annual Vehicle-Miles Traveled (VMT)
by Age for Light Trucks (calculated from 2001 NHTS) Used in MY 2011 Final Rule**

VEHICLE AGE	ESTIMATED SURVIVAL FRACTION	ESTIMATED ANNUAL VMT	SURVIVAL-WEIGHTED ANNUAL VMT
1	0.9950	16,085	16,004
2	0.9741	15,782	15,374
3	0.9603	15,442	14,829
4	0.9420	15,069	14,195
5	0.9190	14,667	13,479
6	0.8913	14,239	12,691
7	0.8590	13,790	11,845
8	0.8226	13,323	10,960
9	0.7827	12,844	10,053
10	0.7401	12,356	9,145
11	0.6956	11,863	8,252
12	0.6501	11,369	7,391
13	0.6042	10,879	6,573
14	0.5517	10,396	5,735
15	0.5009	9,924	4,971
16	0.4522	9,468	4,281
17	0.4062	9,032	3,669
18	0.3633	8,619	3,131
19	0.3236	8,234	2,665
20	0.2873	7,881	2,264
21	0.2542	7,565	1,923
22	0.2244	7,288	1,635
23	0.1975	7,055	1,393
24	0.1735	6,871	1,192
25	0.1522	6,739	1,026
26	0.1332	6,663	887
27	0.1165	6,648	774
28	0.1017	6,648	676
29	0.0887	6,648	590
30	0.0773	6,648	514
31	0.0673	6,648	447
32	0.0586	6,648	390
33	0.0509	6,648	338
34	0.0443	6,648	294
35	0.0385	6,648	256
36	0.0334	6,648	222
Estimated Lifetime Light Truck VMT			190,066

4.2.3.1 Adjusting vehicle use for future fuel prices

The estimates of average annual miles driven by passenger cars and light trucks reported in Table 4-3 and Table 4-4 reflect the historically low gasoline prices that prevailed at the time the 2001 NHTS was conducted. To account for the effect on vehicle use of subsequent increases in fuel prices in the proposal, the estimates of annual vehicle use derived from the NHTS were adjusted to reflect the forecasts of future gasoline prices reported in the Energy Information Administration's Annual Energy Outlook 2009 Updated Reference Case. For this final rulemaking, the agencies updated the analysis with the forecasts of future gasoline prices reported in the Energy Information Administration's Annual Energy Outlook 2010 Early Release. This adjustment accounts for the difference between the average retail price per gallon of fuel forecast during each calendar year over the expected lifetimes of model year 2012-2016 passenger cars and light trucks, and the average price that prevailed when the NHTS was conducted in 2001. The elasticity of annual vehicle use with respect to fuel cost per mile corresponding to the 10 percent fuel economy rebound effect used in this analysis (*i.e.*, an elasticity of -0.10) was used in conjunction with the difference between each future year's fuel prices and those prevailing in 2001 to adjust the estimates of vehicle use derived from the NHTS to reflect the effect of higher future fuel prices. This procedure was applied to the mileage figures reported previously in Table 4-3 and Table 4-4 to adjust annual mileage by age during each calendar year of the expected lifetimes of MY 2012-2016 cars and light trucks.

4.2.3.2 Ensuring consistency with growth in total vehicle use

The estimates of annual miles driven by passenger cars and light trucks at each age were also adjusted to reflect projected future growth in average vehicle use. Increases in the average number of miles cars and trucks are driven each year have been an important source of historical growth in *total* car and light truck use, and are expected to represent an important source of future growth in total light-duty vehicle travel as well. As an illustration of the importance of growth in average vehicle use, the total number of miles driven by passenger cars increased 35 percent from 1985 through 2005, equivalent to a compound annual growth rate of 1.5 percent.[8] During that time, however, the total number of passenger cars registered for in the U.S. grew by only about 0.3 percent annually.[h] Thus growth in the average number of miles automobiles are driven each year accounted for the remaining 1.2 percent (= 1.5 percent - 0.3 percent) annual growth in total automobile use.[i] Further, the AEO 2010 Reference Case forecasts of total car and light truck use and of the number of cars and light trucks in use suggest that their average annual use will continue to increase gradually from 2010 through 2035.

In order to develop reasonable estimates of future growth in average car and light truck use, the agencies calculated the rate of growth in the mileage schedules shown previously in Table 4-6 and Table 4-7 that would be necessary for total car and light truck travel to increase at

---

[h] A slight increase in the fraction of new passenger cars remaining in service beyond age 10 has accounted for a small share of growth in the U.S. automobile fleet. The fraction of new automobiles remaining in service to various ages was computed from R.L. Polk vehicle registration data for 1977 through 2005 by the agency's Center for Statistical Analysis.
[i] *See supra* note k below.

the rate forecast in the AEO 2010 Reference Case. This calculated rate is also consistent with future changes in the overall size and age distributions of the U.S. passenger car and light truck fleets that are implied by the agency's forecasts of total car and light truck sales and the survival rates reported in Table 4-3 and Table 4-4. The growth rate in average annual car and light truck use produced by this calculation is approximately 1.15 percent per year.[j] This rate was applied to the mileage figures reported previously in Table 4-3 and Table 4-4 to estimate annual mileage by age during each calendar year of the expected lifetimes of MY 2012-2016 cars and light trucks.[k]

Table 4-6 and Table 4-7 report the results of applying the adjustments for both future fuel prices and annual growth in car and light truck use to the mileage schedules reported previously in Table 4-2 and Table 4-3. Separate adjustments for projected fuel prices and growth in car and light truck use were made for each calendar year from 2012 through 2030. Because the effects of both fuel prices and cumulative growth in average vehicle use vary by year, these adjustments result in differing VMT schedules for each future year. The adjusted annual VMT estimates reported in Table 4-4 and Table 4-5 and their lifetime totals represent the *averages* of the adjusted values of annual car and light truck use by age for calendar years 2012-2030. However, the estimates of fuel savings and other impacts of improved fuel efficiency for *individual* calendar years over the lifetimes of model year 2012-16 cars and light trucks employ the adjusted values of car and light truck use by age during those specific calendar years.

While the adjustment for future fuel prices reduces average mileage at each age from the values shown previously, the adjustment for expected future growth in average vehicle use increases it. Comparing the mileage estimates in Table 4-6 and Table 4-7 to those shown previously in Table 4-2 and Table 4-3 shows that the net effect of these two adjustments is to increase expected lifetime mileage significantly. As an illustration, expected lifetime mileage for passenger cars, this figure rises to 195,264 miles from the 161,847 miles reported previously in Table 4-3 (or by 21 percent), while expected lifetime mileage for light trucks increases from the 190,066 miles reported previously in Table 4-4 to 225,865 miles (19 percent). As previously noted, the estimates of survival-weighted mileage decline to less than 1,000 miles per year after age 20 for cars and after age 27 for light trucks. Thus they have relatively little impact on

---

[j] It was not possible to estimate separate growth rates in average annual use for cars and light trucks, because of the significant reclassification of light truck models as passenger cars discussed previously.

[k] The agency has also identified an unintentional discrepancy between the estimates of expected lifetime VMT used by EPA and NHTSA in their respective analyses of proposed GHG and CAFE standards reported in the NPRM. EPA's estimates of expected lifetime VMT for model year 2012-26 vehicles reflect the shared assumption that the average number of miles driven annually by cars and light trucks of all ages would grow at a rate of 1.15 percent per year beginning in 2001. Although NHTSA's description of the procedures used to calculate its estimates of expected lifetime VMT for passenger cars and light trucks indicated that it had also adjusted the base-year estimates of vehicle use to account for annual growth (see Preliminary Regulatory Impact Assessment, Chapter VIII, p. 367), this adjustment was not in fact applied in NHTSA's analysis of the effects of proposed increases in CAFE standards for model years 2012-16. This omission caused the estimates of expected lifetime VMT for passenger cars and light trucks that NHTSA actually used in its NPRM analysis of CAFE standards for model years 2012-16 to be lower than those used by EPA. This error has been corrected by NHTSA, and this correction is reflected in its analysis of the impacts of CAFE standards for model year 2012-16 passenger cars and light trucks reported in the Final Rule. This error did not occur in the analysis of environmental impacts of alternative increases in CAFE standards reported in the agency's recent Draft Environmental Impact Statement.

lifetime fuel savings or other benefits from higher fuel economy, particularly after discounting the benefits that occur in those distant future years to their present values.

The VMT schedules used in the proposal and in this final rulemaking are presented below.   To summarize the earlier discussion, the slight (~2.5 percent) increase in lifetime VMT schedule is attributable to the lower fuel prices projected in AEO 2010 Early Release as compared to the updated AEO 2009.

Table 4-5 Summary of Expected Lifetime VMT Schedules

	MY 2012-2016 Proposal	MY 2012-2016 Final Rulemaking
Car	190,271	195,264
Trucks	221,199	225,865

Table 4-6 Survival Rates and Adjusted Annual Vehicle-Miles Traveled (VMT) by Age for Passenger Cars (average values for 2012-2030)

Vehicle Age	Estimated Survival Fraction	Adjusted Annual VMT	Survival-Weighted Annual VMT
1	0.9950	17,270	17,183
2	0.9900	16,943	16,774
3	0.9831	16,599	16,319
4	0.9731	16,163	15,728
5	0.9593	15,761	15,119
6	0.9413	15,337	14,437
7	0.9188	14,881	13,672
8	0.8918	14,429	12,868
9	0.8604	13,940	11,994
10	0.8252	13,495	11,136
11	0.7866	12,964	10,198
12	0.7170	12,510	8,970
13	0.6125	11,990	7,344
14	0.5094	11,470	5,843
15	0.4142	10,997	4,555
16	0.3308	10,543	3,488
17	0.2604	10,125	2,637
18	0.2028	9,714	1,970
19	0.1565	9,307	1,456
20	0.1200	8,891	1,067
21	0.0916	8,546	783
22	0.0696	8,285	577
23	0.0527	8,136	429
24	0.0399	7,896	315
25	0.0301	7,699	232
26	0.0227	7,530	171
Adjusted Lifetime Passenger Car VMT			195,264

Table 4-7 Survival Rates and Adjusted Annual Vehicle-Miles Traveled (VMT) by Age for Light Trucks (average values for 2012-2030)

Vehicle Age	Estimated Survival Fraction	Adjusted Annual VMT	Survival-Weighted Annual VMT
1	0.9950	19,219	19,123
2	0.9741	18,782	18,296
3	0.9603	18,419	17,688
4	0.9420	17,946	16,905
5	0.9190	17,502	16,085
6	0.8913	16,952	15,109
7	0.8590	16,439	14,121
8	0.8226	15,829	13,021
9	0.7827	15,218	11,911
10	0.7401	14,648	10,841
11	0.6956	13,992	9,733
12	0.6501	13,450	8,744
13	0.6042	12,832	7,753
14	0.5517	12,212	6,737
15	0.5009	11,600	5,811
16	0.4522	11,069	5,005
17	0.4062	10,617	4,313
18	0.3633	10,125	3,679
19	0.3236	9,650	3,123
20	0.2873	9,238	2,654
21	0.2542	8,882	2,258
22	0.2244	8,667	1,945
23	0.1975	8,400	1,659
24	0.1735	8,395	1,456
25	0.1522	8,197	1,248
26	0.1332	8,188	1,091
27	0.1165	8,218	957
28	0.1017	8,216	836
29	0.0887	8,213	728
30	0.0773	8,211	635
31	0.0673	8,210	553
32	0.0586	8,208	481
33	0.0509	8,203	418
34	0.0443	8,196	363
35	0.0385	8,182	315
36	0.0334	8,167	273
Adjusted Lifetime Light Truck VMT			225,865

4.2.4 Accounting for the fuel economy rebound effect

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

use that stems from improved fuel economy occurs because vehicle owners respond to the resulting reduction in vehicle fuel consumption and operating costs by driving slightly more.

The magnitude of the rebound effect is one of the determinants of the actual fuel savings that are likely to result from adopting stricter fuel economy or emissions standards, and thus an important parameter affecting EPA's and NHTSA's evaluation of alternative standards for future model years. It can be measured directly by estimating the elasticity of vehicle use with respect to fuel economy itself, or indirectly by the elasticity of vehicle use with respect to fuel cost per mile driven.[l] When expressed as a positive percentage, either of these parameters gives the fraction of fuel savings that would otherwise result from adopting stricter standards, but is offset by the increase in fuel consumption that results when vehicles with increased fuel economy are driven more.

The fuel economy rebound effect for light-duty vehicles has been the subject of a large number of studies since the early 1980s. Although they have reported a wide range of estimates of its exact magnitude, these studies generally conclude that a significant rebound effect occurs when vehicle fuel efficiency improves.[m] The most common approach to estimating its magnitude has been to analyze household survey data on vehicle use, fuel consumption, fuel prices (often obtained from external sources), and other determinants of household travel demand to isolate the response of vehicle use to higher fuel economy. Other studies have relied on econometric analysis of annual U.S. data on vehicle use, fuel economy, fuel prices, and other variables to identify the response of total or average vehicle use to changes in fleet-wide average fuel economy and its effect of fuel cost per mile driven. Two recent studies analyzed yearly variation in vehicle ownership and use, fuel prices, and fuel economy among individual states over an extended time period in order to measure the response of vehicle use to changing fuel economy.[n]

This section surveys these previous studies, summarizes recent work on the rebound effect, and explains the basis for the 10 percent rebound effect EPA and NHTSA are using in this rulemaking.[9]

4.2.4.1 Summary of historical literature on rebound effect

It is important to note that a majority of the studies previously conducted on the rebound effect rely on data from the 1950-1990s. While these older studies provide valuable information on the potential magnitude of the rebound effect, studies that include more recent information (e.g., data within the last decade) may provide more reliable estimates of how this rule will affect

---

[l] Fuel cost per mile is equal to the price of fuel in dollars per gallon divided by fuel economy in miles per gallon, so this figure declines when a vehicle's fuel economy increases.

[m] Some studies estimate that the long-run rebound effect is significantly larger than the immediate response to increased fuel efficiency. Although their estimates of the adjustment period required for the rebound effect to reach its long-run magnitude vary, this long-run effect is most appropriate for evaluating the fuel savings and emissions reductions resulting from stricter standards that would apply to future model years.

[n] In effect, these studies treat U.S. states as a data "panel" by applying appropriate estimation procedures to data consisting of each year's average values of these variables for the separate states.

future driving behavior. Therefore, the more recent studies have been described in more detail below.

Estimates based on aggregate U.S. vehicle travel data published by the U.S. Department of Transportation, Federal Highway Administration, covering the period from roughly 1950 to 1990, have found long-run rebound effects on the order of 10-30 percent. Some of these studies are summarized in the following table.

Table 4-8 Estimates of the Rebound Effect Using U.S. Aggregate Time-Series Data on Vehicle Travel[1]

AUTHOR (YEAR)	SHORT-RUN	LONG-RUN	TIME PERIOD
Mayo & Mathis (1988)	22%	26%	1958-84
Gately (1992)	9%	9%	1966-88
Greene (1992)	Linear 5-19% Log-linear 13%	Linear 5-19% Log-linear 13%	1957-89
Jones (1992)	13%	30%	1957-89
Schimek (1996)	5-7%	21-29%	1950-94

[1] Source: Sorrell and Dimitropolous (2007) table 4.6.

Table 4-9 Estimates of the Rebound Effect Using U.S. State Level Data[1]

AUTHOR (YEAR)	SHORT-RUN	LONG-RUN	TIME PERIOD
Haughton & Sarkar (1996)	9-16%	22%	1973-1992
Small and Van Dender (2007)	4.5%	22%	1961-2001

[1] Source: Sorrell and Dimitropolous (2007) table 4.7.

While national (Table 4-6) and state level (Table 4-9) data have found relatively consistent long-run estimates of the rebound effect, household surveys display more variability (Table 4-10). There are several possible explanations for this larger variability. One explanation is that some of these studies do not include vehicle age as an explanatory variable, thus leading to omitted variable bias.[10] Another explanation is that it is difficult to differentiate between the impacts of residential density and fuel prices, since households with higher fuel prices are more likely to be in urban areas.[11]

Table 4-10 Estimates of the Rebound Effect Using U.S. Survey Data

AUTHOR (YEAR)	SHORT-RUN	LONG-RUN	TIME PERIOD
Goldberg (1966)	0%		CES 1984-90
Greene (1999)		23%	EIA RTECS

			1979-1994
Pickrell & Schimek (1999)		4-34%	NPTS 1995 Single year
Puller & Greening (1999)	49%		CES 1980-90 Single year, cross-sectional
West (2004)	87%		CES 1997 Single year

An important distinction among studies of the rebound effect is whether they assume that the effect is constant, or varies over time in response to the absolute levels of fuel costs, personal income, or household vehicle ownership. Most studies using aggregate annual data for the U.S. assume a constant rebound effect, although some of these studies test whether the effect can vary as changes in retail fuel prices or average fuel economy alter fuel cost per mile driven. Many studies using household survey data estimate significantly different rebound effects for households owning varying numbers of vehicles, although they arrive at differing conclusions about whether the rebound effect is larger among households that own more vehicles. Finally, one recent study using state-level data concludes that the rebound effect varies directly in response to changes in personal income and the degree of urbanization of U.S. cities, as well as fuel costs.

In order to provide a more comprehensive overview of previous estimates of the rebound effect, EPA and NHTSA reviewed 22 studies of the rebound effect conducted from 1983 through 2005. The agencies then performed a detailed analysis of the 66 separate estimates of the long-run rebound effect reported in these studies, which is summarized in

Table 4-11 below.[o] As the table indicates, these 66 estimates of the long-run rebound effect range from as low as 7 percent to as high as 75 percent, with a mean value of 23 percent. Limiting the sample to 50 estimates reported in the 17 published studies of the rebound effect yields the same range, but a slightly higher mean estimate (24 percent).

The type of data used and authors' assumption about whether the rebound effect varies over time have important effects on its estimated magnitude. The 34 estimates derived from analysis of U.S. annual time-series data produce a mean estimate of 18 percent for the long-run rebound effect, while the mean of 23 estimates based on household survey data is considerably larger (31 percent), and the mean of 9 estimates based on state data (25 percent) is close to that for the entire sample. The 37 estimates assuming a constant rebound effect produce a mean of 23 percent, identical to the mean of the 29 estimates reported in studies that allowed the rebound effect to vary in response to fuel prices, vehicle ownership, or household income.

Table 4-11 Summary Statistics for Estimates of the Rebound Effect

---

[o] In some cases, NHTSA derived estimates of the overall rebound effect from more detailed results reported in the studies. For example, where studies estimated different rebound effects for households owning different numbers of vehicles but did not report an overall value, the agency computed a weighted average of the reported values using the distribution of households among vehicle ownership categories.

Category of Estimates	Number of Studies	Number of Estimates	Range		Distribution		
			Low	High	Median	Mean	Std. Dev.
All Estimates	22	66	7%	75%	22%	23%	14%
Published Estimates	17	50	7%	75%	22%	24%	14%
U.S. Time-Series Data	7	34	7%	45%	14%	18%	9%
Household Survey Data	13	23	9%	75%	31%	31%	16%
Pooled U.S. State Data	2	9	8%	58%	22%	25%	14%
Constant Rebound Effect (1)	15	37	7%	75%	20%	23%	16%
Variable Rebound Effect: (1)	10	29	10%	45%	23%	23%	10%

4.2.4.2   Summary of recent studies and analyses of the rebound effect

More recent studies since 2007 indicate that the impacts of fuel prices and fuel economy have been decreasing over time as incomes increase and real gasoline prices fall. The theoretical argument for why the rebound effect should vary is that the responsiveness to the fuel cost of driving will be larger when it is a larger proportion of the total cost of driving. As incomes rise (or fuel prices fall), the responsiveness to the fuel cost per mile of driving will decrease if people view the time cost of driving – which is likely to be related to their income levels – as a larger component of the total cost.

Small and Van Dender combined time series data for each of the 50 States and the District of Columbia to estimate the rebound effect, allowing the magnitude of the rebound to vary over time.[12] For the time period from 1966-2001, their study found a long-run rebound effect of about 22 percent, which is consistent with previously published studies. But for the most recent five year period (1997-2001), the long-run rebound effect decreased to 11 percent. Furthermore, when the authors updated their estimates with data through 2004, the long-run rebound effect for the most recent five year period (2000-2004) dropped to 6 percent.[13]

New research conducted by David Greene in 2008-2009 at EPA's request further appears to support the theory that the magnitude of the rebound effect is declining over time.[14] Over the entire time period analyzed (1966-2007), Greene found that fuel prices had a statistically significant impact on VMT, while fuel economy did not. In spite of this result, Greene also tested Small and Van Dender's formulation which allows the elasticity of fuel cost per mile to decrease with increasing per capita income. The results of estimation using national time series data confirmed the results obtained by Small and Van Dender using a time series of state level data.

While Small and Van Dender did not find a statistically significant coefficient for fuel efficiency, they did find a statistically significant coefficient for the price of fuel. They then tested the hypothesis that the elasticity of vehicle travel with respect to the price of fuel was equal to its elasticity with respect to the rate of fuel consumption (gallons per mile), and found that the data could not reject that hypothesis. As a consequence, they estimated the rebound effect as the elasticity of vehicle travel with respect to fuel cost per mile, which constrains these elasticities to be equal in magnitude. Greene also attempted to re-estimate the Small and Van Dender results using his national data set. When using Greene's preferred functional form, the

projected rebound effect is approximately 12 percent in 2007, and drops to 10 percent in 2010, 9 percent in 2016 and 8 percent in 2030.

4.2.4.3   NHTSA analysis of the rebound effect

To provide additional insight into the rebound effect for the purposes of this rulemaking, NHTSA developed several new estimates of its magnitude. These estimates were developed by estimating and testing several econometric models of the relationship between vehicle miles-traveled and factors that influence it, including household income, fuel prices, vehicle fuel efficiency, road supply, the number of vehicles in use, vehicle prices, and other factors.

As the study by Small and Van Dender pointed out, it is important to account for the effect of fuel prices when attempting to estimate the rebound effect. Failing to control for changes in fuel prices is likely to bias estimates of the rebound effect. Therefore, changes in fuel prices are taken into account in Volpe's analysis of the rebound effect. Several different approaches were used to estimate the fuel economy rebound effect for light duty vehicles, including single equation OLS regressions, multiple equation systems estimated using two- and three-stage least squares regression, vector autoregression, and vector error-correction models. With the exception of single-equation regressions estimated using OLS, all of these procedures attempt to account for the endogenous relationship of fuel efficiency to fuel prices.

The results from each of these approaches are presented in Table 4-12 below. The table reports the value of the rebound effect calculated over the entire period from 1950 through 2006, as well as for the final year of that period. In addition, the table presents forecasts of the average rebound effect between 2010 and 2030, which utilize forecasts of personal income, fuel prices, and fuel efficiency from EIA's AEO 2009 Reference Case.

The results of NHTSA's analysis are broadly consistent with the findings from previous research summarized above. The historical average long-run rebound effect is estimated to range from 16-30 percent, and comparing these estimates to its calculated values for 2006 (which range from 8-14 percent) gives some an indication that it is declining in magnitude. The forecast values of the rebound effect shown in the table also suggest that this decline is likely to continue through 2030, as they range from 4-16 percent.

Table 4-12 Summary of NHTSA Estimates of the Rebound Effect

Model	VMT Measure	Variables Included in VMT Equation	Estimation Technique	Rebound Effects:		
				1950-2006	2006	2010-2030*
Small-Van Dender single VMT equation	annual VMT per adult	fuel cost per mile, per Capita income, vehicle stock, road miles per adult, fraction of population that is adult, fraction of population living in urban areas, fraction of population living in urban areas with heavy rail, dummy variables for fuel rationing, time trend	OLS	33.0%	15.8%	8.0%
Small-Van Dender three-equation system	annual VMT per adult	fuel cost per mile, per Capita income, vehicle stock, road miles per adult, fraction of population that is adult, fraction of population living in urban areas, fraction of population living in urban areas with heavy rail, dummy variables for fuel rationing, time trend	3SLS	21.6%	5.8%	3.4%
Single-equation VMT model	annual VMT per adult	personal income, road miles per Capita, time trend	OLS	18.4%	11.7%	9.2%
Single-equation VMT model	annual VMT per vehicle	fuel cost per mile, personal income, road miles per Capita, time trend	OLS	17.6%	15.2%	15.7%
Single-equation VMT model	annual VMT per adult	fuel cost per mile, personal income, road miles per Capita, dummy variables for fuel rationing, time trend	OLS	34.0%	20.8%	13.6%
Single-equation VMT model	annual VMT per vehicle	fuel cost per mile, personal income, vehicles per road mile, % of fleet manufactured under CAFE standards, new vehicle prices	IV (for fuel cost per mile)	16.3%	9.2%	7.0%
Three-equation system for VMT, fuel efficiency, and vehicle stock	annual VMT per vehicle	fuel cost per mile, personal income, vehicles per capita, vehicles per road mile, fraction of adult population licensed to drive, new vehicle prices, % of fleet manufactured under CAFE standards	2SLS	29.5%	13.4%	15.9%
Three-equation system for VMT, fuel efficiency, and vehicle stock	annual VMT per vehicle	fuel cost per mile, personal income, vehicles per capita, vehicles per road mile, fraction of adult population licensed to drive, new vehicle prices, % of fleet manufactured under CAFE standards	3SLS	29.8%	13.7%	16.2%
Three-equation system for VMT,	annual VMT per vehicle	fuel cost per mile, personal income, vehicles per capita, vehicles per road mile, fraction of adult population	Vector auto-regression	19.9%	10.8%	--

4.2.4.4 Basis for rebound effect used by EPA and NHTSA in this rule

As the preceding discussion indicates, there is a wide range of estimates for both the historical magnitude of the rebound effect and its projected future value, and there is some evidence that the magnitude of the rebound effect appears to be declining over time. Nevertheless, NHTSA requires a single point estimate for the rebound effect as an input to its analysis, although a range of estimates can be used to test the sensitivity to uncertainty about its exact magnitude. For the final rulemaking, the agencies chose to use 10 percent as their primary estimate of the rebound effect, with a range of 5-15 percent for use in sensitivity testing.

As Tables 4-10 and 4-11 indicate, the 10 percent figure is well below those reported in almost all previous research, and Table 4-12 shows that it is also below most estimates of the historical and current magnitude of the rebound effect developed by NHTSA. However, other recent research – particularly that conducted by Small and Van Dender and by Greene – reports persuasive evidence that the magnitude of the rebound effect is likely to be declining over time, and the forecasts developed by NHTSA and reported in Table 4-12 also suggest that this is likely to be the case. As a consequence, the agencies concluded that a value below the historical estimates reported in Tables 4-10, 4-11, and 4-12 is likely to provide a more reliable estimate of its magnitude during the future period spanned by the agencies' analyses of the impacts of this rule. The 10 percent estimate meets this condition, since it lies below the 15-30 percent range of estimates for the historical rebound effect reported in most previous research, and at the upper end of the 5-10 percent range of estimates for the future rebound effect reported in the recent studies by Small and Van Dender and by Greene. As Table 4-12 shows, it also lies within the 3-16 percent range of forecasts of the future magnitude of the rebound effect developed by NHTSA in its recent research. In summary, the 10 percent value was not derived from a single point estimate from a particular study, but instead represents a reasonable compromise between the historical estimates and the projected future estimates. The Agencies will continue to review the estimate of the rebound effect for future rulemakings.

In their proposed rules, the agencies sought comment on other alternatives for estimating the rebound effect. As one illustration, under the assumption that drivers respond similarly to changes in the cost of driving whether they are caused by variation in fuel prices or fuel economy, the short-run price elasticity of demand for gasoline – which measures the sensitivity of gasoline consumption to changes in its price per gallon – may provide some indication about the magnitude of the rebound effect itself. Thus, the agencies sought comment on whether it would be appropriate to use the price elasticity of demand for gasoline, or other alternative approaches, to guide their choice of a value for the rebound effect.

During the public comment period, EPA and NHTSA did not receive new data or analysis on the level of the rebound effect, but did receive some supportive comments on the 10 percent level. Hence, EPA and NHTSA have elected to continue to use the 10 percent estimate of the rebound effect in the analyses supporting this final rule.

4.2.5 Benefits from increased vehicle use

The increase in vehicle use from the rebound effect provides additional benefits to their owners, who may make more frequent trips or travel farther to reach more desirable destinations.

This additional travel provides benefits to drivers and their passengers by improving their access to social and economic opportunities away from home. As evidenced by their decisions to make more frequent or longer trips when improved fuel economy reduces their costs for driving, the benefits from this additional travel exceed the costs drivers and passengers incur in making more frequent or longer trips.

The analysis estimates the economic benefits from increased rebound-effect driving as the sum of fuel costs drivers incur plus the consumer surplus they receive from the additional accessibility it provides.[p] Because the increased in travel depend on the extent of improvement in fuel economy, the value of benefits it provides differs among model years and alternative CAFE standards. Under even those alternatives that would impose the highest standards, however, the magnitude of these benefits represents a small fraction of total benefits.

4.2.6 Added costs from increased vehicle use

Although it provides some benefits to drivers, increased vehicle use associated with the rebound effect also contributes to increased traffic congestion, motor vehicle accidents, and highway noise. Depending on how the additional travel is distributed over 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.

Increased vehicle use due to the rebound effect may also increase the costs associated with traffic accidents. Drivers may take account of the potential costs they (and their passengers) face from the possibility of being involved in an accident when they decide to make additional trips. However, they probably do not consider all of the potential costs they impose on occupants of other vehicles and on pedestrians when accidents occur, so any increase in these "external" accident costs must be considered as another cost of additional rebound-effect driving. Like increased delay costs, any increase in these external accident costs caused by added driving is likely to depend on the traffic conditions under which it takes place, since accidents are more frequent in heavier traffic (although their severity may be reduced by the slower speeds at which heavier traffic typically moves).

Finally, added vehicle use from the rebound effect may also increase traffic noise. Noise generated by vehicles causes inconvenience, irritation, and potentially even discomfort to occupants of other vehicles, to pedestrians and other bystanders, and to residents or occupants of surrounding property. Because these effects are unlikely to be taken into account by the drivers whose vehicles contribute to traffic noise, they represent additional externalities associated with motor vehicle use. Although there is considerable uncertainty in measuring their value, any

---

[p] The consumer surplus provided by added travel is estimated as one-half of the product of the decline in fuel cost per mile and the resulting increase in the annual number of miles driven.

increase in the economic costs of traffic noise resulting from added vehicle use must be included together with other increased external costs from the rebound effect.

EPA and NHTSA rely on estimates of congestion, accident, and noise costs caused by automobiles and light trucks developed by the Federal Highway Administration to estimate the increased external costs caused by added driving due to the rebound effect.[15] NHTSA employed these estimates previously in its analysis accompanying the MY 2011 final rule, and continues to find them appropriate for this NPRM after reviewing the procedures used by FHWA to develop them and considering other available estimates of these values. They are intended to measure the increases in costs from added congestion, property damages and injuries in traffic accidents, and noise levels caused by automobiles and light trucks that are borne by persons other than their drivers (or "marginal" external costs).

Updated to 2007 dollars, FHWA's "Middle" estimates for marginal congestion, accident, and noise costs caused by automobile use amount to 5.2 cents, 2.3 cents, and 0.1 cents per vehicle-mile (for a total of 7.6 cents per mile), while those for pickup trucks and vans are 4.7 cents, 2.5 cents, and 0.1 cents per vehicle-mile (for a total of 7.3 cents per mile).[16, q] These costs are multiplied by the annual increases in automobile and light truck use from the rebound effect to yield the estimated increases in congestion, accident, and noise externality costs during each future year.

4.2.7 Petroleum and energy security impacts

4.2.7.1   Impact on U.S. petroleum imports

In 2008, U.S. petroleum import expenditures represented 21 percent of total U.S. imports of all goods and services.[17] In 2008, the United States imported 66 percent of the petroleum it consumed, and the transportation sector accounts for 70 percent of total U.S. petroleum consumption. This compares roughly to 37 percent of petroleum from imports and 55 percent consumption of petroleum in the transportation sector in 1975.[18] It is clear that petroleum imports have a significant impact on the U.S. economy. Requiring lower-GHG vehicle technology and improved fuel economy in the U.S. is expected to lower U.S. petroleum imports.

4.2.7.2   Background on U.S. energy security

U.S. energy security is broadly defined as protecting the U.S. economy against circumstances that threaten significant short- and long-term increases in energy costs. Most discussion of U.S. energy security revolves around the topic of the economic costs of U.S. dependence on oil imports. The problem is that the U.S. relies on sources of imported oil from

---

[q] The Federal Highway Administration's estimates of these costs agree closely with some other recent estimates. For example, recent published research conducted by Resources for the Future (RFF) estimates marginal congestion and external accident costs for increased light-duty vehicle use in the U.S. to be 3.5 and 3.0 cents per vehicle-mile in year-2002 dollars. *See* Ian W.H. Parry and Kenneth A. Small, "Does Britain or the U.S. Have the Right Gasoline Tax?" Discussion Paper 02-12, Resources for the Future, 19 and Table 1 (March 2002). *Available at* http://www.rff.org/rff/Documents/RFF-DP-02-12.pdf (last accessed Feb. 15, 2010).

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). Finally, these factors contribute to the vulnerability of the U.S. economy to episodic oil supply shocks and price spikes. In 2008, U.S. imports of crude oil were $326 billion (in 2007$, see Figure 4-1).
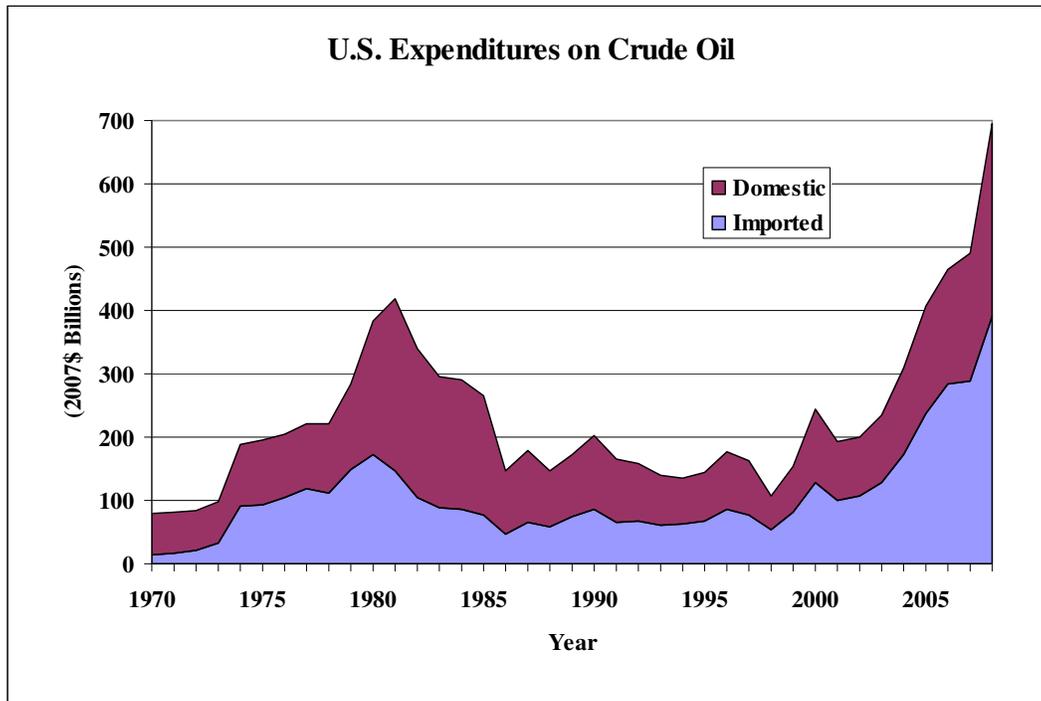
Figure 4-1 U.S. Expenditures on Crude Oil from 1970 through 2008[r]

One effect of the EPA/NHTSA joint rule is that it promotes more efficient use of transportation fuels in the U.S. The result is that it reduces U.S. oil 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 is a measure of improved U.S. energy security. For this rule, an "oil premium" approach is utilized to identify those energy-security related impacts 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.

4.2.7.2.1   *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

---

[r] For historical data through 2006: EIA Annual Energy Review, various editions.
For data 2006-2008: EIA Annual Energy Outlook (AEO) 2009 (Update Reference (Stimulus) Base Case).
See file "aeostimtab_11.xls" available at http://www.eia.doe.gov/oiaf/servicerpt/stimulus/aeostim.html

evaluating the social costs and energy security implications of oil use. The energy security estimates provide 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 recent study is included as part of the docket for this rulemaking.[19] This ORNL study is an update version of the approach to estimating the energy security benefits of U.S. oil import reductions developed in an ORNL 1997 Report by Leiby, Paul N., Donald W. Jones, T. Randall Curlee, and Russell Lee, entitled "*Oil Imports: An Assessment of Benefits and Costs.*"

When conducting this recent 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. import demand on the world oil price and on OPEC market power (*i.e.*, the "demand" or "monopsony" costs); and (2) the risk of reductions in U.S. economic output and disruption of the U.S. economy caused by sudden disruptions in the supply of imported oil to the U.S. (*i.e.*, macroeconomic disruption/adjustment costs). Maintaining a U.S. military presence to help secure stable oil supply from potentially vulnerable regions of the world was not included in this analysis because its attribution to particular missions or activities is difficult (as discussed further below).

Section III.H of the preamble contains a detailed discussion of how the monopsony and macroeconomic disruption/adjustment components were treated for this analysis. As that discussion indicates, the monopsony cost represents a transfer of resources from consumers of petroleum products to oil producers, and does not involve the consumption of real economic resources. Reducing the magnitude of the monopsony cost does not produce a savings in economic resources, although it does reduce the value of resources transferred from U.S. consumers of petroleum products to foreign suppliers of petroleum. In contrast, the macroeconomic disruption and adjustment costs that arise from U.S. petroleum imports do represent real economic costs, and reductions in their magnitude do represent real economic benefits from reducing U.S. consumption and imports of petroleum. Therefore, the remainder of this discussion focuses on estimating the magnitude of the macroeconomic disruption and adjustment costs.

As part of the process for using the ORNL energy security estimates, EPA sponsored an independent-expert peer review of this ORNL study. A report compiling the peer reviewers' comments is provided in the docket.[20] In addition, EPA has 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 for this rule. 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.

For this rule, ORNL further updated the energy security premium by incorporating the most recent oil price forecast and energy market trends in AEO 2009 into its model. In order for the energy security premium estimated to be used in EPA's VECTOR model, ORNL developed energy security estimates for a number of different years; *i.e.*, 2015, 2020, 2030, and 2040. NHTSA used just the 2015 estimates to estimate the energy security benefits associated with this rule.

For 2015, ORNL has estimated that the total energy security premium associated with a reduction of imported oil is $18.49/barrel. On a dollar per gallon basis, energy security benefits for 2015 are $0.44/gallon. Based upon alternative sensitivities regarding OPEC supply behavior, and the responsiveness of oil demand and supply to a change in the world oil price, the energy security premium ranges from $9.80 to $28.08/barrel. In terms of dollars per gallon, the energy security premium ranges from $0.23/gallon to $0.67/gallon. Please refer to Table 4-13 for similar information for years 2015, 2020, 2030 and 2040,[s] as well as a breakdown of the components of the energy security premium for each year. The components of the energy security premium and their values are discussed below.

Table 4-13 Energy Security Premium in 2015, 2020, 2030 and 2040[t]

(2007$/Barrel)

Year	Monopsony (Range)	Macroeconomic Disruption/Adjustment Costs (Range)	Total Mid-Point (Range)
2015	$11.79 ($4.26 - $21.37)	$6.70 ($3.11 – $10.67)	$18.49 $9.80 - $28.08
2020	$12.31 ($4.46 - $22.53)	$7.62 ($3.77 – $12.46)	$19.94 ($10.58 - $30.47)
2030	$10.57 ($3.84 – 18.94)	$8.12 ($3.90 – $13.04)	$18.69 ($10.52 - $27.89)
2040	$10.57 ($3.84 – $18.94)	$8.12 ($3.90 – $13.04)	$18.69 ($10.52 - $27.89)

4.2.7.2.1.1 *Effect of oil use on long-run oil price, U.S. import costs, and economic output*

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 foreign 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 the increased availability and use of other transportation fuels, 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. If a 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

---

[s] AEO 2009 forecasts energy market trends and values only to 2030. The energy security premia post-2030 were assumed to be the 2030 estimate.

[t] AEO 2009 world oil prices were used, as in the proposed rule. The analysis was not updated using the recently-released AEO 2010 forecast of world oil prices, because EPA and NHTSA believe that the changes in the fuel prices would be too small to cause a change in the Energy Security Premium estimates.

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 minus $441 million) is equivalent to an incremental benefit of $59 per barrel of oil imports 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 oil purchases. This additional benefit arises only to the extent that reduction in U.S. oil imports affects the world oil price. ORNL estimates this component of the energy security benefit in 2015 to be $11.79/barrel, with a range of $4.26 – $21.37/barrel of imported oil reduced.

4.2.7.2.1.2   *Short-run disruption premium from expected costs of sudden supply disruptions*

The second component of the oil import premium, the "macroeconomic disruption/adjustment costs premium," arises from the effect of oil imports on the expected cost of disruptions. A sudden increase in oil prices triggered by a disruption in world oil supplies has two main effects: (1) it increases the costs of imports in the short run, further expanding the transfer of U.S. wealth to foreign producers, and (2) it can lead to macroeconomic contraction, dislocation and Gross Domestic Product (GDP) losses. ORNL estimates the composite estimate of these two factors that comprise the macroeconomic disruption/adjustment costs premium to be $6.70/barrel in 2015, with a range of $3.11 – $10.67/barrel of imported oil reduced.

4.2.7.2.1.2.1 *Higher costs of oil imports during shocks*

During oil price shocks, the higher price of imported oil causes increased payments for imports from the U.S to oil exporters. This increased claim on U.S. economic output is a loss to the U.S. that is separate from and additional to any reduction in economic output due to the shock. The increased oil payments during shocks are counted as a loss to the degree that the expected price increase is not anticipated and internalized by oil consumers.

4.2.7.2.1.2.2 *Macroeconomic costs: potential output loss and dislocation/adjustment costs*

Macroeconomic losses during price shocks reflect both aggregate output losses and "allocative" losses. The former are a reduction in the level of output that the U.S. economy can produce fully using its available resources; and the latter stem from temporary dislocation and underutilization of available resources due to the shock, such as labor unemployment and idle plant capacity. The aggregate output effect, a reduction in "potential" economic output, will last so long as the 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 increase in prices for petroleum products, as well as whether and how rapidly these prices return to their pre-disruption levels.

In addition to the aggregate contraction, there are "allocative" or "adjustment" costs associated with dislocated energy markets. Because supply disruptions and resulting price increases occur suddenly, empirical evidence shows they also impose additional costs on businesses and households which 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 was 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.

In summary, the steps needed to calculate the disruption or security premium are: 1) determine the likelihood of an oil supply disruption in the future; 2) assess the likely impacts of a potential oil supply disruption on the world oil price; 3) assess the impact of the oil price shock on the U.S. economy (in terms of import costs and macroeconomic losses); and 4) determine how these costs change with oil imports. The value of price spike costs avoided by reducing oil imports becomes the oil security portion of the premium.

In the energy security literature, the macroeconomic disruption component of the energy security premium traditionally has included both (1) increased payments for petroleum imports associated with a rapid increase in world oil prices, and (2) the GDP losses and adjustment costs that result from projected future oil price shocks. One commenter suggested that the increased payments associated with rapid increases in petroleum prices (i.e., price increases in a disrupted market) represent transfers from U.S. oil consumers to petroleum suppliers rather than real economic costs, and therefore, should not be counted as a benefit.

This approach would represent a significant departure from how the macroeconomic disruption costs associated with oil price shocks have been quantified in the broader energy security literature, and the Agencies believe it should be analyzed in more detail before being applied in a regulatory context. In addition, the Agencies also believe that there are compelling reasons to treat higher oil import costs during oil supply disruptions differently than simple wealth transfers that reflect the exercise of market power by petroleum sellers or consumers. According to the OMB definition of a transfer: "Benefit and cost estimates should reflect real resource use. Transfer payments are monetary payments from one group to another that do not affect total resources available to society…The net reduction in the total surplus (consumer plus producer) is a real cost to society, but the transfer from buyers to sellers resulting from a higher price is not a real cost since the net reduction automatically accounts for the transfer from buyers

to sellers."[u] In other words, pure transfers do not lead to changes in the allocation or consumption of economic resources, whereas changes in the resource allocation or use produce real economic costs or benefits.

While price increases during oil price disruptions can result in large transfers of wealth, they also result 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 (i.e., the U.S.) suffer very high costs. Businesses' and households' emergency responses to supply disruptions and rapid price increases are likely to consume some real economic resources, in addition to causing financial losses to the U.S. economy that are matched by offsetting gains elsewhere in the global economy.

While households and businesses can reduce their petroleum consumption, invest in fuel switching technologies, or use futures markets to insulate themselves in advance against the potential costs of rapid increases in oil prices, when deciding how extensively to do so, 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.[v] Therefore, the ORNL estimate of macroeconomic disruption and 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 of petroleum products. The Agencies believe that, as the ORNL analysis argues, the uninternalized oil import costs that occur during oil supply interruptions represents a real cost associated with U.S. petroleum consumption and imports, and that reducing its value by lowering domestic petroleum consumption and imports thus represents a real economic benefit from lower fuel consumption.

4.2.7.2.2 *Cost of existing U.S. energy security policies*
The last often-identified component of the full economic costs of U.S. oil imports is the costs to the U.S. taxpayers of existing U.S. energy security policies. The two primary examples are maintaining a military presence to help secure a stable oil supply from potentially vulnerable regions of the world and maintaining the Strategic Petroleum Reserve (SPR). 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. a response option should a

---

[u] OMB Circular A-4, September 17, 2003. See http://www.whitehouse.gov/omb/assets/omb/circulars/a004/a-4.pdf
[v] For a more complete discussion of the reasons why the oil import cost component of the macroeconomic disruption and adjustment costs includes some real costs and does not represent a pure transfer, see Paul N. Leiby, Estimating the Energy Security Benefits of Reduced U.S. Oil Imports: Final Report, ORNL-TM-2007-028, Oak Ridge National Laboratory, March 14, 2008, pp. 21-25.

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.

U.S. military costs are excluded from the analysis performed by ORNL because their attribution to particular missions or activities is difficult. 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. Similarly, 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 SPR is factored into the ORNL analysis, the cost of maintaining the SPR is excluded.

4.2.7.2.3 *Modifications to analysis based upon peer reviewer comments*
The EPA commissioned ORNL to conduct a number of sensitivity analyses to address the comments of the peer reviewers. Based upon the peer reviewer comments, key parameters that influence the "oil import" premium were assessed. Since not all the comments were in agreement with each other, several ranges of different parameters were developed for the analyses. These sensitivities used the most recent price forecasts and energy market trends available at the time the peer review was being conducted and completed, the AEO 2007 Reference Case. Thus, the results presented below are suggestive of how the energy security premium is influenced by alternative assumptions of key parameters that influence world oil markets. A summary of the results of the analyses are shown in Table 4-14.

Three key parameters were varied in order to assess their impacts on the oil import premium: (1) the response of OPEC supply, (2) the combined response of non-U.S., non-OPEC demand and supply and (3) the GDP response to a change in the world oil as a result of reduced U.S. oil imports. The cases used updated supply/demand elasticities for non-U.S./non-OPEC region after considering more recent estimates than those used in 1997 study. As a result, the total market responsiveness is greater than previous ORNL estimates. Only small changes to the world oil price are anticipated from a substantial reduction in U.S. demand, on average, about $0.70/barrel for every million-barrels-per-day reduction in demand.

In the ORNL framework, OPEC-behavior is treated parametrically, with a wide range of possible responses represented by a range of supply elasticities. Case One in Table 4-14 below refers to the AEO 2007 estimates of energy market trends and uses the elasticity parameters from the original 1997 ORNL study. In Case Two, the OPEC supply elasticities range for 0.25 to 6 with a mean elasticity of 1.7. Case Three alters the distribution of the OPEC supply elasticities so that the mean elasticity is 2.2 instead of 1.7. With the more elastic OPEC oil supply in Case Three, the oil premium is lower. Alternatively, a candidate rule for OPEC strategic response behavior, adapted from a lead article on what behavior maximizes OPEC's long run net revenue in a robust way,[21] would have OPEC responding to preserve its worldwide oil market share. This is presented as Case Seven. Application of this rule instead of the range of OPEC supply responses used leads to an estimate of the oil import premium that is between Case Two and Case Three.

The second key parameter that was varied based upon peer reviewer comments was non-OPEC, non-U.S. demand and supply responsiveness to a change in the U.S. oil import demand and, hence, the world oil price. In Case Four, the mean non-U.S./non-OPEC demand and supply elasticities are taken to each be 0.3 in absolute value terms. When combined together, the net elasticity of import demand from this region — the non-U.S./non-OPEC region is — roughly 1.6. Case Five takes the Case Four assumptions of a more elastic OPEC supply behavior and combines those assumptions with the 1.6 net elasticity of import demand for the non-U.S./non-OPEC region. Case Six looks at the consequences of a yet higher net elasticity of import demand — 2.28 — for the non-U.S./non-OPEC region. The impact on the oil import premium is relatively modest.

Cases Eight and Nine consider a reduced GDP elasticity, the parameter which summarizes the sensitivity of GDP to oil price shocks. Several reviewers suggested a lower estimate for this parameter. In response to their comments, a couple of cases were examined where the GDP elasticity was lowered to 0.032 in comparison to the original ORNL estimate of 0.0495. As anticipated, this change lowered the oil import premium modestly. For example, compared with Case Four where OPEC supply is more elastic, lowering the GDP elasticity with respect to the world oil price reduced the oil import premium by roughly $0.40/barrel. This is because the GDP-dislocation component is only about one-quarter of the total premium, and there are offsetting changes in other components. The last case examined, Case Nine, looks at the consequences for the oil import premium with a reduced elasticity of GDP if OPEC attempts to maintain its share of the world oil market.

Clearly there is an unavoidable degree of uncertainty about the magnitude of marginal economic costs from the U.S. importation of petroleum, and the size of the oil import premium. ORNL sought to reflect this with probabilistic risk analysis over key input factors, guided by the available literature and the best judgment of oil market experts. Cases shown in Table 4-14 explore some reasonable variations in the ranges of input assumptions and the mean oil premium estimates vary in a fairly moderate range between roughly $11 and $15/barrel of imported oil. On balance, Case Eight suggested a reasonable and cautious assessment of the premium value to ORNL, and is ORNL's recommended case. This is based on a review of important driving factors, the numerical evaluations and simulations over major uncertainties, and taking into consideration the many comments and suggestion from the reviewers, the EPA and other Agencies. This recommended case, and the premium range resulting from 90 percent of the simulated outcomes, encompasses a wide array of perspectives and potential market outcomes in response to a reduction of U.S. imports.

As mentioned previously, this recommended case relied on the most recent available projections of the U.S. and world oil market for the next ten years based upon the AEO 2007 Reference Case. OPEC-behavior was treated parametrically, with a wide range of possible responses represented by a wide range of supply elasticities, from small to quite large. This recommended case recognized that the OPEC response is the most uncertain single element of this analysis. It could vary between inelastic defense of output levels, or market share, or could be highly elastic in defense of price, probably at the expense of longer run cartel power and discounted net profits. The balance between possible elastic and inelastic OPEC response was essentially even over a fairly wide range of elasticities. ORNL concluded that this is the best way to estimate OPEC behavior until greater progress can be made in synthesizing what insights

are available from the evolving strategic game-theoretic and empirical research on OPEC behavior, and advancing that research. An alternative would have been to use OPEC strategic response behavior to maximize long-run net revenue, which may well correspond to market-share preservation behavior (*e.g.*, Case Seven), and a somewhat higher premium value.

Finally, ORNL's recommended case used a GDP elasticity range, the parameter which summarizes the sensitivity of GDP to oil price shocks, which is reduced compared to earlier estimates, and compared to the full range of historically-based estimates. This helped address the concerns of those who either question the conclusions of past empirical estimates or expect that the impacts of oil shocks may well be declining.

Table 4-14 Summary Results – Oil Import Premium Under Various Cases ($2007/BBL)

Component	Statistic	1) AEO2007 Base Outlook, 1997 Study Elasticities	2) AEO2007 Base Outlook, Wider Range of OPEC Supply Elasticities	3) Case 2 with Revised Wider Range of OPEC Supply Elasticities	4) Case 2 with Updated Non-OPEC Supply/Demand Elasticities	5) Case 4 plus Revised Wider Range of OPEC Supply Elasticities	6) Case 4 Variant with Wider, Higher Range of Non-U.S./Non-OPEC Supply/Demand Elasticities	7) Case 6 with Applied Strategic OPEC Behavioral Rule: Maintain Market Share	8) Case 4 with Reduced GDP Elasticity	9) Case 7 with Reduced GDP Elasticity
Monopsony Component	Mean	$5.57	$10.26	$8.16	$7.77	$6.52	$6.44	$9.36	$7.86	$9.42
	Range	($3.60 - $8.19)	($3.10 - $21.22)	($3.12 - $19.30)	($2.94 - $13.75)	($2.90 - $13.06)	($2.69 - $11.33)	($6.69 - $12.42)	($2.94 - $13.89)	($6.72 - $12.54)
Disruption Import Costs	Mean	$2.36	$2.33	$2.34	$1.92	$1.94	$1.93	$1.89	$2.20	$2.16
	Range	($0.51 - $4.66)	($0.58 - $4.57)	($0.66 - $4.61)	($0.39 - $3.75)	($0.38 - $3.84)	($0.42 - $3.70)	($0.44 - $3.66)	($0.63 - $4.07)	($0.62 - $3.96)
Disruption Dislocation Costs	Mean	$3.83	$3.70	$3.76	$3.42	$3.45	$3.47	$3.41	$2.67	$2.64
	Range	($1.06 - $6.69)	($1.04 - $6.57)	($1.06 - $6.74)	($0.92 - $6.23)	($0.94 - $6.10)	($0.92 - $6.13)	($0.87 - $6.26)	($0.90 - $4.84)	($0.87 - $4.87)
Economic Disruption/Adjustment Costs	Mean	$6.19	$6.03	$6.10	$5.34	$5.39	$5.40	$5.30	$4.87	$4.81
	Range	($2.94 - $10.01)	($2.94 - $9.75)	($2.91 - $9.85)	($2.53 - $8.69)	($2.60 - $8.62)	($2.58 - $8.92)	($2.54 - $8.74)	($2.23 - $7.85)	($2.25 - $7.77)
Total Mid-Point	Mean	$11.75	$16.29	$14.27	$13.11	$11.90	$11.86	$14.65	$12.71	$14.23
	Range	($8.04 - $15.96)	($8.10 - $27.42)	($7.90 - $25.49)	($7.26 - $19.59)	($6.96 - $18.62)	($6.79 - $17.23)	($11.03 - $18.61)	($7.07 - $19.02)	($10.76 - $18.25)
Total Premium, in $/Gallon	Mean	$0.28	$0.39	$0.34	$0.31	$0.28	$0.28	$0.35	$0.30	$0.34
Price Reduction ($/MMBD)	Mean	$0.52	$1.04	$0.81	$0.75	$0.61	$0.60	$0.90	$0.75	$0.90

Cases

1) Based on AEO2007. Updated oil market outlook from AEO1994 Base Case to AEO2007 Base Case. Among other things, this means average crude price rises from $20.33 to $48.34. All elasticities match 1997 values. Non-U.S. elasticity of import demand = -0.

2) AEO2007 Base Outlook, with wider range of OPEC supply elasticities, 0.25 to 6.0 and a mean elasticity of 1.76.

3) Revise Case 2, with OPEC behavior distributed over elasticities 0 to 6, so that 25% of response is inelastic (< 1.0), mode elasticity is 2.0 (mean elasticity is 2.2 rather than 1.76)

4) Updated Case 2 supply/demand elasticities for non-OPEC region with more recent estimates. Elasticity of non-U.S. demand -0.2 to -0.4, with mean and mode -0.3, non-U.S. Supply = 0.2 to 0.4, with mean and mode 0.3, implying (mode) net elasticity of impo

5) Revise Case 4, with OPEC behavior distributed over elasticities 0 to 6, so that 25% of response is inelastic (< 1.0), mode elasticity is 2.0 (mean elasticity is 2.2 rather than 1.76). Net elasticity of import demand is -1.6 for the non-U.S./non-OPEC r

6) Alternative to Case 4 with expanded (and higher) range of non-U.S. supply/demand elasticities. Elasticity of non-U.S. demand = -0.3 to -0.7, triangular distribution with mode -0.4 mean -0.467, elasticity of non-U.S. supply = 0.2 to 0.6, mode 0.3 and m

7) Applied Strategic OPEC Behavioral Rule to Case 6: Maintain Market Share (Gately 2004 paper best strategy). This rule implies that OPEC Supply elasticity matches that of all non-OPEC supply. As a result non-U.S. elasticity of import demand ranges from

8) Variant on version Case 4, considered reduced GDP elasticity for future disruptions (range -0.01 to -0.054; midcase value -0.032; mean value is -0.032, reduced from mean value of -0.0495). OPEC-behavior treated parametrically.

9) Revise Case 7 (which applied Strategic OPEC Behavioral Rule to Case 6: Maintain Market Share (Gately 2004 paper best strategy)) with reduced GDP elasticity for future disruptions (range -0.01 to -0.054; midcase value -0.032; mean value is -0.032, reduc

4.2.7.2.4   *Energy security premium values for this rule*

After the peer review process was completed, EPA worked with ORNL to further update the analysis for this vehicle program. Using the same methodology as the peer reviewed model, but updating the analysis using AEO 2009 world oil price values, ORNL calculated energy security premium estimates for the years 2015, 2020, and 2030. Since the AEO 2009 ends its forecast in the year 2030, EPA and NHTSA assumed that the post-2030 energy security premium estimates were the same as the 2030 estimate. The results of this analysis are shown above in Table 4-13in Chapter 4.2.8.

The monopsony cost represents a transfer of resources from consumers of petroleum products to oil producers, and does not entail the use of real economic resources. Reducing the magnitude of the monopsony cost does not produce a savings in economic resources, although it does reduce the value of resources transferred from U.S. consumers of petroleum products to foreign suppliers of petroleum. In contrast, the macroeconomic disruption and adjustment costs that arise from U.S. petroleum imports do represent real economic costs, and reductions in their magnitude do represent real economic benefits from reducing U.S. consumption and imports of petroleum. Hence the agencies' estimates of economic benefits from reducing fuel consumption via CAFE and GHG emission standards include ORNL's estimates of the economic value of resulting reductions in macroeconomic and disruption costs, but exclude reductions in the monopsony cost component of the oil import premium.

4.2.7.2.5   *The impact of fuel savings on U.S. petroleum imports*

Based on a detailed analysis of differences in fuel consumption, petroleum imports, and imports of refined petroleum products among the Reference Case, High Economic Growth, and Low Economic Growth Scenarios presented in AEO 2009, NHTSA and EPA estimate that approximately 50 percent of the reduction in fuel consumption resulting from adopting improved fuel efficiency standards and GHG standards is likely to be reflected in reduced U.S. imports of refined fuel, while the remaining 50 percent would be expected to be reflected in reduced domestic fuel refining.[w] Of this latter figure, 90 percent is anticipated to reduce U.S. imports of crude petroleum for use as a refinery feedstock, while the remaining 10 percent is expected to reduce U.S. domestic production of crude petroleum.[x] Thus on balance, each gallon of fuel saved as a consequence of improved fuel efficiency standards and GHG standards is anticipated to reduce total U.S. imports of crude petroleum or refined fuel by 0.95 gallons.[y] Section 5.3 of the RIA contains a discussion regarding caveats for the fuel savings estimated due to implementation of this rule.

---

[w] Differences between forecast annual U.S. imports of crude petroleum and refined products among these three scenarios range from 24-89 percent of differences in projected annual gasoline and diesel fuel consumption in the U.S. These differences average 49 percent over the forecast period spanned by AEO 2009. This analysis has not been updated using forecasts from AEO 2010, because to date only the Reference Case from AEO 2010 has been released by EIA.

[x] Differences between forecast annual U.S. imports of crude petroleum among these three scenarios range from 67-97 percent of differences in total U.S. refining of crude petroleum, and average 85 percent over the forecast period spanned by AEO 2009.

[y] This figure is calculated as $0.50 + 0.50*0.9 = 0.50 + 0.45 = 0.95$.

The energy security analysis conducted for this rule estimates that the world price of oil will fall modestly in response to lower U.S. demand for refined fuel. One potential result of this decline in the world price of oil would be an increase in the consumption of petroleum products outside the U.S., which would in turn lead to a modest increase in emissions of greenhouse gases, criteria air pollutants, and airborne toxics from their refining and use. While additional information would be needed to analyze this "leakage effect" in detail, NHTSA provides a sample estimate of its potential magnitude in its Final EIS.[z] This analysis indicates that the leakage effect is likely to offset only a modest fraction of the reductions in emissions projected to result from the rule.

4.2.8 Air pollutant emissions

Car and light truck use, fuel refining, and fuel distribution and retailing also generate emissions of certain criteria air pollutants, including carbon monoxide (CO), hydrocarbon compounds (usually referred to as "volatile organic compounds," or VOC), nitrogen oxides (NO_x), fine particulate matter ($PM_{2.5}$), and sulfur dioxide (SO_2). Emissions of most of these pollutants are associated with the number of vehicle miles driven, rather than with the quantity of fuel consumed. While reductions in fuel refining and distribution that result from lower fuel consumption will reduce emissions of criteria pollutants, additional vehicle use associated with the rebound effect from higher fuel economy will increase emissions of most of these pollutants. Sulfur dioxide is an exception, as described below.

Thus the net effect of stricter fuel efficiency and GHG standards on total emissions of each criteria pollutant depends on the relative magnitudes of reduced emissions in fuel refining and distribution, and increases in emissions from vehicle use. Because the relationship between emission rates (emissions per gallon refined of fuel or mile driven) in fuel refining and vehicle use is different for each criteria pollutant, the net effect of fuel savings from increased fuel efficiency and GHG standards on total emissions of each pollutant is likely to differ.

4.2.8.1   Reductions in emissions of criteria air pollutants

For the analysis of criteria emissions over the lifetime of the model years covered by this rule, EPA and NHTSA estimate the increases in emissions of each criteria air pollutant from additional vehicle use by multiplying the increase in total miles driven by cars and light trucks of each model year and age by their estimated emission rates per vehicle-mile of each pollutant. These emission rates differ between cars and light trucks as well as between gasoline and diesel vehicles, and both their values for new vehicles and the rates at which they increase with age and accumulated mileage can vary among model years. With the exception of SO_2, the agencies calculated the increase in emissions of these criteria pollutants from added car and light truck use by multiplying the estimated increases in their vehicles' use

---

[z] NHTSA Final Environmental Impact Statement: Corporate Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Years 2012-2016, February 2010, page 3-14.

during each year over their expected lifetimes by per-mile emission rates appropriate to each vehicle type, fuel used, model year, and age as of that future year.

These emission rates were estimated by U.S. EPA using its newly updated Motor Vehicle Emission Simulator (MOVES2010). For the proposal, emission rates were estimated using Draft MOVES2009.

The MOVES model assumes that the per-mile rates at which these pollutants are emitted are determined by EPA regulations and the effectiveness of catalytic after-treatment of engine exhaust emissions, and are thus unaffected by changes in car and light truck fuel economy. As a consequence, the effects of required increases in fuel economy on emissions of these pollutants from car and light truck use are determined entirely by the increases in driving that result from the fuel economy rebound effect. As discussed in the EPA RIA, anticipated changes in the fuel supply composition will also affect criteria pollutant emissions.

Emission factors in the MOVES database are expressed in the form of grams per vehicle-hour of operation. To convert these emission factors to grams per mile for use in EPA and NHTSA's calculations, MOVES was run for the year 2050, and was programmed to report aggregate emissions from vehicle starting and running exhaust operation. EPA analysts selected the year 2050 in order to generate emission factors that were representative of lifetime average emission rates for vehicles meeting the agency's Tier 2 emission standard.[aa] Separate estimates were developed for each vehicle type and model year, as well as for each state and month, in order to reflect the effects of regional and temporal variation in temperature and other relevant variables on emissions.

The MOVES emissions estimates were then summed to the model year level and divided by average distance traveled in order to produce per-mile emission factors for each pollutant. The resulting emission rates represent average values across the nation, and incorporate typical temperature variations over an entire calendar year. These national average rates also reflect county-specific differences in fuel composition, as well as in the presence and type of vehicle inspection and maintenance programs.[bb]

Emission rates for the criteria pollutant SO_2 were calculated by EPA and NHTSA using average fuel sulfur content estimates supplied by EPA, together with the assumption that the entire sulfur content of fuel is emitted in the form of SO_2. These calculations assumed that national average gasoline and diesel sulfur levels would remain at current levels.[cc]

[aa] Because all light-duty emission rates in MOVES2010 are assumed to be invariant after MY 2010, a calendar-year 2050 run produced a full set of emission rates that reflect anticipated deterioration in the effectiveness of vehicles' emission control systems with increasing age and accumulated mileage for post-MY 2010 vehicles.

[bb] The national mix of fuel types includes county-level market shares of conventional and reformulated gasoline, as well as county-level variation in sulfur content, ethanol fractions, and other fuel properties. Inspection/maintenance programs at the county level account for detailed program design elements such as test type, inspection frequency, and program coverage by vehicle type and age.

[cc] These are 30 and 15 parts per million (ppm, measured on a mass basis) for gasoline and diesel respectively, which produces emission rates of 0.17 grams of SO_2 per gallon of gasoline and 0.10 grams per gallon of diesel.

There, unlike many other criteria pollutants, sulfur dioxide emissions from vehicle use decrease proportionally to the decrease in fuel consumption.

Emissions of criteria air pollutants also occur during each phase of fuel production and distribution, including crude oil extraction and transportation, fuel refining, and fuel storage and transportation. The reduction in emissions during each of these phases depends on the extent to which fuel savings result in lower imports of refined fuel, or in reduced domestic fuel refining. To a lesser extent, they also depend on whether reductions in domestic gasoline refining are reflected in reduced imports of crude oil or in reduced domestic extraction of petroleum.

Both EPA's and NHTSA's analyses assume that reductions in imports of refined fuel would reduce criteria pollutant emissions during fuel storage and distribution only. Reductions in domestic fuel refining using imported crude oil as a feedstock are assumed to reduce emissions during fuel refining, storage, and distribution, because each of these activities would be reduced. Finally, reduced domestic fuel refining using domestically-produced crude oil is assumed to reduce emissions during all four phases of fuel production and distribution.[dd]

EPA estimated the reductions in criteria pollutant emissions from producing and distributing fuel that would occur with alternative fuel efficiency and GHG standards using emission rates obtained from Argonne National Laboratories' Greenhouse Gases and Regulated Emissions in Transportation (GREET) model.[22] The GREET model provides separate estimates of air pollutant emissions that occur in four phases of fuel production and distribution: crude oil extraction, crude oil transportation and storage, fuel refining, and fuel distribution and storage.[ee] EPA modified the GREET model to change certain assumptions about emissions during crude petroleum extraction and transportation, as well as to update its emission rates to reflect adopted and pending EPA emission standards. EPA also incorporated emission factors for the air toxics estimated in this analysis: benzene, 1,3-butadiene, acetaldehyde, acrolein, and formaldehyde. The resulting emission factors are shown in Table 4-15.

[dd] In effect, this assumes that the distances crude oil travels to U.S. refineries are approximately the same regardless of whether it travels from domestic oilfields or import terminals, and that the distances that gasoline travels from refineries to retail stations are approximately the same as those from import terminals to gasoline stations.

[ee] Emissions that occur during vehicle refueling at retail gasoline stations (primarily evaporative emissions of volatile organic compounds, or VOCs) are already accounted for in the "tailpipe" emission factors used to estimate the emissions generated by increased light truck use. GREET estimates emissions in each phase of gasoline production and distribution in mass per unit of gasoline energy content; these factors are then converted to mass per gallon of gasoline using the average energy content of gasoline.

Table 4-15 Emissions by Stage of Fuel Production and Distribution (grams/million Btu)

Pollutant	Fuel Type	Petroleum Extraction & Transportation[1]	Refinery Energy Use Upstream Emissions	Petroleum Refining On-Site	Petroleum Refining[2]	Fuel Transport, Storage, Distribution[3]
CO	Conventional Gasoline	4.908	0.928	5.596	6.525	0.748
	Reformulated Gasoline	4.908	0.908	5.662	6.571	0.768
	Low Sulfur Diesel	4.908	0.800	5.103	5.903	0.780
VOC	Conventional Gasoline	3.035	0.602	2.560	3.162	42.91
	Reformulated Gasoline	3.035	0.627	2.584	3.211	42.92
	Low Sulfur Diesel	3.035	0.552	2.511	3.063	1.261
NOx	Conventional Gasoline	14.91	3.328	14.442	17.771	3.691
	Reformulated Gasoline	14.91	3.288	14.575	17.863	3.786
	Low Sulfur Diesel	14.91	2.895	12.972	15.866	3.570
SOx	Conventional Gasoline	3.926	4.398	9.678	14.076	0.886
	Reformulated Gasoline	3.926	4.422	9.922	14.344	0.909
	Low Sulfur Diesel	3.926	3.893	9.187	13.080	0.840
PM2.5	Conventional Gasoline	0.645	1.442	1.789	3.231	0.155
	Reformulated Gasoline	0.645	1.487	1.838	3.325	0.159
	Low Sulfur Diesel	0.645	1.309	1.635	2.943	0.133
Air Toxics						
1,3-Butadiene	Conventional Gasoline	0.0017	0.0003	0.0014	0.0017	0.0001
	Reformulated Gasoline	0.0017	0.0003	0.0014	0.0018	0.0001
	Low Sulfur Diesel	0.0017	0.0003	0.0014	0.0017	0.0001
Acetaldehyde	Conventional Gasoline	0.0002	0.0000	0.0002	0.0002	0.0046
	Reformulated Gasoline	0.0002	0.0000	0.0002	0.0002	0.0047
	Low Sulfur Diesel	0.0002	0.0000	0.0002	0.0002	0.0044
Acrolein	Conventional Gasoline	0.0001	0.0000	0.0001	0.0001	0.0006
	Reformulated Gasoline	0.0001	0.0000	0.0001	0.0001	0.0006
	Low Sulfur Diesel	0.0001	0.0000	0.0001	0.0001	0.0006
Benzene	Conventional Gasoline	0.0313	0.0062	0.0264	0.0326	0.0787
	Reformulated Gasoline	0.0313	0.0064	0.0264	0.0328	0.0788
	Low Sulfur Diesel	0.0313	0.0058	0.0264	0.0322	0.0015
Formaldehyde	Conventional Gasoline	0.0050	0.0010	0.0042	0.0052	0.0326
	Reformulated Gasoline	0.0050	0.0010	0.0042	0.0052	0.0335
	Low Sulfur Diesel	0.0050	0.0009	0.0042	0.0051	0.0316

[1] The petroleum extraction and transport emission factors are only applied to domestic crude oil.
[2] Refinery emissions factors are applied to domestic refineries, whether refining domestic or imported crude.
[3] Fuel transport, storage, and distribution emission factors represent domestic emissions and are applied to all finished fuel, whether refined domestically or internationally.

The agency converted these emission rates from the mass per fuel energy content basis on which GREET reports them to mass per gallon of fuel supplied using the estimates of fuel energy content reported by GREET. The resulting emission rates were applied to both EPA's and NHTSA's estimates of fuel consumption under alternative fuel efficiency standards to develop estimates of total emissions of each criteria pollutant during fuel production and distribution. The assumptions about the effects of *changes* in fuel consumption on domestic

and imported sources of fuel supply discussed above were then employed to calculate the effects of reductions in fuel use from alternative fuel efficiency and GHG standards on changes in domestic emissions of each criteria pollutant.

Finally, EPA and NHTSA calculated the *net* changes in domestic emissions of each criteria pollutant by summing the increases in its emissions projected to result from increased vehicle use, and the reductions in emissions anticipated to result from lower domestic fuel refining and distribution.[ff] As indicated previously, the effect of adopting improved fuel efficiency and GHG standards on total emissions of each criteria pollutant depends on the relative magnitudes of the resulting reduction in emissions from fuel refining and distribution, and the increase in emissions from additional vehicle use. Although these net changes vary significantly among individual criteria pollutants, we project that on balance, adopting improved fuel efficiency and GHG standards would reduce emissions of all criteria air pollutants except carbon monoxide (CO). The analysis of criteria emissions during specific calendar years is described independently in NHTSA's Environmental Impact Statement and EPA's RIA.

4.2.8.2 Estimated values of reducing PM related emissions in the model year analysis

In this analysis, EPA and NHTSA estimate the economic value of the human health benefits associated with reducing exposure to $PM_{2.5}$ using benefit-per-ton estimates for the analysis of PM-related benefits over the lifetime of specific model years. Due to analytical limitations, the estimated benefit-per-ton values do not include comparable benefits related to reductions in other criteria pollutants (such as ozone, NO_2 or SO_2) or toxic air pollutants, nor do they monetize all of the potential health and welfare effects associated with $PM_{2.5}$ or the other criteria pollutants. As a result these values underestimate the benefits associated with reductions of these pollutants. Note that EPA conducted full-scale photochemical air quality modeling for the calendar year analysis. Please refer to Chapter 7.2 of the RIA for a description of EPA's air quality modeling results and to Chapter 7.3 for a description of the quantified and monetized PM- and ozone-related health impacts of the FRM.

The analysis of PM-related benefits over the lifetime of specific model years uses a "benefit-per-ton" method to estimate selected $PM_{2.5}$-related health benefits. These $PM_{2.5}$-related benefit-per-ton estimates provide the total monetized human health benefits (the sum of premature mortality and premature morbidity) of reducing one ton of directly emitted $PM_{2.5}$, or one ton of a pollutant that contributes to secondarily-formed $PM_{2.5}$ (such as NOx, SOx, and VOCs) from a specified source. Ideally, the human health benefits would be estimated based on changes in ambient $PM_{2.5}$ concentrations and population exposure, as determined by full-scale air quality and exposure modeling.

The dollar-per-ton estimates for reductions in $PM_{2.5}$ emissions used in this analysis are provided in Table 4-16.

[ff] All emissions from increased vehicle use are assumed to occur within the U.S., since fuel efficiency standards would apply only to vehicles produced for sale in the U.S.

Table 4-16 Benefits-per-ton Values (2007$) Derived Using the ACS Cohort Study for PM-related Premature Mortality (Pope et al., 2002)[a]

Year[c]	All Sources[d]		Stationary (Non-EGU) Sources		Mobile Sources	
	SO$_X$	VOC	NO$_X$	Direct PM2.5	NO$_X$	Direct PM2.5
Estimated Using a 3 Percent Discount Rate[b]						
2015	$28,000	$1,200	$4,700	$220,000	$4,900	$270,000
2020	$31,000	$1,300	$5,100	$240,000	$5,300	$290,000
2030	$36,000	$1,500	$6,100	$280,000	$6,400	$350,000
2040	$43,000	$1,800	$7,200	$330,000	$7,600	$420,000
Estimated Using a 7 Percent Discount Rate[b]						
2015	$26,000	$1,100	$4,200	$200,000	$4,400	$240,000
2020	$28,000	$1,200	$4,600	$220,000	$4,800	$270,000
2030	$33,000	$1,400	$5,500	$250,000	$5,800	$320,000
2040	$39,000	$1,600	$6,600	$300,000	$6,900	$380,000

[a] The benefit-per-ton estimates presented in this table are based on an estimate of premature mortality derived from the ACS study (Pope et al., 2002). If the benefit-per-ton estimates were based on the Six-Cities study (Laden et al., 2006), the values would be approximately 145% (nearly two-and-a-half times) larger.
[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 2015, 2020, and 2030. For 2040, EPA and NHTSA extrapolated exponentially based on the growth between 2020 and 2030.
[d] Note that the benefit-per-ton value for SOx is based on the value for Stationary (Non-EGU) sources; no SOx value was estimated for mobile sources. The benefit-per-ton value for VOCs was estimated across all sources.
[e] Non-EGU denotes stationary sources of emissions other than electric generating units.

As Table 4-16 indicates, EPA projects that the per-ton values for reducing emissions of criteria pollutants from both vehicle use and stationary sources such as fuel refineries and storage facilities will increase over time. These projected increases reflect rising income levels, which are assumed to increase affected individuals' willingness to pay for reduced exposure to health threats from air pollution, as well as population growth into the future, expanding the population exposed to air pollution in both urban and rural areas.[23]

For certain PM$_{2.5}$-related pollutants (such as direct PM$_{2.5}$ and NOx), EPA estimates different per-ton values for reducing mobile source emissions than for reductions in emissions of the same pollutant from stationary sources such as fuel refineries and storage facilities. These reflect differences in the typical geographic distributions of emissions of each pollutant, their contributions to ambient levels of PM$_{2.5}$, and resulting changes in population exposure. EPA and NHTSA apply these separate values to its estimates of changes in emissions from vehicle use and from fuel production and distribution to determine the net change in total economic damages from emissions of those pollutants.

The benefit per-ton technique has been used in previous analyses, including EPA's recent Ozone National Ambient Air Quality Standards (NAAQS) RIA,[24] the proposed Portland Cement National Emissions Standards for Hazardous Air Pollutants (NESHAP) RIA,[25] and final NO$_2$ NAAQS.[26] Table 4-17 shows the quantified and unquantified PM$_{2.5}$-related co-benefits captured in these benefit-per-ton estimates.

Table 4-17 Human Health and Welfare Effects of PM$_{2.5}$

Pollutant / Effect	Quantified and Monetized in Primary Estimates	Unquantified Effects Changes in:
PM$_{2.5}$	Adult premature mortality	Subchronic bronchitis cases
	Bronchitis: chronic and acute	Low birth weight
	Hospital admissions: respiratory and cardiovascular	Pulmonary function
	Emergency room visits for asthma	Chronic respiratory diseases other than chronic bronchitis
	Nonfatal heart attacks (myocardial infarction)	Non-asthma respiratory emergency room visits
	Lower and upper respiratory illness	Visibility
	Minor restricted-activity days	Household soiling
	Work loss days	
	Asthma exacerbations (asthmatic population)	
	Infant mortality	

Consistent with the NO$_2$ NAAQS,[gg] the benefits estimates utilize concentration-response functions as reported in the epidemiology literature. Readers interested in reviewing the complete methodology for creating the benefit-per-ton estimates used in this analysis can consult the Technical Support Document (TSD)[27] accompanying the recent final ozone NAAQS RIA. Readers can also refer to Fann et al. (2009)[28] for a detailed description of the benefit-per-ton methodology.[hh]

As described 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 mobile sources; direct PM emitted from stationary sources). Our estimate of total PM$_{2.5}$ benefits is therefore based on the total direct PM$_{2.5}$ and PM$_{2.5}$–related precursor emissions (NOx, SOx, and VOCs) controlled from each source and multiplied by the respective per-ton values of reducing emissions from that source.

The benefit-per-ton coefficients in this analysis were derived using modified versions of the health impact functions used in the PM NAAQS Regulatory Impact Analysis. Specifically, this analysis uses the benefit-per-ton estimates first applied in the Portland Cement NESHAP RIA, which incorporated concentration-response functions directly from

---

[gg] Although we summarize the main issues in this chapter, we encourage interested readers to see benefits chapter of the NO2 NAAQS for a more detailed description of recent changes to the PM benefits presentation and preference for the no-threshold model.

[hh] The values included in this report are different from those presented in the article cited above. Benefits methods change to reflect new information and evaluation of the science. Since publication of the June 2009 article, EPA has made two significant changes to its benefits methods: (1) We no longer assume that a threshold exists in PM-related models of health impacts, which is consistent with the findings reported in published research; and (2) We have revised the Value of a Statistical Life to equal $6.3 million (year 2000$), up from an estimate of $5.5 million (year 2000$) used in the June 2009 report. Please refer to the following website for updates to the dollar-per-ton estimates: http://www.epa.gov/air/benmap/bpt.html

the epidemiology studies, without any adjustment for an assumed threshold. Removing the threshold assumption is a key difference between the method used in this analysis to estimate PM co-benefits and the methods used in analyses prior to EPA's Portland Cement NESHAP. As a consequence, the benefit-per-ton estimates used in this analysis include incremental benefits of reductions in $PM_{2.5}$ concentrations down to their lowest modeled levels.

Reductions in PM-related mortality provide the majority of the monetized value in each benefit-per-ton estimate. Typically, the premature mortality-related effect coefficients that underlie the benefits-per-ton estimates are drawn from epidemiology studies that examine two large population cohorts: the American Cancer Society cohort (Pope et al., 2002)[29] and the Harvard Six Cities cohort (Laden et al., 2006).[30] The concentration-response (C-R) function developed from the extended analysis of American Cancer Society (ACS) cohort, as reported in Pope et al. (2002), has previously been used by EPA to generate its primary benefits estimate. The extended analysis of the Harvard Six Cities cohort, as reported by Laden et al (2006), was published after the completion of the Staff Paper for the 2006 $PM_{2.5}$ NAAQS and has been used as an alternative estimate in the $PM_{2.5}$ NAAQS RIA and $PM_{2.5}$ co-benefits estimates in analyses completed since the $PM_{2.5}$ NAAQS.

These studies provide logical choices for anchor points when presenting PM-related benefits because, while both studies are well designed and peer-reviewed, there are strengths and weaknesses inherent in each. Although this argues for using both studies to generate benefits estimates, due to the analytical limitations associated with this analysis, EPA and NHTSA have chosen to use the benefit-per-ton value derived from the ACS study. The agencies note that benefits would be approximately 145 percent (or nearly two-and-a-half times) larger if the per-ton benefit values based on the Harvard Six Cities were used instead.

As is the nature of benefits analyses, assumptions and methods evolve over time to reflect the most current interpretation of the scientific and economic literature. For a period of time (2004-2008), EPA's Office of Air and Radiation (OAR) valued mortality risk reductions using a value of statistical life (VSL) estimate derived from a limited analysis of some of the available studies. OAR arrived at a VSL using a range of $1 million to $10 million (2000$) consistent with two meta-analyses of the wage-risk literature.

The $1 million value represented the lower end of the interquartile range from the Mrozek and Taylor (2002)[31] meta-analysis of 33 studies. The $10 million value represented the upper end of the interquartile range from the Viscusi and Aldy (2003)[32] meta-analysis of 43 studies. The mean estimate of $5.5 million (2000$) was also consistent with the mean VSL of $5.4 million estimated in the Kochi et al. (2006)[33] meta-analysis. However, the Agency neither changed its official guidance on the use of VSL in rule-makings nor subjected the interim estimate to a scientific peer-review process through the Science Advisory Board (SAB) or other peer-review group.

Until updated guidance is available, EPA determined that a single, peer-reviewed estimate applied consistently best reflects the SAB-EEAC advice it has received. Therefore,

EPA has decided to apply the VSL that was vetted and endorsed by the SAB in the Guidelines for Preparing Economic Analyses (U.S. EPA, 2000)[34] while they continue efforts to update their guidance on this issue.[ii] This approach calculates a mean value across VSL estimates derived from 26 labor market and contingent valuation studies published between 1974 and 1991. The mean VSL across these studies is $6.3 million (2000$). The dollar-per-ton estimates used in this analysis are based on this revised VSL.

The benefit-per-ton estimates are subject to a number of assumptions and uncertainties.

a.   They do not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors that might lead to an overestimate or underestimate of the actual benefits of controlling fine particulates in specific locations. EPA conducted full-scale air quality modeling for the calendar year analysis in an effort to capture this variability. Please refer to Chapter 7.2 of the RIA for a description of EPA's air quality modeling results and to Chapter 7.3 for the description of the agency's quantification and monetization of PM- and ozone-related health impacts for the FRM.

b.   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 engines and other industrial sources. At the present time, however, no clear scientific grounds exist for supporting differential effects estimates by particle type.

c.   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 initial concentrations of $PM_{2.5,}$ including both regions that are in attainment with fine particle standard and those that do not meet the standard, down to the lowest modeled concentrations.

d.   There are several health benefits categories that EPA and NHTSA were unable to quantify due to limitations associated with using benefits-per-ton estimates, several of which could be substantial. Because NO_X and VOC emissions are also precursors to ozone, changes in NO_X and VOC would also impact ozone formation and the health effects associated with ozone exposure. Benefits-per-ton estimates for ozone 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. Please refer to Chapter 7.3 of the RIA for a description of the quantification and monetization of both PM- and ozone-related health impacts for the FRM and a description of the unquantified co-pollutant benefits associated with this rulemaking.

[ii] In the (draft) update of the Economic Guidelines (U.S. EPA, 2008c), EPA retained the VSL endorsed by the SAB with the understanding that further updates to the mortality risk valuation guidance would be forthcoming in the near future. Therefore, this report does not represent final agency policy. The draft update of the Economic Guidelines is available on the Internet at <http://yosemite.epa.gov/ee/epa/eermfile.nsf/vwAN/EE-0516-01.pdf/$File/EE-0516-01.pdf>.

As mentioned above, emissions changes and benefits-per-ton estimates alone are not a good indication of local or regional air quality and health impacts, as the localized impacts associated with the rulemaking may vary significantly. Additionally, the atmospheric chemistry related to ambient concentrations of $PM_{2.5}$, ozone and air toxics is very complex. Full-scale photochemical modeling is therefore necessary to provide the needed spatial and temporal detail to more completely and accurately estimate the changes in ambient levels of these pollutants and their associated health and welfare impacts. For the final rule, EPA conducted a national-scale air quality modeling analysis in 2030 to analyze the impacts of the standards on $PM_{2.5}$, ozone, and selected air toxics.

4.2.9 Reductions in emissions of greenhouse gases

Emissions of carbon dioxide and other greenhouse gases (GHGs) occur throughout the process of producing and distributing transportation fuels, as well as from fuel combustion itself. By reducing the volume of fuel consumed by passenger cars and light trucks, higher fuel efficiency standards will thus reduce GHG emissions generated by fuel use, as well as throughout the fuel supply cycle. Lowering these emissions is likely to slow the projected pace and reduce the ultimate extent of future changes in the global climate, thus reducing future economic damages that changes in the global climate are otherwise expected to cause. Further, by reducing the probability that climate changes with potentially catastrophic economic or environmental impacts will occur, lowering GHG emissions may also result in economic benefits that exceed the resulting reduction in the expected future economic costs caused by gradual changes in the earth's climatic systems. Quantifying and monetizing benefits from reducing GHG emissions is thus an important step in estimating the total economic benefits likely to result from establishing improved fuel efficiency and GHG standards.

4.2.9.1 Estimating reductions in GHG emissions

The agencies estimated emissions of carbon dioxide (CO_2) from passenger car and light truck use by multiplying the number of gallons of each type of fuel (gasoline and diesel) they are projected to consume with each alternative CAFE standard in effect by the quantity or mass of CO_2 emissions released per gallon of fuel consumed. This calculation assumes that the entire carbon content of each fuel is ultimately converted to CO_2 emissions during the combustion process. The weighted average CO_2 content of gasoline is estimated to be approximately 8,900 grams per gallon, while that of diesel fuel is estimated to be approximately 10,200 grams per gallon. For details, please see EPA's RIA and NHTSA's RIA.

Although carbon dioxide emissions account for nearly 95 percent of total GHG emissions that result from fuel combustion during vehicle use, emissions of other GHGs are potentially significant as well because of their higher "potency" as GHGs than that of CO_2 itself. EPA and NHTSA estimated the increases in emissions of methane (CH_4) and nitrous oxide (N_2O) from additional vehicle use by multiplying the increase in total miles driven by cars and light trucks of each model year and age by emission rates per vehicle-mile for these GHGs. These emission rates, which differ between cars and light trucks as well as between gasoline and diesel vehicles, were estimated by EPA using its recently-developed Motor

Vehicle Emission Simulator (Draft MOVES 2009), as subsequently updated for use in this analysis.

The MOVES model assumes that the per-mile rates at which cars and light trucks emit these GHGs are determined by the efficiency of fuel combustion during engine operation and chemical reactions that occur during catalytic after-treatment of engine exhaust, and are thus independent of vehicles' fuel consumption rates. Thus MOVES emission factors for these GHGs, which are expressed per mile of vehicle travel, are assumed to be unaffected by changes in fuel economy.

Increases in emissions of non-CO_2 GHGs are converted to equivalent increases in CO_2 emissions using estimates of the Global Warming Potential (GWP) of methane and nitrous oxide. These GWPs are one way of accounting for the higher radiative forcing capacity and differing lifetimes of methane and nitrous oxide when they are released into the earth's atmosphere, measured relative to that of CO_2 itself. Because these gases differ in atmospheric lifetimes, their relative damages are not constant over time. Impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike methane and other greenhouse gases, contribute to ocean acidification. Methane contributes to health and ecosystem effects arising from increases in tropospheric ozone, while damages from methane emissions are not offset by the positive effect of CO_2 fertilization. Noting these caveats, the CO_2 equivalents of increases in emissions of these gases are then added to the increases in emissions of CO_2 itself to summarize the effect of the total increase in CO_2-equivalent GHG emissions from vehicle use. However, only the CO2 emissions were monetized for purposes of valuing benefits of the rule.

4.2.9.2 Economic benefits from reducing GHG emissions

NHTSA and EPA have taken the economic benefits of reducing CO_2 emission into account in this rulemaking, both in developing alternative CAFE standards and in assessing the economic benefits of each alternative that was considered. Specifically, EPA and NHTSA assigned a dollar value to reductions in CO_2 emissions using the marginal dollar value (i.e., cost) of climate-related damages resulting from carbon emissions, also referred to as "social cost of carbon" (SCC). The SCC is intended to measure the monetary value society places on impacts resulting from increased GHGs, such as property damage from sea level rise, forced migration due to dry land loss, and mortality changes associated with vector-borne diseases. Published estimates of the SCC vary widely as a result of uncertainties about future economic growth, climate sensitivity to GHG emissions, procedures used to model the economic impacts of climate change, and the choice of discount rates.

EPA and NHTSA developed new SCC estimates through an interagency modeling exercise. The modeling exercise involved running three integrated assessment models using inputs agreed upon by the interagency group for climate sensitivity, socioeconomic and emissions trajectories, and discount rates. A more complete discussion of SCC, including the revised estimates and underlying methodology, can be found in the SCC TSD, *Social Cost of*

Carbon for Regulatory Impact Analysis Under Executive Order 12866 (February 2010).[jj] See also preamble Sections II.F, III.H.6 and IV.C.3, EPA RIA 7.5, and NHTSA RIA VIII for discussion about the application of new SCC estimates to this final rule. The revised SCC estimates corresponding to assumed values of the discount rate are shown below in Table 4-18.

Table 4-18 Social Cost of CO$_2$, 2010 Emissions[a] (in 2007 dollars)

Discount Rate	5%	3%	2.5%	3%
Source	Average of Estimates	Average of Estimates	Average of Estimates	95th Percentile
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

[a] Monetized GHG benefits exclude the value of reductions in non-CO$_2$ GHG emissions (HFC, CH$_4$ and N$_2$O) expected under this final rule. Although the agencies have not monetized the benefits of reductions in these non-CO$_2$ emissions, the value of these reductions should not be interpreted as zero. Rather, the reductions in non-CO$_2$ GHGs will contribute to this rule's climate benefits, as explained in Section III.F.2. The SCC TSD notes the difference between the social cost of non-CO$_2$ emissions and CO$_2$ emissions, and specifies a goal to develop methods to value non-CO$_2$ emissions in future analyses.

4.2.10   The value of increased driving range

Improving the fuel economy of passenger cars and light-duty trucks may also increase their driving range before they require refueling. By reducing the frequency with which drivers typically refuel their vehicles and extending the upper limit of the range they can travel before requiring refueling, improving fuel economy thus provides some additional benefits to their owners. Alternatively, if manufacturers respond to improved fuel economy by reducing the size of fuel tanks to maintain a constant driving range, the resulting cost saving will presumably be reflected in lower vehicle sales prices. If manufacturers respond by doing so, this presumably reflects their judgment that the value to economic benefits to vehicle buyers from lower purchase prices exceeds that from extended refueling range.

[jj] Interagency Working Group on Social Cost of Carbon, U.S. Government, with participation by Council of Economic Advisers, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of Transportation, Environmental Protection Agency, National Economic Council, Office of Energy and Climate Change, Office of Management and Budget, Office of Science and Technology Policy, and Department of Treasury, "Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," February 2010, available in docket EPA-HQ-OAR-2009-0472.

No direct estimates of the value of extended vehicle range are readily available, so the agencies' analyses calculate the reduction in the annual number of required refueling cycles that results from improved fuel economy, and applies DOT-recommended values of travel time savings to convert the resulting time savings to their economic value.[35] As a coarse illustration of how the value of extended refueling range is estimated, a typical small light truck model has an average fuel tank size of approximately 20 gallons.[kk] Based on a California Air Resources Board Study, the average fuel purchase is approximately 55% of tank volume.[36] Therefore, increasing this model's actual on-road fuel economy from 24 to 25 mpg would extend its driving range from 216 miles (= 9 gallons x 24 mpg) to 225 miles (= 9 gallons x 25 mpg). Assuming that this vehicle is driven 12,000 miles/year, this reduces the number of times it needs to be refueled each year from 55.5 (= 12,000 miles per year / 216 miles per refueling) to 53.3 (= 12,000 miles per year / 225 miles per refueling), or by 2.2 refuelings per year.

Weighted by the nationwide mix of urban (about 2/3) and rural (about 1/3) driving and average vehicle occupancy for all driving trips (1.6 persons), the DOT-recommended value of travel time per vehicle-hour is $24.00 (in 2006 dollars).[ll] Assuming that locating a station and filling up requires five minutes, the annual value of time saved as a result of less frequent refueling amounts to $4.40 (calculated as 5/60 x 2.2 x $24.00). This calculation is repeated for each future calendar year that light trucks of each model year affected by the alternative fuel economy standards considered in this rule would remain in service. Like fuel savings and other benefits, however, the value of this benefit declines over a model year's lifetime, because a smaller number of vehicles originally produced during that model year remain in service each year, and those remaining in service are driven fewer miles. The detailed values used in this calculation by each agency are available in EPA's RIA and NHTSA's FRIA respectively.

The agencies' estimate of benefits from less frequent refueling is subject to several sources of uncertainty. First, this analysis assumes that manufacturers will not adjust fuel tank capacities downward (from the current average of 19.3 gallons) when they improve the fuel economy of their vehicle models, so that the entire increase in fuel economy will be reflected in increased driving range.

Should manufacturers choose to downsize fuel tanks, and all other factors have been estimated with no error, the current estimates of refueling benefits would be overstated. Should manufacturers downsize tanks to fully offset any increase in vehicle range, there would be no extension in driving range and no resultant benefit to consumers. However,

---

[kk] Based on the Volpe Model Market Data file for Model Year 2011, average tank volumes for cars and trucks are 16.6 gallons and 23.0 gallons, respectively. This produces a production weighted average of 19.3 gallons.
[ll] The hourly wage rate during 2006 is estimated to be $24.00. Personal travel (94.4 percent of urban travel) is valued at 50 percent of the hourly wage rate. Business travel (5.6 percent of urban travel) is valued at 100 percent of the hourly wage rate. For intercity travel, personal travel (87 percent) is valued at 70 percent of the wage rate, while business travel (13 percent) is valued at 100 percent of the wage rate. The resulting values of travel time are $12.67 for urban travel and $17.66 for intercity travel, and must be multiplied by vehicle occupancy (1.6) to obtain the estimate value of time per vehicle hour.

should fuel tank sizes be reduced, vehicle space, utility and value would increase and vehicle weight and production costs would decrease, improving fuel economy and CO_2 emissions.

A larger fuel tank size requires additional manufacturing costs (if for nothing more than increased materials or increased molding costs to squeeze more tank volume in unusually shaped spaces underbody), adds weight (thus, reduces fuel economy and increases CO_2 emissions) and takes up potentially usable vehicle space. It also increases vehicle range (a widely advertised vehicle attribute), which reduces the frequency of vehicle refueling for at least some owners and (less frequently) increases peace of mind when operating a vehicle in areas with limited refueling options. Given this clear trade-off, manufacturers must use some type of optimization schema to determine the appropriate tank size for each vehicle. If manufacturers choose to retain the current fuel tank size, then the impact on manufacturing costs is obvious: zero. At least some portion of the driving public will save a considerable amount of time with some value. Given range is a widely publicized vehicle attribute, manufacturers will only reduce tank size if it lowers production costs sufficiently to overcome the loss in vehicle desirability. Thus, either consumers save time or production costs go down. Much as the agencies assume that cost increases are passed through to consumers, the agencies assume that cost savings from reducing fuel tank size (by reducing engineering complexity and materials required) would be passed through to consumers.

Further, the agencies assume that manufacturers operate in a manner that maintains or increases the desirability of a vehicle. Consequently, should a manufacturer choose to reduce fuel tank size, this option should provide welfare gains equivalent to or greater than the loss in welfare from reducing driving range. In the context of the rule, the improvement in CO_2 or fuel economy from downsizing a fuel tank will additionally decrease a manufacturers cost of compliance with the standards. The weight reduction estimates modeled in OMEGA and the CAFE Model do not include any reduction in the size and weight of fuel tanks, excluding potential light weight materials substitution which would not affect fuel volume, thus this benefit has not been counted elsewhere.

Second, the agencies' analysis assumes that fuel purchases average 55 percent of fuel tank capacity. However, as shown in the California Air Resource Board (CARB) report, refueling patterns vary. Moreover, the 55 percent estimate implies that drivers, *on average*, are either refueling when nearly a half tank of gas remains in their vehicles, or that they are habitually not filling their tanks. Since many drivers only refuel when their tanks are very low, and since many drivers habitually refuel, this in turn implies that many drivers in the CARB study are refueling when their tanks are still well above 50 percent full. While based on field data, this estimate may thus overestimate the impact of refueling benefits.

For the primary analysis in both the proposal and this final rulemaking, the agencies assume that 100 percent of all refueling is demand-based; *i.e.*, that every gallon of fuel which is saved would reduce the need to return to the refueling station. Based on anecdotal evidence, this value is potentially an overestimate. As an example, some people may refuel every Sunday morning at the same time as they buy their newspaper and chewing gum. Barring unusually long trips, these people would not benefit from an increased driving range.

In order to understand how sensitive the overall estimate of the refueling benefit is to this specific input, we provide the following example. If 25 percent of gallons are refueled on a habitual rather than demand-based schedule, and the rest of the assumptions remain constant, the value of increased driving range decreases by 25 percent. There would be no value of increased driving range derived from these gallons. Returning to the example light truck discussed above, which generated a value of increased driving range worth $4.40 in the first year, if this owner refilled ¼ of his annual fuel on a habitual rather than demand based schedule, the value of increased driving range would decrease to $3.30. Unfortunately, the agencies do not have a basis for this 25 percent value, thus this example is for illustrative purposes only. However, as noted below, DOT is undertaking a new survey which may provide a data-based basis for revising our 100 percent assumption for future analysis.

Third, the agencies' estimate of refueling benefits assumes that refueling stops involve the same number of vehicle occupants as the overall average for all vehicle trips (1.6 persons). To the extent that drivers refuel while doing other errands or in advance of picking up passengers, this figure may overestimate the typical vehicle occupancy during refueling, and thus the total savings in refueling time. Similarly, the hourly value used to estimate the economic value of savings in refueling time reflects the typical mix of personal and business travel purposes, and drivers are likely to assign different values to their time when traveling for these different purposes. To the extent that drivers seek to refuel when traveling for purposes that typically use less valuable time, the hourly value used in the agencies' analysis may overstate the benefits from saving refueling time.

Finally, the agencies assume that both finding and using a refueling station takes, on average, five minutes. There are few, if any, data sources on average refueling time, and this estimate is subject to significant uncertainty.

For these reasons, the agencies' estimate of savings in refueling time is uncertain. To reduce the uncertainty, a new project is being planned by DOT which will include a detailed study of refueling events, using a random sample of refueling stations across the U.S. It is projected to include ~7,000 observations (time to refuel, # gallons refueled, etc.) and ~5,000 surveys of refueling participants. The agencies anticipate that this will provide a robust data set on which to revise many of the key inputs to the refueling benefit calculation. Some of the specific data categories which will be surveyed are listed below:

- Miles driven and time out of way to get to gas station
- Fuel gage level before and after refueling
- # gallons purchased
- # people in vehicle, above and below 16 years old
- Reasons for travel
- Reason for stopping at gas station (*e.g.*, fuel level too low, or other)

While the study results are not available in time for this final rulemaking, it is anticipated that the data will improve future estimations of the value of increased driving range.

4.2.11 Discounting future benefits and costs

Discounting future fuel savings and other benefits is intended to account for the reduction in their value to society when they are deferred until some future date, rather than received immediately. The discount rate expresses the percent decline in the value of these benefits – as viewed from current perspective – for each year they are deferred into the future. In evaluating the benefits from alternative increases in fuel economy and GHG standards for MY 2012-2016 passenger cars and light trucks, EPA and NHTSA consider a discount rate of both 3 and 7 percent per year.

Three percent may be the appropriate rate for discounting future benefits from increased fuel economy and GHG standards because most or all of vehicle manufacturers' costs for complying with improved fuel economy and GHG standards are likely to be reflected in higher sales prices for their new vehicle models. By increasing sales prices for new cars and light trucks, CAFE regulation will thus primarily affect vehicle purchases and other private consumption decisions.

Both economic theory and OMB guidance on discounting indicate that the future benefits and costs of regulations that mainly affect private consumption should be discounted at the consumption rate of time preference.[37] OMB guidance indicates that savers appear to discount future consumption at an average real (that is, adjusted to remove the effect of inflation) rate of about 3 percent when they face little risk about its likely level, which makes it a reasonable estimate of the consumption rate of time preference.[38] Thus EPA and NHTSA have employed the 3 percent rate to discount projected future benefits and costs resulting from improved fuel economy and GHG standards for MY 2012-2016 passenger cars and light trucks.

Because there is some uncertainty about the extent to which vehicle manufacturers will be able to recover their costs for complying with improved fuel economy and GHG standards by increasing vehicle sales prices, however, the use of a higher percent discount rate may also be appropriate. OMB guidance indicates that the real economy-wide opportunity cost of capital is the appropriate discount rate to apply to future benefits and costs when the primary effect of a regulation is "…to displace or alter the use of capital in the private sector," and estimates that this rate currently averages about 7 percent.[39] Thus the agencies estimate net present values using both 3 and 7 percent discount rates.

One important exception to these values are the rates used to discount benefits from reducing CO_2 emissions from the years in which reduced emissions occur, which span the lifetimes of model year 2012-16 cars and light trucks, to their present values. In order to ensure consistency in the derivation and use of the interagency group's estimates of the unit values of reducing CO_2 emissions, the total benefits from reducing those emissions during each future year are discounted using the same rates that were used to derive the alternative values of reducing each ton of CO_2 emissions. As described previously in Section 4.2.10.2, these rates are 2.5, 3.0, and 5.0 percent.

References

[1] EPA, Fuel Economy Labeling of Motor Vehicles: Revisions To Improve Calculation of Fuel Economy Estimates; Final Rule, 40 CFR Parts 86 and 600, Federal Register, December 27, 2006, pp. 77872-77969, http://www.epa.gov/fedrgstr/EPA-AIR/2006/December/Day-27/a9749.pdf.

[2] EPA, *Final Technical Support Document: Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates*, Office of Transportation and Air Quality EPA420-R-06-017 December 2006, Chapter II, http://www.epa.gov/fueleconomy/420r06017.pdf.

[3] Energy Information Administration, Annual Energy Outlook 2010, Early Release Reference Case (December 2009), Table 12. *Available at* http://www.eia.doe.gov/oiaf/servicerpt/stimulus/excel/aeostimtab_12.xls

[4] Energy Information Administration, Annual Energy Outlook 2009, Revised Updated Reference Case (April 2009), Table 12. *Available at* http://www.eia.doe.gov/oiaf/servicerpt/stimulus/excel/aeostimtab_12.xls (last accessed July 26, 2009). EIA's Updated Reference Case reflects the effects of the American Reinvestment and Recovery Act of 2009, as well as the most recent revisions to the U.S. and global economic outlook.

[5] Kahan, A. and Pickrell D. "Energy Information Administration's Annual Energy Outlook 2009 and 2010" Memo to Docket EPA-HQ-OAR-2009-0472 and NHTSA–2009–0059.

[6] http://www.eia.doe.gov/oiaf/aeo/forecast.html (last accessed July 26, 2009), and Table 16, http://www.eia.doe.gov/oiaf/aeo/pdf/table16.pdf (last accessed July 26, 2009).

[7] Lu, S., NHTSA, Regulatory Analysis and Evaluation Division, "Vehicle Survivability and Travel Mileage Schedules," DOT HS 809 952, 8-11 (January 2006). *Available at* http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/Rpts/2006/809952.pdf (last accessed Feb. 15, 2010). These updated survival rates suggest that the expected lifetimes of recent-model passenger cars and light trucks are 13.8 and 14.5 years.

[8] FHWA, Highway Statistics, Summary to 1995, Table vm201at http://www.fhwa.dot.gov/ohim/summary95/vm201a.xlw , and annual editions 1996-2005, Table VM-1 at http://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.htm (last accessed Feb. 15, 2010).

[9] Sorrell, S. and J. Dimitropoulos, 2007. "UKERC Review of Evidence for the Rebound Effect, Technical Report 2: Econometric Studies", UKERC/WP/TPA/2007/010, UK Energy Research Centre, London, October and Greening, L.A., D.L. Greene and C. Difiglio, 2000. "Energy Efficiency and Consumption – The Rebound Effect – A Survey", Energy Policy, vol. 28, pp. 389-401.

[10] Greening et al. 2000.

[11] Pickrell, D. and P. Schimek, 1999. "Growth in Motor Vehicle Ownership and Use: Evidence from the Nationwide Personal Transportation Survey", Journal of Transportation and Statistics, vol. 2, no. 1, pp. 1-17.

[12] Small, K. and K. Van Dender, 2007a. "Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect", The Energy Journal, vol. 28, no. 1, pp. 25-51.

[13] Small, K. and K. Van Dender, 2007b. "Long Run Trends in Transport Demand, Fuel Price Elasticities and Implications of the Oil Outlook for Transport Policy," OECD/ITF Joint Transport Research Centre Discussion Papers 2007/16, OECD, International Transport Forum.

[14] Revised Report by David Greene of Oak Ridge National Laboratory to EPA, "Rebound 2007: Analysis of National Light-Duty Vehicle Travel Statistics," February 9, 2010 (Docket EPA-HQ-OAR-2009-0472-0220). This paper has been accepted for an upcoming special issue of Energy Policy, although the publication date has not yet been determined.

[15] FHWA. 1997 *Federal Highway Cost Allocation Study*; http://www.fhwa.dot.gov/policy/hcas/final/index.htm (last accessed July 29, 2009).

[16] 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 Feb. 15, 2010).

[17] U.S. Bureau of Economic Analysis, U.S. International Transactions Accounts Data, as shown on June 24, 2009.

[18] U.S. Department of Energy, Annual Energy Review 2008, Report No. DOE/EIA-0384(2008), Tables 5.1 and 5.13c, June 26, 2009.

[19] Leiby, Paul N. "Estimating the Energy Security Benefits of Reduced U.S. Oil Imports," Oak Ridge National Laboratory, ORNL/TM-2007/028, Final Report, 2008.

[20] *Peer Review Report Summary: Estimating the Energy Security Benefits of Reduced U.S. Oil Imports*, ICF, Inc., September 2007.

[21] Gately, Dermot 2004. "OPEC's Incentives for Faster Output Growth," The Energy Journal, 25(2):75-96, "What Oil Export Levels Should We Expect From OPEC?" The Energy Journal, 28(2):151-173, 2007

[22] Argonne National Laboratories, *The Greenhouse Gas and Regulated Emissions from Transportation (GREET) Model*, Version 1.8, June 2007, *available at* http://www.transportation.anl.gov/software/GREET/index.html (last accessed April 20, 2008).

[23] The issue is discussed in more detail in the PM NAAQS RIA from 2006. See U.S. Environmental Protection Agency. 2006. Final Regulatory Impact Analysis (RIA) for the Proposed National Ambient Air Quality Standards for Particulate Matter. Prepared by: Office of Air and Radiation. October 2006. Available at http://www.epa.gov/ttn/ecas/ria.html.

[24] U.S. Environmental Protection Agency (U.S. EPA). 2008. Regulatory Impact Analysis, 2008 National Ambient Air Quality Standards for Ground-level Ozone, Chapter 6. Office of Air Quality Planning and Standards, Research Triangle Park, NC. March. Available at <http://www.epa.gov/ttn/ecas/regdata/RIAs/6-ozoneriachapter6.pdf>. EPA-HQ-OAR-2009-0472-0238

[25] U.S. Environmental Protection Agency (U.S. EPA). 2009. Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry. Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available on the Internet at <http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementria_4-20-09.pdf>. EPA-HQ-OAR-2009-0472-0241

[26] U.S. Environmental Protection Agency (U.S. EPA). 2010. Final NO2 NAAQS Regulatory Impact Analysis (RIA). Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available on the Internet at http://www.epa.gov/ttn/ecas/regdata/RIAs/FinalNO2RIAfulldocument.pdf. Accessed March 15, 2010. EPA-HQ-OAR-2009-0472-0237

[27] U.S. Environmental Protection Agency (U.S. EPA). 2008. Technical Support Document: Calculating Benefit Per-Ton estimates, Ozone NAAQS Docket #EPA-HQ-OAR-2007-0225-0284. Office of Air Quality Planning and Standards, Research Triangle Park, NC. March. Available on the Internet at <http://www.regulations.gov>. EPA-HQ-OAR-2009-0472-0228

[28] Fann, N. et al. (2009). The influence of location, source, and emission type in estimates of the human health benefits of reducing a ton of air pollution. Air Qual Atmos Health. Published online: 09 June, 2009. EPA-HQ-OAR-2009-0472-0229

[29] Pope, C.A., III, R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G.D. Thurston. 2002. "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution." Journal of the American Medical Association 287:1132-1141. EPA-HQ-OAR-2009-0472-0263

[30] Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery. 2006. "Reduction in Fine Particulate Air Pollution and Mortality." American Journal of Respiratory and Critical Care Medicine 173:667-672. Estimating the

Public Health Benefits of Proposed Air Pollution Regulations. Washington, DC: The National Academies Press. EPA-HQ-OAR-2009-0472-1661

[31] Mrozek, J.R., and L.O. Taylor. 2002. "What Determines the Value of Life? A Meta-Analysis." Journal of Policy Analysis and Management 21(2):253-270. EPA-HQ-OAR-2009-0472-1677

[32] Viscusi, V.K., and J.E. Aldy. 2003. "The Value of a Statistical Life: A Critical Review of Market Estimates throughout the World." Journal of Risk and Uncertainty 27(1):5-76. EPA-HQ-OAR-2009-0472-0245

[33] Kochi, I., B. Hubbell, and R. Kramer. 2006. An Empirical Bayes Approach to Combining Estimates of the Value of Statistical Life for Environmental Policy Analysis. Environmental and Resource Economics. 34: 385-406. EPA-HQ-OAR-2009-0472-0235

[34] U.S. Environmental Protection Agency (U.S. EPA). 2000. Guidelines for Preparing Economic Analyses. EPA 240-R-00-003. National Center for Environmental Economics, Office of Policy Economics and Innovation. Washington, DC. September. Available on the Internet at <http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html/$file/cover.pdf>. EPA-HQ-OAR-2009-0472-0226

[35] See http://ostpxweb.dot.gov/policy/Data/VOT97guid.pdf and http://ostpxweb.dot.gov/policy/Data/VOTrevision1_2-11-03.pdf

[36] California Environmental Protection Agency, Air Resources Board. Draft Assessment of the Real-World Impacts of Commingling California Phase 3 Reformulated Gasoline. August 2003

[37] *Id.*

[38] Office of Management and Budget, Circular A-4, "Regulatory Analysis," September 17, 2003, 33. *Available at* http://www.whitehouse.gov/omb/circulars/a004/a-4.pdf (last accessed July 24, 2009).

[39] *Id.*