U.S. Department Of Transportation

National Highway Traffic Safety Administration

Final Regulatory Impact Analysis:

Final Rulemaking for Model Years 2024-2026 Light-Duty Vehicle Corporate Average Fuel Economy Standards

March 2022

Table of Contents

Tables

Figures

Table of Acronyms and Abbreviations

AC	Air Conditioning
ADAS	Advanced Driver Assistance Systems
ADEAC	Advanced Cylinder Deactivation
ADSL	Advanced Diesel
AEB	Automatic Emergency Braking
AEO	Annual Energy Outlook
AEO 2021	U.S. Energy Information Administration's *Annual Energy Outlook 2021*
AERO	Aerodynamic drag technology
AERO15	Aero Drag Reduction, Level 1 (10% Reduction)
AIS	Abbreviated Injury Scale
AT10L2	10-Speed Automatic Transmission, Level 2
AT5	5-Speed Automatic Transmission
AT6	6-Speed Automatic Transmission
AT7L2	7-Speed Automatic Transmission, Level 2
AT8	8-Speed Automatic Transmission
AT8L2	8-Speed Automatic Transmission, Level 2
AT9L2	9-Speed Automatic Transmission, Level 2
AWD	All-wheel drive
BEV	Battery electric vehicle
BEV200	200-mile range BEV
BEV300	300-mile range BEV
BEV400	400-mile range BEV
BEV500	500-mile range BEV
BISG	Belt Integrated Starter Generator
BMW	BMW of North America, LLC
BPT	Benefit-per-ton
BSD	Blind Spot Detection
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CBI	Confidential business information
CEGR1	Cooled Exhaust Gas Recirculation, Level 1 (2.0409 bar)
CFR	Code of Federal Regulations
CFRP	Carbon Fiber Reinforced Plastics
CH_4	Methane
CI	Confidence interval

CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
COVID-19	Coronavirus disease of 2019
CUV	Crossover utility vehicle
CVT	Continuously Variable Transmission
CVTL2	Continuously Variable Transmission, Level 2
CY	Calendar Year
DC	Domestic Passenger Cars
DCT	Dual-clutch transmission
DEAC	Cylinder deactivation
DFS	Dynamic fleet share
DMC	Direct manufacturing costs
DOE	U.S. Department of Energy
DOHC	Dual overhead cam
DOT	U.S. Department of Transportation
DSLI	Diesel Engine Improvements
DSLIAD	Diesel Engine Improvements with ADEAC
EFR	Engine Friction Reduction
EIA	U.S. Energy Information Administration
EIS	Environmental Impact Statement
EISA	Energy Independence and Security Act of 2007
EPA	U.S. Environmental Protection Agency
EPCA	Energy Policy and Conservation Act of 1975
EPS	Electric Power Steering
ESC	Electronic Stability Control
EV	Electric vehicle
FARS	Fatal Accident Reporting System
FCA	Fiat Chrysler Automobiles
FCV	Fuel cell vehicle
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
FR	Federal Register
FRIA	Final Regulatory Impact Analysis
Final SEIS	Final Supplemental Environmental Impact Statement
GDP	Gross Domestic Product
GES	General Estimates System

GGE	Gasoline Gallon Equivalent
GHG	Greenhouse Gas
GI	Global Insight
GM	General Motors
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GVWR	Gross vehicle weight rating
GWP	Global Warming Potential
HCR	High Compression Ratio
HCR0	High Compression Ratio Engine, Level 0
HCR1	High Compression Ratio Engine, Level 1
HCR1D	High Compression Ratio Engine, Level 1 with DEAC
HEV	Hybrid electric vehicle
HTF	Highway Trust Fund
IACC	Improved Accessories Devices
IC	Imported Passenger Cars
ICE	Internal Combustion Engine
IHS	IHS Markit
IWG	Interagency Working Group on Social Cost of Greenhouse Gases
JLR	Jaguar Land Rover
KABCO	Scale used to represent injury severity in crash reporting
LCA	Lane Change Alert
LDT	Light-duty Trucks
LDV	Light-duty passenger vehicle
LDW	Lane Departure Warning
LE	Learning Effects
LKA	Lane Keep Assist
LTVs	Light trucks and vans
MAIS	Maximum abbreviated injury scale
MDPCS	Minimum domestic passenger car standard
MMT	Million Metric Tons
MOVES	Motor Vehicle Emission Simulator
MPG	Miles per gallon
MR0	Baseline Mass
MR2	Mass Reduction, Level 2 (7.5% Reduction in Gilder Weight)
MR3	Mass Reduction, Level 3 (10% Reduction in Gilder Weight)
MR4	Mass Reduction, Level 4 (15% Reduction in Gilder Weight)
MR5	Mass Reduction, Level 5 (20% Reduction in Gilder Weight)

MR6	Mass Reduction, Level 6 (28.2% Reduction in Gilder Weight)
MSRP	Manufacturer suggested retail price
MT	Manual transmission
MY	Model Year
N_2O	Nitrous oxide
NEMS	National Energy Modeling System
NEPA	National Environmental Policy Act
NHTSA	National Highway Traffic Safety Administration
NO_X	Nitrogen oxide
NPRM	Notice of proposed rulemaking
OC	Off-cycle
OEM	Original equipment manufacturer
OMB	Office of Management and Budget
PDO	Property Damage-Only
PEF	Petroleum Equivalency Factor
PHEV	Plug-in hybrid electric vehicle
PM	Particulate matter
$PM_{2.5}$	Particulate matter 2.5 microns or less in diameter
RAM	RAM Trucks
RIA	Regulatory Impact Analysis
ROLL	Tire rolling resistance
ROLL20	Low Rolling Resistance Tires, Level 1 (10% Reduction)
RPE	Retail Price Equivalent
SC-CH_4	Social cost of methane
SC-GHG	Social cost of greenhouse gases
SC-N_2O	Social cost of nitrous oxide
SCC	Social cost of carbon
SDGI	Stoichiometric gasoline direct injection
SHEV	Strong hybrid electric vehicle
SHEVP2	P2 strong hybrid/electric vehicle
SHEVPS	Power split hybrid/electric vehicle
SO_X	Sulfur oxide
SS12V	12V strong hybrid/electric vehicle
SUV	Sport utility vehicle
TAR	Technical Assessment Report
TCO	Total Cost of Ownership
Fuel TS&D	Refined Gasoline and Diesel

TURBO1	Turbocharging and Downsizing, Level 1 (1.5271 bar)
TURBO2	Turbocharging and Downsizing, Level 2 (2.0409 bar)
TURBOAD	Turbocharging and Downsizing with ADEAC
U.S.	United States
U.S.C.	United States Code
UNFCCC	United Nations Framework Convention on Climate Change
VCR	Variable Compression Ratio Engine
VMT	Vehicle miles traveled
VSL	Value of a Statistical Life
VTG	Variable Turbo Geometry
VTGE	Variable Turbo Geometry (Electric)
VVL	Variable Valve Lift
VVT	Variable Valve Timing
VW	Volkswagen
VWA	Volkswagen Group of America
ZEV	Zero Emission Vehicle

1. Introduction

This Final Regulatory Impact Analysis (FRIA) has been prepared to assess the potential and anticipated consequences of amended and alternative Corporate Average Fuel Economy (CAFE) standards for passenger cars and light trucks for model years (MYs) 2024-2026. Regulatory analysis is a tool used to anticipate and evaluate likely consequences of rules. It provides a formal way of organizing the evidence on the key effects, positive and negative, of the various alternatives that are considered in developing regulations. The goal of this FRIA is to consolidate that evidence to help inform decision-makers of the potential consequences of choosing among the considered regulatory paths.

The National Highway Traffic Safety Administration (NHTSA) is required by law to take regulatory action and does not have the discretion not to set standards. NHTSA is required to set CAFE standards by the Energy Policy and Conservation Act of 1975 (EPCA), as amended by the Energy Independence and Security Act of 2007 (EISA). CAFE standards must be set (or amended, if the amendment is to result in higher stringency) at least 18 months prior to the beginning of the model year; must be set separately for each model year and for passenger cars and light trucks; must be "attribute-based and defined by a mathematical function;" and must be set at the maximum feasible level that NHTSA determines manufacturers can reach for that fleet in that model year, among other requirements.[1]

This assessment examines the costs and benefits of amended and alternative CAFE standards levels for passenger cars and light trucks for MYs 2024 through 2026. In this notice, NHTSA is revisiting existing CAFE standards that were finalized in 2020, as directed by Executive Order 13990. This action today is taken under the agency's statutory authority. This assessment examines the costs and benefits of setting fuel economy standards for passenger cars and light trucks that change at a variety of different rates during those model years.[2] It includes a discussion of the technologies that can improve fuel economy, as well as analysis of the potential impacts on vehicle retail prices, lifetime fuel savings and their value to consumers, and other societal effects such as energy security, changes in pollutant emissions levels, and safety.[3] Estimating impacts also involves consideration of consumers' responses to standards – for example, whether and how changes in vehicle prices as a result of changes in CAFE standards could affect sales of new and used vehicles.

As explained above, EISA requires NHTSA to set attribute-based CAFE standards that are based on a mathematical function. The mathematical function or "curve" representing the standards is a constrained linear function that provides a separate fuel economy target for each vehicle footprint, and there are separate curves for cars and for trucks. Vehicle footprint has been used as the relevant attribute for the curves since MY 2011. Under all of the regulatory alternatives, the standards would become more stringent for each model year from 2024 to 2026, relative to

[1] *See* 49 U.S.C. 32902 and Section VI of the final rule preamble that this FRIA accompanies for more information.
[2] Throughout this FRIA, cost and benefit analyses are presented for individual model years as well as the cumulative total for all model years through MY 2029, although some physical effects are presented on a calendar year basis instead, as appropriate.
[3] This analysis does not contain NHTSA's assessment of the potential environmental impacts of the final rule for purposes of the National Environmental Policy Act (NEPA), 42 U.S.C. 4321–4347, which is contained in the agency's Final Supplemental Environmental Impact Statement (Final SEIS) accompanying the final rule.

the MY 2023 standards. Generally, the larger the vehicle footprint, the less numerically stringent the corresponding vehicle miles per gallon (mpg) target, except at the largest and smallest footprint sizes where targets are flat across footprint sizes. With footprint-based standards, the burden of compliance is theoretically distributed across all vehicle footprints and across all manufacturers. Each manufacturer is subject to individualized standards for passenger cars and light trucks, in each model year, based on the vehicles it produces.

We constructed an analysis fleet representing the entire MY 2020 light-duty fleet in detail as a starting point to evaluate the costs and benefits of the rule, against which we simulate manufacturers' year-by-year response through MY 2050[4] to standards defining each regulatory alternative. The analysis fleet is comprised of the best information available as of early 2021 regarding the MY 2020 fleet, and, for each of 3,627 specific model/configurations, contains information such as production volumes, fuel economy ratings, dimensions (footprint), curb weight and gross vehicle weight rating (GVWR), engine characteristics, transmission characteristics, and other key engineering information. For each regulatory alternative, we used the CAFE Model to simulate manufacturers' year-by-year application of technology that improves fuel economy, assuming that manufacturers would respond not only to the year-by-year standards defining the regulatory alternative, but also to a baseline consisting of the CAFE standards finalized in 2020, California's Zero Emission Vehicle (ZEV) program, U.S. Environmental Protection Agency (EPA)'s baseline (i.e., those finalized in 2020) fleetwide greenhouse gas (GHG) standards, the "Framework Agreements" made between California and 5 major manufacturers, and buyers' willingness to pay for a portion of the fuel savings expected to occur over vehicles' lifetimes.

NHTSA is setting amended CAFE standards that increase at 8 percent, 8 percent, and 10 percent per year during MYs 2024, 2025, and 2026, respectively, because that is what NHTSA has concluded is maximum feasible in those model years, under the EPCA factors. Although NHTSA and EPA took separate actions in this round of rulemaking for a variety of reasons, NHTSA sought to coordinate its action with EPA's to the greatest extent possible given our statutory and programmatic differences. NHTSA finds that the amended CAFE and GHG standards for MY 2026 represent roughly equivalent levels of stringency and may serve as a coordinated starting point for subsequent standards. While the CAFE and GHG standards for MYs 2024-2026 are different, this is largely due to the difference in the "start year" for the revised regulations, which affects the analysis of what technologies are available and when they can be applied – EPA has issued revised standards for MY 2023, while EPCA's lead time requirements prevent NHTSA from amending standards until MY 2024. The differences in what the two agencies' standards require of the overall industry become smaller each year, until near alignment is achieved in MY 2026.

While NHTSA's and EPA's programs differ in certain other respects, like programmatic flexibilities, those differences are not new in this notice. Some parts of the programs are harmonized, and others differ, often as a result of statute. Since NHTSA and EPA began regulating together under President Obama, differences in programmatic flexibilities have meant

[4] As in prior analyses, today's analysis exercises the CAFE Model using inputs that extend the explicit compliance simulation through MY 2050 – many years beyond the last year for which we propose to issue revised standards. This has been done because interactions between the new and used vehicles markets impact benefits and costs over the lives of vehicles produced in the rulemaking timeframe.

that manufacturers have had (and will have) to plan their compliance strategies considering both the NHTSA standards and the EPA standards and assure that they are in compliance with both, but they are sophisticated companies accustomed to operating under multiple regulatory regimes simultaneously and we remain confident that they will achieve that goal. For purposes of this FRIA, we have only attempted to report costs and benefits for the NHTSA CAFE standards, and not also EPA's standards. We refer readers to EPA's documents for more information about their standards and its effects, and note (as in the joint rules since 2012) that costs and benefits of the two programs will largely overlap, since manufacturers will take many actions that respond to both programs simultaneously.

EPCA, as amended by EISA, contains a number of provisions governing how NHTSA must set CAFE standards. EPCA requires that CAFE standards be set separately for passenger cars and light trucks[5] at the "maximum feasible average fuel economy level that the Secretary decides the manufacturers can achieve in that model year,"[6] based on the agency's consideration of four statutory factors: technological feasibility, economic practicability, the effect of other standards of the Government on fuel economy, and the need of the United States to conserve energy.[7] EPCA does not define these terms or specify what weight to give each concern in balancing them – such considerations are left within the discretion of the Secretary of Transportation (delegated to NHTSA) based upon current information. Accordingly, NHTSA interprets these factors and determines the appropriate weighting that leads to the maximum feasible standards given the circumstances present at the time of promulgating each CAFE standard rulemaking.

As stated above, NHTSA is amending standards for passenger cars and light trucks that the agency concludes represent maximum feasible CAFE standards for MYs 2024-2026, pursuant to its statutory authority. While the actual standards are footprint-based target curves, NHTSA estimates that the standards would require, on an average industry fleet-wide basis, roughly 49 mpg in MY 2029.

NHTSA projects that under these standards, required technology costs could increase by $90 billion over the lifetimes of vehicles through MY 2029, and civil penalty payments could increase by about $9 billion. If those costs are passed on to consumers as average increases in manufacturer suggested retail price (MSRP) (rather than, for example, to shareholders as foregone gains, or to employees as foregone compensation), we estimate that per-vehicle costs paid by U.S. consumers for new vehicles would increase by roughly $1,100, on average, as compared to if the baseline standards were retained; but concurrently, fuel savings for those vehicles would increase significantly, by roughly $1,700, undiscounted, on average. Overall total discounted benefits attributable to the standards vary from $145 billion at a 3 percent discount rate (3 percent discount rate for social cost of greenhouse gas [SC-GHG]) to $100

[5] 49 U.S.C. 32902(b)(1).
[6] 49 U.S.C. 32902(a).
[7] 49 U.S.C. 32902(f).

billion at a 7 percent discount rate (3 percent discount rate for SC-GHG).[8][9] It is important to stress that these estimates could change – sometimes dramatically – with different assumptions. For example, if estimates of future fuel prices or the SC-GHG are too low, corresponding input revisions could significantly increase net benefits.

The results of this analysis are set forth in the rest of this document. Note that for readers seeking to compare these results to those set forth in the 2020 final rule and accompanying documentation, not only have many inputs and modeling approaches changed since that rulemaking, but also the directionality of many outputs may appear different, because in today's action we are amending to *raise* CAFE stringency from a baseline rather than *decrease* it.

Table 1-1 – Estimated Present Value of Benefits and Costs of Preferred Alternative for Model Years 2024 through 2026, 3 Percent Discount Rate for All Costs and Benefits (billions in 2018$)[10]

MY	Cost	Benefit	Net Benefits
2024	5.1	4.5	-0.6
2025	10.4	13.8	3.3
2026	13.9	19.9	6.0
Sum	18.9	28.9	10.0

NHTSA and EPA estimate benefits, costs, and net benefits using similar methodologies. However, different reporting approaches may give the false appearance of significant divergences. Table 1-1 presents NHTSA estimates of benefits and costs attributable to vehicles produced for sale in year MYs 2024-2026, over the full useful lives of these vehicles. Even though EPA's rulemaking, like NHTSA's, extends through MY 2026, EPA presents cost and benefit information in its RIA covering calendar years (CYs) through 2050, accounting for all vehicles EPA projects to be on the road in each of those years. NHTSA has also estimated

[8] Climate benefits are based on changes (reductions) in CO_2, methane (CH_4), and nitrous oxide (N_2O) emissions and are calculated using four different estimates of the social cost of carbon (SCC), methane (SC-CH_4), and nitrous oxide (SC-N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four estimates. We show the average SC-GHG discount of 3 percent for climate benefits in this rule for presentational purposes. The full range of climate benefits is shown in Chapter 7 of the FRIA. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

[9] Monetized values do not include other important unquantified effects, such as certain climate benefits, certain energy security benefits, distributional effects, and certain air quality benefits from the reduction of toxic air pollutants and other emissions, among other things.

[10] Climate benefits are based on changes (reductions) in CO_2, CH_4, and N_2O emissions and are calculated using four different estimates of the SCC, SC-CH_4, and SC-N_2O (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four estimates. We show one primary estimate in this table for climate benefits for presentational purposes (model average at 2.5 percent discount rate). The full range of climate benefits is shown in Chapter 7 of the FRIA. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021), a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

benefits, costs, and physical impacts on this basis, and finds that with climate benefits discounted at 3 percent and all other benefits and costs discounted at 3 percent, costs, benefits, and net benefits total be $367 billion, $478 billion, $112 billion, respectively.

Additionally, the following tables provide the benefits and net benefits over a range of climate benefit discount rates for each alternative evaluated by the agency, while keeping all other costs and benefits at a 3 percent and 7 percent discount rate, respectively.

Table 1-2 – Incremental Benefits and Costs Over the Lifetimes of Total Fleet Produced Through 2029 (2018$ Billions), 3 Percent Discount Rate, by Alternative, All SC-GHG Levels

Alternative	1	2	2.5	3
Total Incremental Social Benefits, Average SC-GHG Values at 5% Discount Rate	68.5	111.1	124.2	156.4
Total Incremental Social Benefits, Average SC-GHG Values at 3% Discount Rate	79.2	129.4	144.6	182.2
Total Incremental Social Benefits, Average SC-GHG Values at 2.5% Discount Rate	86.7	142.2	158.9	200.3
Total Incremental Social Benefits, 95th Percentile SC-GHG Values at 3% Discount Rate	108.4	179.2	200.3	252.5
Net Incremental Social Benefits, Average SC-GHG Values at 5% Discount Rate	9.9	-2.8	-4.2	-9.4
Net Incremental Social Benefits, Average SC-GHG Values at 3% Discount Rate	20.6	15.5	16.3	16.4
Net Incremental Social Benefits, Average SC-GHG Values at 2.5% Discount Rate	28.1	28.3	30.6	34.5
Net Incremental Social Benefits, 95th Percentile SC-GHG Values at 3% Discount Rate	49.8	65.2	71.9	86.7

Table 1-3 – Incremental Benefits and Costs Over the Lifetimes of Total Fleet Produced Through 2029 (2018$ Billions), 7 Percent Discount Rate, by Alternative, All SC-GHG Levels

Alternative	1	2	2.5	3
Total Incremental Social Benefits, Average SC-GHG Values at 5% Discount Rate	43.8	71.0	79.3	100.0
Total Incremental Social Benefits, Average SC-GHG Values at 3% Discount Rate	54.5	89.3	99.7	125.8
Total Incremental Social Benefits, Average SC-GHG Values at 2.5% Discount Rate	62.0	102.1	114.1	143.9
Total Incremental Social Benefits, 95th Percentile SC-GHG Values at 3% Discount Rate	83.6	139.0	155.4	196.1
Net Incremental Social Benefits, Average SC-GHG Values at 5% Discount Rate	0.8	-13.9	-16.5	-24.3
Net Incremental Social Benefits, Average SC-GHG Values at 3% Discount Rate	11.5	4.3	3.9	1.5
Net Incremental Social Benefits, Average SC-GHG Values at 2.5% Discount Rate	19.0	17.2	18.3	19.6

Net Incremental Social Benefits, 95th Percentile SC-GHG Values at 3% Discount Rate	40.6	54.1	59.6	71.8

NHTSA describes its cost and benefit accounting approach in Section V of the final rule.

2. Baseline and Alternatives Considered

Agencies typically consider regulatory alternatives as a way of evaluating the comparative effects of different potential ways of accomplishing their desired goal. Executive Orders 12866 and 13563, as well as Office of Management and Budget (OMB) Circular A-4, encourage agencies to evaluate regulatory alternatives in their rulemaking analyses.[11] This does not amount to a requirement that agencies evaluate the widest conceivable spectrum of alternatives. Rather, the range of alternatives must be reasonable and consistent with the purpose and need of the action.

Alternatives analysis begins with a "No-Action" alternative, typically described as what would occur in the absence of any regulatory action. OMB Circular A-4 states that the "baseline should be the best assessment of the way the world would look absent the regulatory action. The choice of an appropriate baseline may require consideration of a wide range of potential factors, including:

- evolution of the market,
- changes in external factors affecting expected benefits and costs,
- changes in regulations promulgated by the agency or other government entities, and
- the degree of compliance by regulated entities with other regulations.[12]

The No-Action Alternative for this final rule differs in a variety of ways from the No-Action Alternative for the 2020 final rule. First, in the 2020 final rule, the No-Action Alternative represented the most stringent CAFE standards under consideration; in this final rule, the No-Action Alternative represents the *least* stringent CAFE standards under consideration. This means that for readers seeking to compare results between this FRIA and the 2020 FRIA, most of the incremental effects shown in this FRIA are in a direction that is opposite those in the 2020 FRIA.

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[11] NEPA also requires agencies to compare the potential environmental impacts of their proposed actions to those of a reasonable range of alternatives. Regulations regarding implementation of NEPA require agencies to "rigorously explore and objectively evaluate all reasonable alternatives, and for alternatives which were eliminated from detailed study, briefly discuss the reasons for their having been eliminated." 40 CFR 1502.14 (2019).
[12] OMB Circular A-4, "General Issues, 2. Developing a Baseline." *Available at* https://obamawhitehouse.archives.gov/omb/circulars_a004_a-4/, (Accessed: February 14, 2022).

Second, the No-Action Alternative in this final rule includes two elements (new to this rule) in the baseline, in line with the Circular A-4 guidance noted above:

- We have included California's ZEV mandate and its adoption by Section 177 states as part of the No-Action Alternative because these are separate legal requirements applying to automakers during the relevant time period. We have rescinded the 2019 "SAFE I" rule,[13] and EPA rescinded its 2019 withdrawal of the waiver of preemption for California's ZEV mandate.[14] Additionally, California reports that overcompliance with the ZEV mandate has been widespread even under circumstances where California was not legally enforcing the mandate, suggesting that vehicle manufacturers are seeking to meet it whether or not a waiver of preemption is in place. It is therefore reasonably foreseeable that manufacturers selling vehicles in California and in the Section 177 states that have adopted the ZEV mandate will be producing sufficient advanced technology vehicles at levels that would comply with the ZEV mandate during the timeframe of this rulemaking.

- We have included the agreements made between California and BMW of North America, LLC (BMW), Ford, Honda, Volkswagen Group of America (VWA), and Volvo, because these agreements by their terms are legally binding contracts, even though they were entered into voluntarily.[15] We did so by including EPA's baseline GHG standards from the 2020 final rule in our analysis, and then introducing more stringent GHG target functions during MYs 2022-2026, but treating only these five manufacturers as subject to these more stringent target functions. Because a significant portion of the market voluntarily adopted the California Framework Agreements, NHTSA continues to believe that the manufacturers who joined believed it could be met, and because that adoption is legally binding once entered into, it is reasonable to assume that it will occur as expected during the rulemaking timeframe, and thus, reasonable to include in the No-Action Alternative.

Also, as in past analyses, our analysis further assumes that, beyond any technology applied in response to CAFE standards, EPA GHG standards, California/original equipment manufacturer (OEM) agreements, and ZEV mandates applicable in California and the Section 177 states, manufacturers could also make any additional fuel economy improvements estimated to reduce owners' estimated average fuel outlays during the first 30 months of vehicle operation by more than the estimated increase in new vehicle price.

We accomplished much of this through expansion of the CAFE Model after the prior rulemaking. The previous version of the model had been extended to apply to GHG standards as well as CAFE standards but had not been published in a form that simulated simultaneous compliance with both sets of standards. As discussed at greater length in the current CAFE Model documentation, the updated version of the model simulates all the following simultaneously:

[13] 86 FR 74236 (Dec. 29, 2021).
[14] 87 FR 14332 (Mar. 14, 2022).
[15] *See* https://ww2.arb.ca.gov/news/framework-agreements-clean-cars. (Accessed: February 14, 2022).

1. Compliance with CAFE standards
2. Compliance with GHG standards applicable to all manufacturers[16]
3. Compliance with alternative GHG emission reduction commitments made by a subset of manufacturers
4. Compliance with ZEV mandates
5. Further fuel economy improvements applied if sufficiently cost-effective for buyers

Inclusion of the above actions in the No-Action Alternative means that they are necessarily included in each of the Action Alternatives. That is, the impacts of all the alternatives evaluated in this final rule are against the backdrop of these state and Federal actions and voluntary actions to which automakers have formally committed. This is important to remember, because it means that automakers will be taking actions that are projected to alter the technologies applied to vehicles even in the absence of new CAFE standards, and that costs and benefits attributable to those actions are therefore *not* attributable to possible future CAFE standards.

Besides the No-Action Alternative, the final rule also includes four "Action Alternatives." Each of the Action Alternatives is more stringent than the No-Action Alternative during MYs 2024-2026, as mentioned above. These alternatives are specified below, with Alternative 1 being the least stringent in MY 2026, Alternative 3 being the most stringent, and Alternatives 2 and 2.5 falling between Alternatives 1 and 3 in terms of MY 2026 stringency.

2.1 Alternative 1

Alternative 1 would increase CAFE stringency for MY 2024 by 9.14 percent for passenger cars and 11.02 percent for light trucks and increase stringency in MYs 2025 and 2026 by 3.26 percent per year for both passenger cars and light trucks

Table 2-1 – Characteristics of Alternative 1 – Passenger Cars

	2024	2025	2026
a (mpg)	56.15	58.04	60.00
b (mpg)	42.00	43.41	44.88
c (gpm per s.f.)	0.000400	0.000387	0.000374
d (gpm)	0.00141	0.00136	0.00132

[16] At the time the original analysis was conducted.

Table 2-2 – Characteristics of Alternative 1 – Light Trucks

	2024	2025	2026
a (mpg)	46.17	47.73	49.34
b (mpg)	27.73	28.67	29.63
c (gpm per s.f.)	0.000436	0.000422	0.000408
d (gpm)	0.00377	0.00365	0.00353

We have omitted the graphical representations of these coefficients (for this and other alternatives) from this FRIA for brevity; they may be found in Chapter 1 of the accompanying Technical Support Document (TSD). For purposes of this analysis, the coefficients themselves are what the CAFE Model uses directly to estimate manufacturer responses to different levels of CAFE stringency.

Under this alternative, the minimum domestic passenger car standard (MDPCS) is as shown in Table 2-3.

Table 2-3 – Alternative 1 – Minimum Domestic Passenger Car Standard

2024	2025	2026
44.9 mpg	46.4 mpg	48.0 mpg

2.2 Alternative 2

Alternative 2 would increase CAFE stringency at 8 percent per year.

Table 2-4 – Characteristics of Alternative 2 – Passenger Cars

	2024	2025	2026
a (mpg)	55.44	60.26	65.50
b (mpg)	41.48	45.08	49.00
c (gpm per s.f.)	0.000405	0.000372	0.000343
d (gpm)	0.00144	0.00133	0.00122

Table 2-5 – Characteristics of Alternative 2 – Light Trucks

	2024	2025	2026
a (mpg)	44.48	48.35	52.56
b (mpg)	26.74	29.07	31.60
c (gpm per s.f.)	0.000452	0.000416	0.000382
d (gpm)	0.00395	0.00364	0.00334

Under this alternative, the MDPCS is as shown in Table 2-6.

Table 2-6 – Alternative 2 – Minimum Domestic Passenger Car Standard

2024	2025	2026
44.3 mpg	48.2 mpg	52.4 mpg

2.3 Alternative 2.5 – Preferred Alternative

In the proposal preceding the final rule, NHTSA sought comment on a possible modification to Alternative 2, which would have increased the stringency of CAFE standards by 10 percent between MYs 2025 and 2026, rather than by 8 percent. NHTSA determined that this alternative could represent a middle ground between Alternatives 2 and 3.

Table 2-7 – Characteristics of Alternative 2.5 – Passenger Cars

	2024	2025	2026
a (mpg)	55.44	60.26	66.95
b (mpg)	41.48	45.08	50.09
c (gpm per s.f.)	0.000405	0.000372	0.000335
d (gpm)	0.00144	0.00133	0.00120

Table 2-8 – Characteristics of Alternative 2.5 – Light Trucks

	2024	2025	2026
a (mpg)	44.48	48.35	53.73
b (mpg)	26.74	29.07	32.30
c (gpm per s.f.)	0.000452	0.000416	0.000374
d (gpm)	0.00395	0.00364	0.00327

Under this alternative, the MDPCS is as shown in Table 2-9.

Table 2-9 – Alternative 2.5 – Minimum Domestic Passenger Car Standard

2024	2025	2026
44.3	48.2	53.5

NHTSA considered this alternative as a way to evaluate the effects of CAFE standards between Alternative 2 and Alternative 3 allowing for a slower ramp in stringency than Alternative 3 but providing additional lead time to return to a fuel consumption trajectory similar to the standards announced in 2012.

2.4 Alternative 3

Alternative 3 would increase CAFE stringency at 10 percent per year, which we calculate would result in total lifetime fuel saving from vehicles produced during MYs 2021-2029 similar to total lifetime fuel savings that would have occurred if we had promulgated final CAFE standards for MYs 2021-2025 at the augural levels announced in 2012 and, in addition, if we had also promulgated MY 2026 standards that reflected a continuation of that average rate of stringency increase (4.48 percent for passenger cars and 4.54 percent for light trucks).

Table 2-10 – Characteristics of Alternative 3 – Passenger Cars

	2024	2025	2026
a (mpg)	56.67	62.97	69.96
b (mpg)	42.40	47.11	52.34
c (gpm per s.f.)	0.000396	0.000356	0.000321
d (gpm)	0.00141	0.00127	0.00114

Table 2-11 – Characteristics of Alternative 3 – Light Trucks

	2024	2025	2026
a (mpg)	45.47	50.53	56.14
b (mpg)	27.34	30.38	33.75
c (gpm per s.f.)	0.000442	0.000398	0.000358
d (gpm)	0.00387	0.00348	0.00313

Under this alternative, the MDPCS is as shown in Table 2-12.

Table 2-12 – Alternative 3 – Minimum Domestic Passenger Car Standard

2024	2025	2026
45.3 mpg	50.4 mpg	56.0 mpg

We considered this alternative as a way to evaluate the effects of CAFE standards that would return to a fuel consumption trajectory similar to the standards announced in 2012.

The following chapter in this FRIA contains information about how the CAFE Model simulates manufacturer responses to the regulatory alternatives described above, and then calculates economic, environmental, and other effects that could occur as a result of those manufacturer responses.

3. Simulating Alternatives with the CAFE Model

3.1 Overall Purpose and Structure of the CAFE Model

Over time, NHTSA's analyses have expanded to address an increasingly wide range of types of impacts. Today's analysis involves, among other things, estimating how the application of various combinations of technologies could impact vehicles' costs and fuel economy levels (and carbon dioxide [CO_2] emission rates); estimating how vehicle manufacturers might respond to standards by adding fuel-saving technologies to new vehicles; estimating how changes in new vehicles might impact vehicle sales and operation; and estimating how the combination of these changes might impact national-scale energy consumption, emissions, highway safety, and public health. In addition, the Final Supplemental Environmental Impact Statement (Final SEIS) accompanying today's notice addresses impacts on air quality and climate, and the effects that those changes in impacts have on the environment and human health. The analysis of these factors informs and supports NHTSA's application of the statutory factors involved in determining "maximum feasible" fuel-economy standards under EPCA, including, among others, economic practicability, and the need of the United States to conserve energy. The CAFE Model plays a central role in NHTSA's analysis supporting today's notice.

The purpose of this overview is not to provide a comprehensive technical description of the model, but rather to give an overview of the model's functions, and to describe how it simulates the impacts of changes to fuel efficiency standards. The model documentation accompanying today's notice[17] provides a comprehensive and detailed description of the model's functions, design, inputs, and outputs.

The basic design of the CAFE Model is as follows: the system first estimates how vehicle manufacturers might respond to a given regulatory scenario, taking into account inputs defining, among other things, the range of their specific products; the projected efficacy and cost of technologies projected to be commercially available; projected fuel prices and consumer willingness to pay for fuel economy improvements; and the standards defining the regulatory scenario. The system then estimates what impact that response will have on fuel consumption, emissions, and economic externalities. A regulatory scenario involves specification of the form, or shape, of the standards (e.g., flat standards, or linear or logistic attribute-based standards),

[17] The CAFE Model is available at https://www.nhtsa.gov/corporate-average-fuel-economy/compliance-and-effects-modeling-system, (Accessed: February 14, 2022), with documentation and all inputs and outputs supporting today's notice.

scope of regulatory classes,[18] and stringency of the CAFE standards for each model year to be analyzed.

Manufacturer compliance simulation begins with a detailed, user-provided initial representation of the vehicle models offered for sale in a recent model year (MY 2020, in this analysis). The compliance simulation then attempts to bring each manufacturer into compliance with the standards defined by the regulatory scenario. For example, a regulatory scenario may define CAFE standards that increase in stringency by a given percent per year for a given number of consecutive years.

The model applies various technologies to different vehicle models in each manufacturer's product line to simulate how each manufacturer might make progress toward compliance with the specified standard. Subject to a variety of user-controlled constraints, the model applies technologies based on their relative cost-effectiveness, as determined by several input assumptions regarding the cost and effectiveness of each technology, the cost of compliance (determined by the change in CAFE or CO_2 credits, CAFE-related civil penalties, or value of CO_2 credits, depending on the compliance program being evaluated), and the value of avoided fuel expenses. For a given manufacturer, the compliance simulation algorithm applies technologies either until the manufacturer runs out of cost-effective technologies,[19] until the manufacturer exhausts all available technologies, or, if the manufacturer is assumed to be willing to pay civil penalties or acquire credits from another manufacturer, until paying civil penalties or purchasing credits becomes more cost-effective than increasing vehicle fuel economy. At this stage, the system assigns an incurred technology cost and updated fuel economy to each vehicle model, as well as any civil penalties incurred/credits purchased by each manufacturer. This compliance simulation process is repeated for each model year included in the study period (through MY 2050 in this analysis).[20]

This point marks the system's transition between compliance simulation and effects calculations. At the conclusion of the compliance simulation for a given regulatory scenario, the system produces a full representation of the registered light-duty vehicle population in the United States. The CAFE Model then uses this fleet to generate estimates of the following (for each model year and calendar year included in the analysis): lifetime travel, fuel consumption, CO_2 and criteria pollutant emissions, the magnitude of various economic externalities related to vehicular travel (e.g., congestion and noise), and energy consumption (e.g., the economic costs of short-term increases in petroleum prices, or social damages associated with GHG emissions). The system

[18] While the set of regulatory classes is typically consistent across the set of CAFE alternatives, it may occasionally be necessary, as it is in the Baseline (Alternative 0) in this Final Rule, to capture the regulatory classification of the GHG program which uses a similar, but not identical, scheme of classification.
[19] Generally, the model considers a technology "cost-effective" if it pays for itself in fuel savings within 30 months, a duration that reflects buyers' significant undervaluation of fuel savings relative to a simple actuarial projection of lifetime fuel savings. Depending on the settings applied, the model can continue to apply technologies that are *not* cost-effective rather than choosing other compliance options; if it does so, it will apply those additional technologies in order of cost-effectiveness.
[20] The extension through calendar year 2050 reflects a balance between completeness and uncertainty, as well as the need to capture the interactions of the new and used vehicle markets as the vehicles produced in MYs 2024-2026 are used, age, and retire. The Energy Information Administration's 2021 Annual Energy Outlook also uses a modeling horizon that extend through 2050.

then uses these estimates to measure the benefits and costs associated with each regulatory alternative (relative to the No-Action Alternative).

3.2 Simulating Manufacturers' Potential Responses to the Alternatives

3.2.1 Starting Point – the 2020 Fleet

As a starting point, the model needs enough information to represent each manufacturer regulated by the standards. The MY 2020 analysis fleet is contained in the "market data file" and includes information about each regulated manufacturer's:

- Vehicle models offered for sale – their current (again, for this notice, MY 2020) production volumes, fuel economy (as measured on the compliance test procedure), MSRPs, fuel saving technology content (relative to the set of technologies described in Table 3-1 and Table 3-2), footprint (necessary to compute the vehicle's target fuel economy under each regulatory alternative), and other attributes (curb weight, drive type, assignment to technology class and regulatory class),

- Production constraints – product cadence of vehicle models (i.e., schedule of model redesigns and less significant "freshenings"), vehicle platform membership, degree of engine and/or transmission sharing (for each model variant) with other vehicles in the fleet, and

- Compliance constraints and flexibilities – including historical preference for full compliance or civil penalty payment/credit application; voluntary adoption of the California Framework Agreements in the baseline; willingness to apply additional cost-effective fuel saving technology in excess of CAFE requirements; provisions related to compliance value of alternative fuel vehicles; deployment of air conditioning (AC) improvements and off-cycle (OC) technologies for compliance purposes; and current CAFE (and/or GHG) credit balance (by model year and regulatory class) at the start of the simulation.

All of that information together provides the foundation on which the CAFE Model builds an assessment of how each manufacturer could comply with a given regulatory alternative. The regulatory alternatives, while applicable to all manufacturers in the analysis, affect individual manufacturers differently. Each manufacturer's actual CAFE compliance obligation represents the production-weighted harmonic mean of their vehicles' targets in each regulated fleet, where the fuel economy target is a function of the vehicles' footprints. This means that no individual vehicle has a "standard," merely a target, and each manufacturer is free to identify a compliance strategy that makes the most sense given its unique combination of vehicle models, consumers, and competitive position in the various market segments. As the CAFE Model provides flexibility when defining a set of CAFE standards, each manufacturer's requirement is dynamically defined based on the specification of the standards for any simulation and the distribution of footprints within each fleet. The specific details of the MY 2020 analysis fleet are discussed in TSD Chapter 2.2.

3.2.2 Representing Manufacturers' Production Constraints

The current version of the CAFE Model accounts for a number of production constraints that influence manufacturers' compliance options and are relevant to evaluating the economic practicability of different regulatory alternatives. While the earliest CAFE analyses did not account for all of these, both public comments on earlier rules and CAFE Model peer reviewers have consistently found them to be relevant and meaningful inclusions.

3.2.2.1 Product Cadence

Past comments on the CAFE Model have stressed the importance of product cadence—i.e., the development and periodic redesign and freshening of vehicles—involving technical, financial, and other practical constraints on applying new technologies, and U.S. Department of Transportation (DOT) has steadily made changes to both the CAFE Model and its inputs with a view toward accounting for these considerations. For example, early versions of the model added explicit "carrying forward" of applied technologies between model years, subsequent versions applied assumptions that most technologies will be applied when vehicles are freshened or redesigned, and more recent versions applied assumptions that manufacturers would sometimes apply technology earlier than "necessary" in order to facilitate compliance with standards in ensuing model years. Thus, for example, if a manufacturer is expected to redesign many of its products in MYs 2022 and 2027, and a regulatory alternative's stringency increases significantly in MY 2025, the CAFE Model will estimate the potential that the manufacturer will add more technology than necessary for compliance in MY 2022, in order to carry those product changes forward to the next redesign and contribute to compliance with the MY 2025 standard. This explicit simulation of multiyear planning plays an important role in determining year-by-year analytical results, and more accurately reflects the kinds of strategic decisions that manufacturers face when attempting to comply with standards that increase annually. While no generally applied methods or inputs can precisely reproduce every manufacturer's *actual* product planning decisions, staff have considered available information regarding these decisions to arrive at methods and inputs—all discussed in the accompanying TSD—expected to produce realistic simulations of technology pathways manufacturers *could* practicably implement.

As in previous iterations of CAFE rulemaking analysis, our simulation of compliance actions that manufacturers might take is constrained by the pace at which new technologies can practicably be applied in the new vehicle market. For example, it could be technologically feasible for a given sedan to use a turbocharged gasoline engine or a high compression ratio (HCR) engine or a diesel engine, but it would be economically impracticable for a manufacturer to replace that sedan's naturally aspirated gasoline engine with a turbocharged gasoline engine in MY 2021, and then a HCR engine in MY 2022, and then a diesel engine in MY 2023. Operating at the Make/Model level (e.g., Toyota Camry) allows us to account explicitly for the fact that individual vehicle models ordinarily undergo significant redesigns relatively infrequently. Many popular models have historically only been redesigned every six years or so, with some larger/legacy platforms (e.g., Ford Econoline Vans) stretching more than a decade between significant redesigns. Engines, which are often shared among many different models and platforms for a single manufacturer, can last even longer – eight to ten years in most cases.

While these characterizations of product cadence are important to any evaluation of the impacts of CAFE or GHG standards, they are not known with certainty – even by the manufacturers themselves over time horizons as long as those covered by this analysis, which goes out to 2050 because it is necessary to continue to capture the interactions of the new and used vehicle markets as the vehicles produced in MYs 2024-2026 are used, age, and retire. However, lack of certainty about redesign schedules is not license to ignore them.[21] Indeed, when meeting with DOT to discuss plans vis-à-vis CAFE requirements, manufacturers typically present specific and detailed year-by-year information that explicitly accounts for anticipated redesigns. Such year-by-year analysis is also essential to manufacturers' plans to make use of statutory provisions allowing CAFE credits to be carried forward to future model years, carried back from future model years, transferred between regulated fleets, and traded with other manufacturers. Manufacturers are never certain about future plans, but they spend considerable effort developing them.

For every model that appears in the MY 2020 analysis fleet, we have estimated the model years in which future redesigns (and less significant "freshenings," which offer manufacturers the opportunity to make less significant changes to models) will occur. These appear in the market data file for each model variant. Mid-cycle freshenings provide additional opportunities to add some technologies in years where smaller shares of a manufacturer's portfolio are scheduled to be redesigned. Further, our analysis accounts for the potential that manufacturers could earn CAFE credits in some model years and use those credits in later model years, thereby providing another compliance option in years with few planned redesigns. Finally, it should be noted that today's analysis does not account for future new products (or discontinued products) – past trends suggest that some years in which an OEM had few redesigns may have been years when that OEM introduced significant new products. Such changes in product offerings can obviously be important to manufacturers' compliance positions, but cannot be systematically and transparently accounted for with a fleet forecast extrapolated forward ten or more years from a largely-known fleet. While manufacturers' actual plans reflect intentions to discontinue some products and introduce others, those plans are considered confidential business information (CBI), and non-industry commenters have argued strongly in the past that our reliance on this information for building analysis fleets was detrimental to their ability to comment meaningfully. Some non-industry commenters also suggested that manufacturers' actual plans led past analyses to produce unrealistically high estimates of manufacturers' compliance costs, insofar as manufacturers' plans to apply some technologies may have reflected smaller fuel consumption impacts than indicated by inputs to our analysis. Further research would be required in order to determine whether and, if so how, it would be practicable to simulate such decisions, especially without relying on CBI.

3.2.2.2 Component Sharing and Inheritance (Engines, Transmissions, and Platforms)

In practice, manufacturers are limited in the number of engines and transmissions that they produce. Typically, a manufacturer produces a relatively small number of engines and tunes them for slight variants in output for a variety of car and truck applications. Manufacturers limit

[21] Analogously, a previous court decision found that NHTSA's uncertainty about the SC-GHG was not a basis to exclude the SC-GHG from the agency's benefit-cost analysis. CBD v. NHTSA, 538 F.3d 1172, 1191-94 (9th Cir. 2008).

complexity in their engine portfolio for much the same reason as they limit complexity in vehicle variants: they face engineering human resource limitations, and supplier, production, and service costs that scale with the number of unique parts produced.

Prior to the 2016 Draft Technical Assessment Report (TAR), the CAFE Model simulated the application of engine and transmission technologies to individual vehicle models in a manner potentially leading to solutions that would, if followed, create many more unique engines and transmissions than exist in the current portfolio for a given manufacturer (perhaps five to ten times as many). This multiplicity did not account for costs associated with such increased complexity in the product portfolio, and represented a likely unrealistic diffusion of products, as manufacturers have been consolidating global production to increasingly smaller numbers of shared engines and platforms.[22] The lack of a constraint in this area allowed the model to apply different levels of technology to the engine in each vehicle in which it was present at the time that vehicle was redesigned or refreshed, independent of what was done to other vehicles using an identical engine.

One previous CAFE Model peer reviewer commented, "The integration of inheritance and sharing of engines, transmissions, and platforms across a manufacturer's light-duty fleet and separately across its light-duty truck fleet is standard practice within the industry."[23] Recognizing this previous shortcoming, the current version of the CAFE Model, engines (and transmissions) that are shared between vehicles are treated as applying the same levels of technology over time, consistent with engine (or transmission) inheritance. This shared adoption is referred to as "engine inheritance" in the model documentation. In practice, the CAFE Model first chooses an "engine leader" among vehicles sharing the same engine[24] – the vehicle with the highest nameplate sales in MY 2020. If there is a tie, the vehicle with the highest (sales-weighted) average MSRP is chosen, assuming that manufacturers will choose to pilot the newest technology on premium vehicles if possible. The model applies the same logic with respect to the application of transmission changes. After the CAFE Model modifies the engine on the "engine leader" (or transmission on the "transmission leader") when that vehicle model is expected to be redesigned, the changes to that engine propagate through to the other vehicles that share that engine (or transmission) in subsequent years as those vehicles are redesigned. As mentioned above, these modeling procedures reflect standard industry practices and, therefore, increase the model's ability to arrive at technology pathways that, if not predictive of manufacturers' actual decisions, could nevertheless be realistic and practicable (given the focus on the U.S. market). DOT has modified the CAFE Model to provide additional flexibility vis-à-vis product cadence. While engine redesigns are only applied to the engine leader when it is redesigned in the model, followers may now inherit upgraded engines (that they share with the leader) at either refresh or redesign. All transmission changes, whether upgrades to the "leader"

[22] National Research Council. 2015. *Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-Duty Vehicles*. Washington, DC: The National Academies Press. https://doi.org/10.17226/21744, pp. 258-259, (Accessed: February 14, 2022).

[23] https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/812590-cafe-peer-review.pdf, p. 8, (Accessed: February 14, 2022).

[24] The model will not consider a vehicle designated as a ZEV candidate to be an engine or transmission leader (though it may, and likely will, choose a different model variant of the same nameplate when appropriate).

or inheritance to "followers" can occur at refresh as well as redesign. This provides additional opportunities for technology diffusion within manufacturers' product portfolios.

While "follower" vehicles are awaiting redesign, they carry a legacy version of the shared engine or transmission. As one peer reviewer previously stated, "Most of the time a manufacturer will convert only a single plant within a model year. Thus, both the 'old' and 'new' variant of the engine (or transmission) will be produced for a finite number of years." The CAFE Model currently carries no additional cost associated with producing both earlier revisions of an engine and the updated version simultaneously. Further research would be needed to determine whether sufficient data exist to specify explicitly and apply additional costs involved with continuing to produce an existing engine or transmission for some vehicles that have not yet progressed to a newer version.

There are some logical consequences of this approach, the first of which is that forcing engine and transmission changes to propagate through to other vehicles in this way effectively controls the pace at which new technology can be applied and limits the total number of unique engines that the model simulates. In the past, we used "phase-in caps" to limit the amount of technology that can be applied to a manufacturer's fleet in a given year. However, by explicitly tying the engine changes to a specific vehicle's product cadence, rather than letting the timing of changes vary across all the vehicles that share an engine, the model ensures that the design of an engine is only modified when its leader is redesigned (at most). Given that most vehicle redesign cycles are 5-8 years, this approach still represents shorter average lives than most engines in the market (which tend to be in production for eight to ten years or more). It is also the case that vehicles which share an engine in the analysis fleet (MY 2020, for this analysis) are assumed to share that same engine throughout the analysis – unless one or both of them are converted to power-split hybrids (or farther) on the electrification path. The market will likely produce a different outcome; a given manufacturer will more likely choose an engine from among the engines it produces to fulfill the efficiency and power demands of a vehicle model upon redesign. That engine need not be from the same family of engines as the prior version of that vehicle. This is a simplifying assumption in our model. While the model already accommodates detailed inputs regarding redesign schedules for specific vehicles, and commercial information sources are available to inform these inputs, further research would be needed to determine whether design schedules for specific engines and transmissions can practicably be simulated.

The CAFE Model has implemented a similar structure to address shared vehicle platforms. The term "platform" is used loosely in industry, but generally refers to a common structure shared by a group of vehicle variants. The degree of commonality varies, with some platform variants exhibiting traditional "badge engineering" where two products are differentiated by little more than insignias (e.g., the GMC Sierra and Chevrolet Silverado), while other platforms may be used to produce a broad suite of vehicles that bear little outer resemblance to one another.

Given the degree of commonality among variants of a single platform, manufacturers cannot practicably apply any given technology to any given vehicle: while some technologies (e.g., low rolling resistance tires [ROLL20]) are very nearly "bolt-on" technologies, others involve substantial changes to the structure and design of the vehicle, and therefore inevitably are constant among vehicles that share a common platform. As a result, for example, the CAFE Model forces all mass reduction technologies to be constant among variants of a platform.

Within the analysis fleet, each vehicle is associated with a specific platform. Similar to the application of engine and transmission technologies, the CAFE Model defines a platform "leader" as the vehicle variant of a given platform that has the highest level of observed mass reduction present in the analysis fleet. If there is a tie, the CAFE Model chooses the vehicle with the highest sales volume in MY 2020. If there remains a tie, the model begins by choosing the vehicle with the highest MSRP in MY 2020. As the model applies technologies, it effectively levels up all variants on a platform to the highest level of mass reduction technology on the platform. So, if the platform leader is already at MR3 in MY 2020, and a "follower" starts at baseline mass (MR0) in MY 2020, the follower will get MR3 at its next redesign (unless the leader is redesigned again before that time, and further increases the MR level associated with that platform, then the follower would receive the new MR level).

3.2.2.3 Phase-In Caps

The CAFE Model retains the ability to use phase-in caps (specified in model inputs) as proxies for a variety of practical restrictions on technology application. Unlike vehicle-specific restrictions related to redesign, refreshes or platforms/engines, phase-in caps constrain technology application at the vehicle manufacturer level for a given model year. Since the use of phase-in caps has been de-emphasized and manufacturer technology deployment remains tied strongly to estimated product redesign and freshening schedules, technology penetration rates may jump more quickly as manufacturers apply technology to high-volume products in their portfolio. As a result, the model will ignore a phase-in cap to apply inherited technology to vehicles on shared engines, transmissions, and platforms.

In previous CAFE rulemakings, redesign/refresh schedules and phase-in caps were the primary mechanisms to reflect an OEM's limited pool of available resources during the rulemaking time frame and the years preceding it, especially in years when many models may be scheduled for refresh or redesign. However, the representation of platform-, engine-, and transmission-related considerations discussed above augment the model's preexisting representation of redesign cycles, and eliminate the need to rely on phase-in caps. By design, restrictions that enforce commonality of mass reduction on variants of a platform, and those that enforce engine and transmission inheritance, will result in fewer vehicle-technology combinations in a manufacturer's future modeled fleet. The integration of shared components and product cadence as a mechanism to control the pace of technology application also more accurately represents each manufacturer's unique position in the market and its existing technology footprint, rather than a technology-specific phase-in cap that is uniformly applied to all manufacturers in a given year. The only significant application of phase-in caps in this analysis governs the rate at which lower-range battery electric vehicles (BEVs) can be absorbed by the new vehicle market (see full discussion in TSD Chapter 3.3.3.4). While the caps increase over time, the values in this analysis reflect an expectation of limited demand for the *lowest range* BEVs, even after BEVs reach price parity with comparable internal combustion engine (ICE) vehicles.

3.2.2.4 Interactions between Regulatory Classes

The current CAFE Model simulates integrated compliance strategies spanning different regulatory classes, accounting both for standards that apply separately to different classes and for interactions between regulatory classes. Light vehicle CAFE (and GHG) standards are specified separately for passenger cars and light trucks.[25] However, there is considerable sharing between these two regulatory classes – where a single engine, transmission, or platform can appear in both the passenger car and light truck regulatory class. For example, some sport-utility vehicles are offered in 2WD versions classified as passenger cars and 4WD or all-wheel drive (AWD) versions classified as light trucks (but have identical powertrains). As crossover vehicles have grown in popularity, a growing share of new vehicle sales accrue to nameplates that have model variants in each of the regulatory classes. Integrated analysis of manufacturers' passenger car and light truck fleets provides the ability to account for such sharing and reduces the likelihood of finding solutions that could involve introducing potentially impractical levels of complexity in manufacturers' product lines. Additionally, integrated fleet analysis provides the ability to simulate the potential that manufacturers could earn CAFE (or GHG) credits by over-complying with the standard in one fleet and use those credits toward compliance with the standard in another fleet (i.e., to simulate credit transfers between regulatory classes).

While both EPA's GHG standards and the California Framework Agreements distinguish between passenger cars and light trucks, the CAFE Model includes a further distinction that is necessary to capture the compliance requirements of the CAFE program, which requires that manufacturers meet a separate minimum standard for domestically manufactured passenger cars: capturing the difference between passenger cars classified as domestic passenger cars and those classified as imports. The CAFE program regulates those passenger cars separately,[26] and the CAFE Model simulates all three CAFE regulatory classes separately: Domestic Passenger Cars (DC), Imported Passenger Cars (IC), and Light Trucks (LT) – as well as the combined "passenger car" and "light truck" classes of the GHG programs.

CAFE regulations state that standards, fuel economy levels, and compliance are all calculated separately for each class. This level of accounting imposes two additional constraints on manufacturers that sell vehicles in the United States: (1) the domestic minimum floor; and (2) limited transfers between cars classified as "domestic" and those classified as "imported." The domestic minimum floor creates a threshold that every manufacturer's domestic car fleet must exceed without the application of CAFE credits other than those earned in that specific fleet.[27] If a manufacturer's calculated standard is below the domestic minimum floor, then the domestic floor is the binding constraint (even for manufacturers that are assumed to be willing to pay civil penalties for non-compliance). The second constraint poses challenges for manufacturers that sell cars from both the domestic and imported passenger car categories. While the earliest versions of the CAFE Model considered those fleets as a single fleet (i.e., passenger cars), the model currently requires them to comply separately and limits the volume of credits that can be shifted between them for compliance, per the statutory prohibition mentioned above.

3.2.3 Representing Credits and Civil Penalties

EPCA requires that if a fleet does not achieve the CAFE levels required by standard applicable in a given model year, and the manufacturer does not apply compliance credits sufficient to cover the shortfall, the manufacturer must pay a civil penalty to the Federal Government. Some

[25] 49 U.S.C. 32902.
[26] 49 U.S.C. 32902, 32904.
[27] 49 U.S.C. 32903(f)(2), (g)(4).

manufacturers have, in effect, treated this as a compliance flexibility for some fleets in some model years. When considering technology applications to improve fleet fuel economy, the model will add technology up to the point at which compliance is achieved or, depending on inputs regarding the manufacturer's willingness to pay civil penalties and/or apply technology beyond that needed for compliance, the effective cost of the technology (which includes technology cost, consumer fuel savings, and the reduced cost of civil penalties for non-compliance with the standard) is greater than zero. The current implementation further acknowledges that some manufacturers experience transitions between product lines where they rely heavily on credits (either carried forward from earlier model years or acquired from other manufacturers), or simply pay penalties in one or more fleets for some number of years. The model allows the user to specify, on a year-by-year basis, whether each manufacturer should be treated as willing to pay civil penalties for non-compliance. This assumption can be considered as a method to allow a manufacturer not to comply with its standard in some model years, thus treating the civil penalty rate and payment option as a proxy for other actions it may take that are not represented in the CAFE Model, including purchasing credits from another manufacturer or carrying-back credits from future model years.[28]

The first year simulated in this analysis is MY 2020, and each manufacturer begins the simulation with an existing credit position. In the context of CAFE compliance, each manufacturer may have surplus credits – either earned through over-compliance with its own standard or purchased from a competitor – that are specific to both the fleet and model year in which they were earned. CAFE credits may be carried forward for up to five model years, after which they expire.[29] In this analysis, manufacturers with credits earned in MY 2015 may carry them forward into MY 2020 to offset a compliance deficit. The initial banks of credits may include credits that were purchased from other manufacturers, but that have not yet been applied to resolve deficits. In these cases, the credit values have been adjusted[30] to reflect the manufacturer, fleet, and model year banks in which they reside (in the inputs). As this analysis also includes the simultaneous simulation of compliance with GHG standards, starting GHG banks are also relevant to the analysis.[31] Regardless of which program is being simulated (or which compliance metrics are being calculated), the CAFE Model always attempts to apply expiring credits before applying additional technology that is not cost-effective.

In the current analysis, we have relied on past compliance behavior, current compliance positions across fleets, and certified transactions in the credit market to designate some manufacturers as being willing to pay civil penalties (recognizing that this treatment could be a proxy for purchasing credits from competitors) in some model years. The analysis assumes that *all* manufacturers will make extensive use of these compliance flexibilities in MYs 2020-2023, but

[28] DOT staff expect to continue investigating the potential to expand the CAFE Model's representation of provisions regarding compliance credit transfers and trades.
[29] 49 U.S.C. 32903(a).
[30] Credits acquired from other manufacturers are adjusted in the CAFE program to account for differences in standard, fuel economy, fleet, and model year between the company that originally earned the credits and the company that applies them to resolve a compliance deficit. The adjustment works the same for credit transfers between fleets within a single manufacturer's portfolio, and the CAFE Model computes and applies these adjustments dynamically for credits earned and transferred during the simulation.
[31] For manufacturers who have agreed to California Framework Agreements, the CAFE Model treats the existing EPA credit banks as if that program applies nationally and existing credit banks are used consistently with that approach.

that only some manufacturers (BMW, Daimler, Fiat Chrysler Automobiles [FCA], Jaguar Land Rover [JLR], Volvo, and Volkswagen [VW]) will continue to do so in subsequent analysis years. As in past analyses, this assumption for these manufacturers is based, again, on these manufacturers' past compliance behavior. Of those six manufacturers, half (BMW, Volvo, and VW) have committed to greater emission reductions during this time period through the Framework Agreements. As a result of the technologies they are expected to apply to meet those voluntary commitments, some of which will also deliver fuel economy benefits, they are likely to exceed their CAFE standard throughout the analysis, even in the early years, in the process of complying with the California Agreements. While the flexibility exists within the model inputs, the CAFE Model will enforce the relevant (and binding) standard in each year. A full discussion of manufacturers' starting credit positions and behavior with respect to civil penalties is presented in TSD Chapters 2.2.2.3 and 2.2.2.4, respectively.

3.2.4 Representing Fuel-Saving Technology

While some properties of the technologies included in the analysis are specified by the user (e.g., cost of the technology), the set of included technologies is part of the model itself, which contains the information about the relationships between technologies. In particular, the CAFE Model contains the information about the sequence of technologies, the paths on which they reside, any prerequisites associated with a technology's application, and any exclusions that naturally follow once it is applied.

When simulating manufacturers' compliance actions, the application of these technologies across vehicle offerings represents the primary pathway by which manufacturers improve their compliance position. Some of these technologies represent minor modifications to vehicles that can be undertaken at any time (for example, upgrading a vehicle's tires to reduce rolling resistance), while others require more substantial changes to vehicles and must therefore occur during vehicle redesigns (or less substantial "refreshes"). Table 3-1 lists the engine technologies that are available in the model and the restrictions on application. The "application level" describes the system of the vehicle to which the technology is applied, which in turn determines the extent to which that decision affects other vehicles in a manufacturer's fleet. For example, if a technology is applied at the "engine" level, it necessarily affects all other vehicles that share that same engine (though not until they themselves are redesigned, if it happens to be in a future model year). Technologies applied at the "vehicle" level can be applied to a vehicle model without impacting the other models with which it shares components. Platform-level technologies affect all of the vehicles on a given platform, which can easily span technology classes, regulatory classes, and redesign cycles.

The "application schedule" identifies when manufacturers are assumed to be able to apply a given technology – with many available only during vehicle redesigns. The application schedule also accounts for which technologies the CAFE Model tracks, but does not apply. These enter as part of the analysis fleet ("Baseline Only"), and while they are necessary for accounting related to cost and incremental fuel economy improvement, they do not represent a choice that manufacturers make in the model. Technologies that are assigned to "refresh/redesign" can be applied at either a refresh or redesign, while technologies that are assigned to "redesign" can only be applied during a significant vehicle redesign. A brief examination of the tables shows that most technologies are only assumed to be available during a vehicle redesign – and all engine improvements are assumed to be available only during redesign. In a departure from past CAFE analyses, all transmission improvements are assumed to be available during refresh as well as redesign. While there are past and recent examples of mid-cycle product changes, we expect that manufacturers will tend to attempt to keep engineering and other costs down by applying most major changes mainly during vehicle redesigns, and some mostly modest changes during product freshenings.

Table 3-1 – Engine Technologies in the CAFE Model

Technology	Application Level	Application Schedule	Description
SOHC	Engine	Baseline Only	Single Overhead Camshaft Engine
DOHC	Engine	Baseline Only	Double Overhead Camshaft Engine
EFR	Engine	Redesign Only	Engine Friction Reduction
VVT	Engine	Redesign Only	Variable Valve Timing
VVL	Engine	Redesign Only	Variable Valve Lift
SGDI	Engine	Redesign Only	Stoichiometric Gasoline Direct Injection
DEAC	Engine	Redesign Only	Cylinder Deactivation
TURBO1	Engine	Redesign Only	Turbocharging and Downsizing, Level 1 (1.5271 bar)
TURBO2	Engine	Redesign Only	Turbocharging and Downsizing, Level 2 (2.0409 bar)
CEGR1	Engine	Redesign Only	Cooled Exhaust Gas Recirculation, Level 1 (2.0409 bar)
ADEAC	Engine	Redesign Only	Advanced Cylinder Deactivation
HCR0	Engine	Redesign Only	High Compression Ratio Engine, Level 0
HCR1	Engine	Redesign Only	High Compression Ratio Engine, Level 1
HCR1D	Engine	Redesign Only	High Compression Ratio Engine, Level 1 with DEAC
HCR2	Engine	Redesign Only	High Compression Ratio Engine, Level 2
VCR	Engine	Redesign Only	Variable Compression Ratio Engine
VTG	Engine	Redesign Only	Variable Turbo Geometry
VTGE	Engine	Redesign Only	Variable Turbo Geometry (Electric)
TURBOD	Engine	Redesign Only	Turbocharging and Downsizing with DEAC
TURBOAD	Engine	Redesign Only	Turbocharging and Downsizing with ADEAC
ADSL	Engine	Redesign Only	Advanced Diesel
DSLI	Engine	Redesign Only	Diesel Engine Improvements
DSLIAD	Engine	Redesign Only	Diesel Engine Improvements with ADEAC
CNG[32]	Engine	Baseline Only	Compressed Natural Gas Engine

Table 3-2 displays the remaining technologies available in the CAFE Model. These cover upgrades to transmissions, electrification, and body-level technologies that reduce road load.

[32] While the CAFE Model recognizes CNG vehicles, it does not create new ones. In the model year 2020 market, there are no light-duty CNG vehicles. Hence, there are none in this analysis.

Unlike engine technologies, the CAFE Model will build and apply new transmissions at either refresh or redesign. In the case of engines, a vehicle may only inherit a new version during a refresh, rather than producing an engine that is new to the manufacturer's portfolio. This distinction allows transmission technology to permeate the new vehicle fleet much faster, and lowers the cost of improving fuel economy in most cases. While electrification technologies are only available at redesign, they are applied at the "vehicle level." In practice, this means that the CAFE Model can choose to apply higher levels of electrification to individual rows of the market data file (where a model variant may represent only a few thousand units of sales), rather than the larger scale implications of changes to powertrains that are broadly shared across a manufacturer's portfolio. In addition to moderating compliance costs, this level of application also preserves variation in each manufacturer's portfolio (where making significant changes to a smaller number of units can sometimes be a more cost-effective compliance pathway than making more modest changes throughout the portfolio) and enables manufacturers to comply with standards more precisely during years in which they are constrained.

Table 3-2 – Other Vehicle Technologies in the CAFE Model

Technology	Application Level	Application Schedule	Description
MT5	Transmission	Baseline Only	5-Speed Manual Transmission
MT6	Transmission	Redesign Only	6-Speed Manual Transmission
MT7	Transmission	Redesign Only	7-Speed Manual Transmission
AT5	Transmission	Baseline Only	5-Speed Automatic Transmission
AT6	Transmission	Refresh/Redesign	6-Speed Automatic Transmission
AT6L2	Transmission	Refresh/Redesign	6-Speed Automatic Transmission, Level 2
AT7L2	Transmission	Baseline Only	7-Speed Automatic Transmission, Level 2
AT8	Transmission	Refresh/Redesign	8-Speed Automatic Transmission
AT8L2	Transmission	Refresh/Redesign	8-Speed Automatic Transmission, Level 2
AT8L3	Transmission	Refresh/Redesign	8-Speed Automatic Transmission, Level 3
AT9L2	Transmission	Baseline Only	9-Speed Automatic Transmission, Level 2
AT10L2	Transmission	Refresh/Redesign	10-Speed Automatic Transmission, Level 2
AT10L3	Transmission	Refresh/Redesign	10-Speed Automatic Transmission, Level 3
DCT6	Transmission	Refresh/Redesign	6-Speed Dual Clutch Transmission
DCT8	Transmission	Refresh/Redesign	8-Speed Dual Clutch Transmission
CVT	Transmission	Baseline Only	Continuously Variable Transmission
CVTL2	Transmission	Refresh/Redesign	CVT, Level 2
EPS	Vehicle	Refresh/Redesign	Electric Power Steering
IACC	Vehicle	Refresh/Redesign	Improved Accessories
CONV	Vehicle	Baseline Only	Conventional Powertrain (Non-Electric)
SS12V	Vehicle	Redesign Only	12V Micro-Hybrid (Stop-Start)
BISG	Vehicle	Redesign Only	Belt Mounted Integrated Starter/Generator
SHEVP2	Vehicle	Redesign Only	P2 Strong Hybrid/Electric Vehicle
SHEVPS	Vehicle	Redesign Only	Power Split Strong Hybrid/Electric Vehicle
P2HCR0	Vehicle	Redesign Only	SHEVP2 with HCR0 Engine
P2HCR1	Vehicle	Redesign Only	SHEVP2 with HCR1 Engine
P2HCR2	Vehicle	Redesign Only	SHEVP2 with HCR2 Engine
PHEV20	Vehicle	Redesign Only	20-mile Plug-In Hybrid/Electric Vehicle with HCR Engine
PHEV50	Vehicle	Redesign Only	50-mile Plug-In Hybrid/Electric Vehicle with HCR Engine
PHEV20T	Vehicle	Redesign Only	20-mile Plug-In Hybrid/Electric Vehicle with Turbo Engine

Technology	Application Level	Application Schedule	Description
PHEV50T	Vehicle	Redesign Only	50-mile Plug-In Hybrid/Electric Vehicle with Turbo Engine
PHEV20H	Vehicle	Redesign Only	PHEV20 with HCR Engine
PHEV50H	Vehicle	Redesign Only	PHEV50 with HCR Engine
BEV200	Vehicle	Redesign Only	200-mile Electric Vehicle
BEV300	Vehicle	Redesign Only	300-mile Electric Vehicle
BEV400	Vehicle	Redesign Only	400-mile Electric Vehicle
BEV500	Vehicle	Redesign Only	500-mile Electric Vehicle
FCV	Vehicle	Redesign Only	Fuel Cell Vehicle
LDB	Vehicle	Refresh/Redesign	Low Drag Brakes
SAX	Vehicle	Refresh/Redesign	Secondary Axle Disconnect
ROLL0	Vehicle	Baseline Only	Baseline Tires
ROLL10	Vehicle	Refresh/Redesign	Low Rolling Resistance Tires, Level 1 (10% Reduction)
ROLL20	Vehicle	Refresh/Redesign	Low Rolling Resistance Tires, Level 2 (20% Reduction)
AERO0	Vehicle	Baseline Only	Baseline Aero
AERO5	Vehicle	Redesign Only	Aero Drag Reduction, Level 1 (5% Reduction)
AERO10	Vehicle	Redesign Only	Aero Drag Reduction, Level 2 (10% Reduction)
AERO15	Vehicle	Redesign Only	Aero Drag Reduction, Level 3 (15% Reduction)
AERO20	Vehicle	Redesign Only	Aero Drag Reduction, Level 4 (20% Reduction)
MR0	Platform	Baseline Only	Baseline Mass
MR1	Platform	Redesign Only	Mass Reduction, Level 1 (5% Reduction in Glider Weight)
MR2	Platform	Redesign Only	Mass Reduction, Level 2 (7.5% Reduction in Glider Weight)
MR3	Platform	Redesign Only	Mass Reduction, Level 3 (10% Reduction in Glider Weight)
MR4	Platform	Redesign Only	Mass Reduction, Level 4 (15% Reduction in Glider Weight)
MR5	Platform	Redesign Only	Mass Reduction, Level 5 (20% Reduction in Glider Weight)
MR6	Platform	Redesign Only	Mass Reduction, Level 6 (28.2% Reduction in Glider Weight)

These technologies are grouped into paths in the CAFE Model that represent logical progressions along each set of technologies within a vehicle subsystem. Figure 3-1 displays the paths that a vehicle may traverse while improving the fuel efficiency of its engine in the CAFE Model. Each large box represents engine technologies that are grouped together, and arrows between boxes denote a sequential progression between technologies. For example, when considering the technologies in the turbocharging path, the CAFE Model will consider turbocharging and downsizing, level 1 (TURBO1), then turbocharging and downsizing, level 2 (TURBO2), and finally cooled exhaust gas recirculation, level 1 (2.0409 bar) (CEGR1). Within any system, the sub-paths themselves are mutually exclusive: a vehicle only has one engine, and so can have only one type of advanced engine. Along the basic engine path, this is not the case; variable valve lift (VVL), SGDI, and cylinder deactivation (DEAC) can be applied in any order and in any combination. Once the model progresses past the basic engine path, it considers all of the more advanced engine paths (Turbo, Adv. Turbo, variable compression ratio engine [VCR], variable turbo geometry [VTG], HCR, Diesel, and advanced cylinder deactivation [ADEAC]) simultaneously. Once one path is taken, it locks out the others to avoid situations where the model could be perceived to force manufacturers to change engine architecture radically with each redesign, incurring stranded capital costs and lost opportunities for learning. While this keeps each given engine focused on a path expected to limit stranded capital costs and maximize opportunities for cost learning, the CAFE Model is still able to choose different paths for different engines.

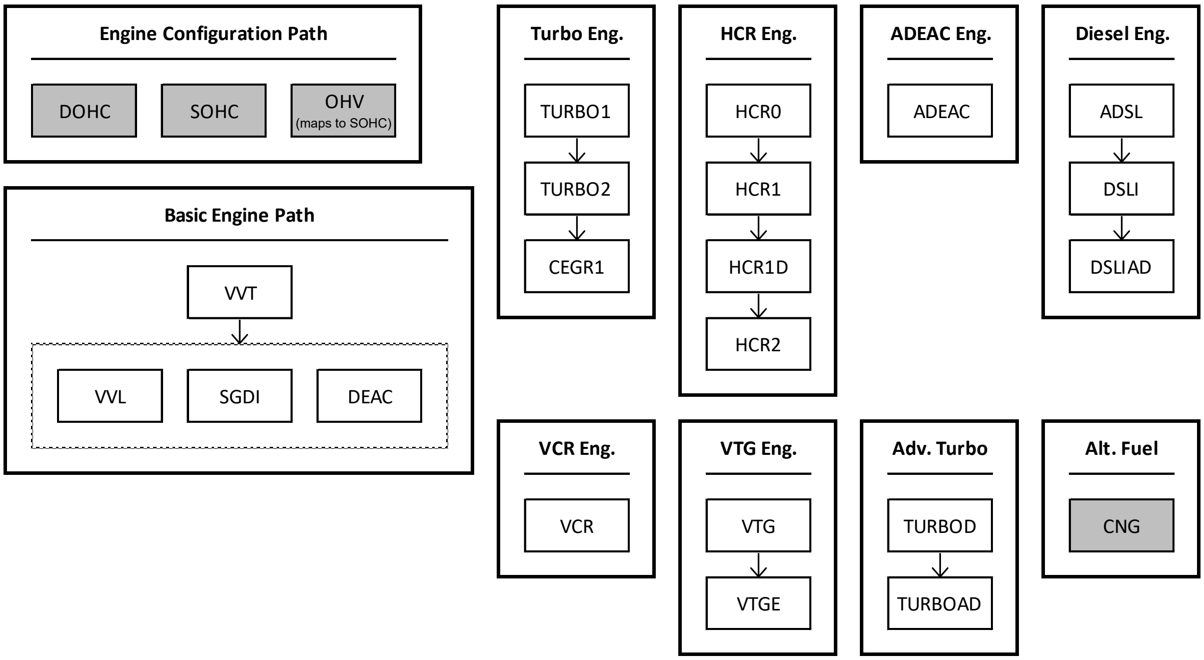

Figure 3-1 – Engine Technology Paths in the CAFE Model

The electrification paths appear in Figure 3-2 as three discrete paths. The electric improvements path (that includes electric power steering [EPS] and accessory improvements, IACC) are considered pre-requisites for further progress down either the basic electrification path or the path consisting of hybrids and beyond. The sequence of hybrids on the far right of the figure reflects (parallel) strong hybrid systems paired with HCR engines, which can be less expensive than other engines and match well in hybrid systems. These nodes exist so that vehicles that currently have another advanced engine can change that engine for a HCR engine, as long as it is paired with a strong hybrid system. The two strong hybrid systems represent two different types of hybrids – the power split system, the power split hybrid/electric vehicle (SHEVPS), and the parallel system, P2 strong hybrid/electric vehicle (SHEVP2). While the power split system has a dedicated (Atkinson) engine in the CAFE Model, the parallel hybrid system may be paired with (almost) any of the engine technologies.

Like other paths, the CAFE Model considers electrification technologies sequentially, but is not required to apply them that way. While the model seeks to apply the most cost-effective technology solution in each step, that solution may not be the next technology in a sequence. In those cases, it will simply bypass the lower-level electrification technologies and progress to higher degrees of electrification.

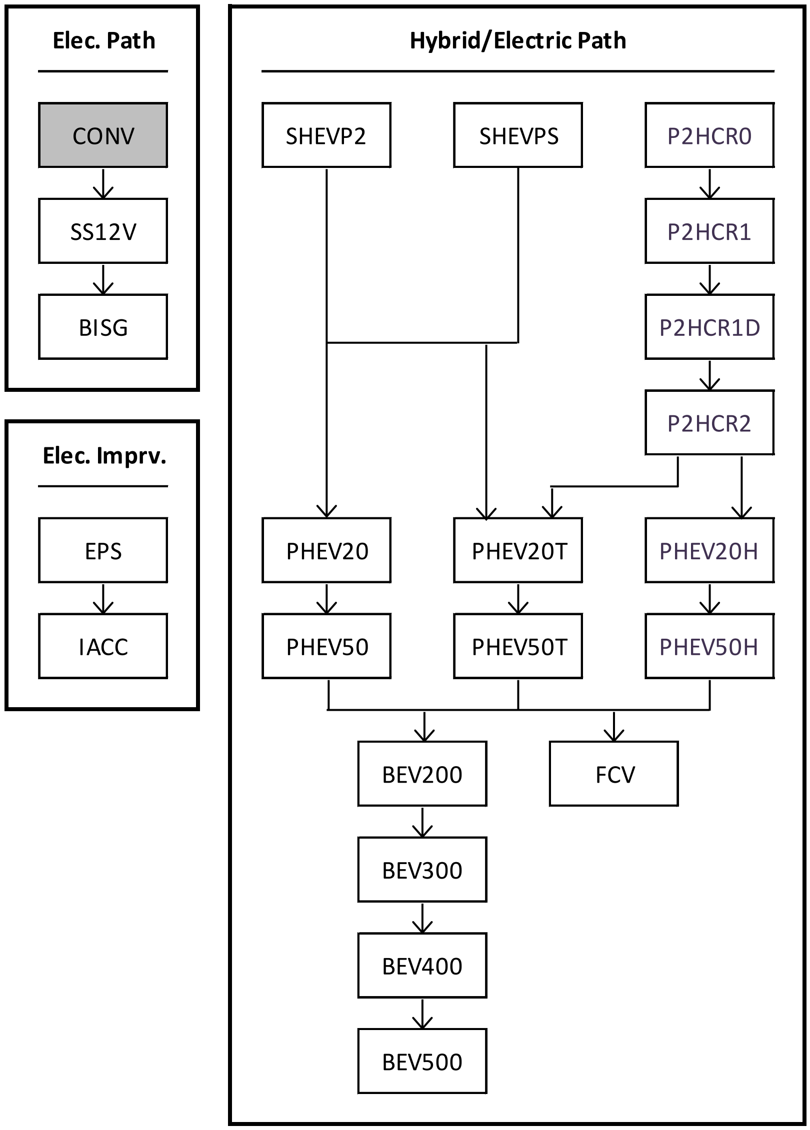

Figure 3-2 – Electrification Technology Paths in the CAFE Model

Figure 3-3 displays the transmission paths in the CAFE Model. The MT path is reserved for vehicles that enter the MY 2020 fleet with MTs already; those vehicles may progress further along the MT path, but the CAFE Model will not convert other vehicles to MTs, given that MTs are falling out of favor in the U.S. market. Similarly, vehicles that enter the model with 5-speed automatic transmissions (AT5), may progress to either dual-clutch transmissions (DCT), progress through the set of automatic transmissions, or (eventually) become advanced continuously variable transmissions (CVTs). There are three other transmissions for which the model accounts, but does not build: 7-speed automatic, level 2 (AT7L2), 9-speed automatic transmission, level 2(AT9L2), and CVT. Vehicles may enter the analysis with one of those transmissions (and many do), but they eventually evolve to either higher gear automatic transmissions or advanced CVT (continuously variable transmission, level 2 [CVTL2]), respectively.

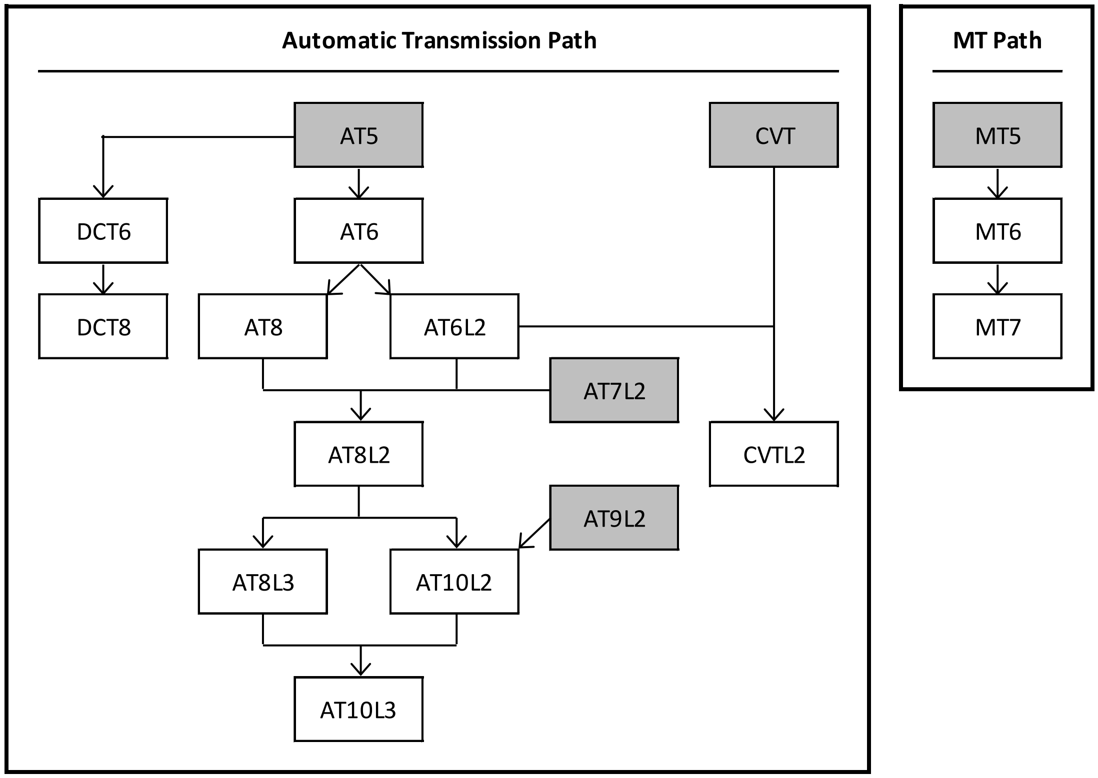

Figure 3-3 – Transmission Paths in the CAFE Model

The body-level technology paths are described in Figure 3-4, and these are generally sequential (and thus less complicated) than the other technology paths. With the exception of mass reduction, all of these technologies are applied at the vehicle level but with different availability constraints. The Dynamic Load Reduction (DLR) path and the tire rolling resistance (ROLL) path can be applied to vehicles at either refresh or redesign, while AERO (aerodynamic drag technology) improvements and MR improvements must be applied at redesign. The fact that MR improvements are applied at the platform level further reduces the frequency of their application in the model and ensures that platform redesigns occur at a reasonable pace inside the simulation.

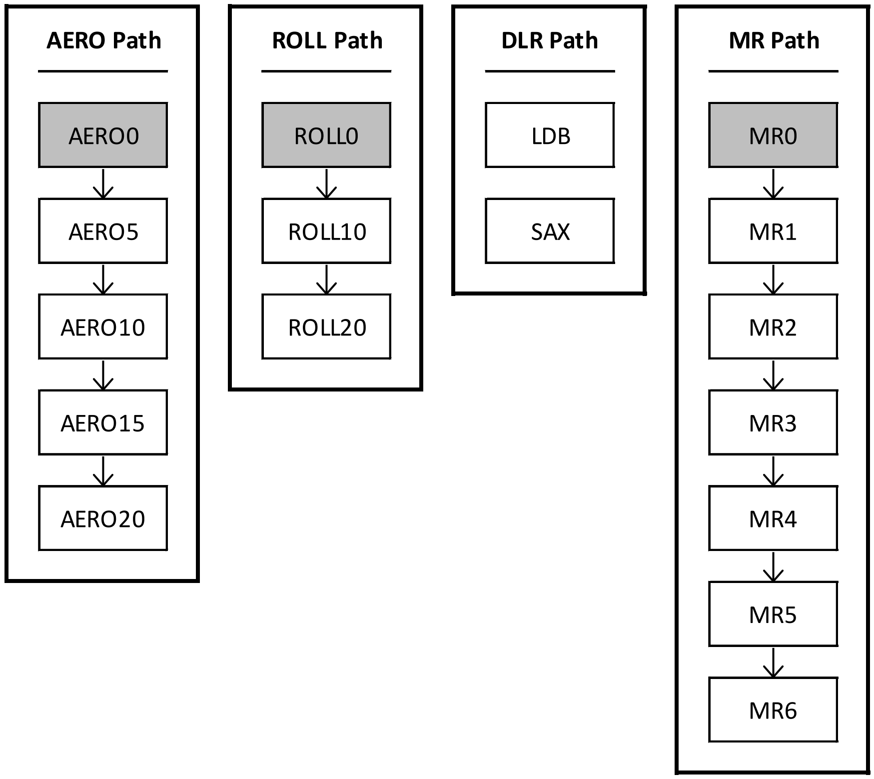

Figure 3-4 – Other Technology Paths in the CAFE

Each of the technologies described above has a cost and an effectiveness in the CAFE Model that differs based on the *technology class* in which they are applied. Technology classes are a means for specifying common technology input assumptions for vehicles that share similar characteristics. Predominantly, these classes signify the degree of applicability of each of the available technologies to a specific class of vehicles, and represent a specific set of Autonomie simulations (conducted as part of the Argonne National Lab large-scale simulation study) that determine the effectiveness of each technology to improve fuel economy. The vehicle technology classes also define, for each technology, the additional cost associated with application. The CAFE Model currently uses ten technology classes that differ by body style (see Table 3-3) and performance level (where each of the five classes in Table 3-3 has a higher performance version). Each vehicle in the MY 2020 fleet is mapped to a technology class, and that association is preserved throughout the analysis.

Table 3-3 – Technology Classes in the CAFE Model

Class	Description
SmallCar	Small passenger cars
MedCar	Medium to large passenger cars
SmallSUV	Small sport utility vehicles and station wagons
MedSUV	Medium to large sport utility vehicles, minivans, and passenger vans
Pickup	Light-duty pickups and other vehicles with ladder frame construction

3.2.4.1 Technology Effectiveness

Technology effectiveness in the CAFE Model is based on a large-scale, full vehicle simulation project with Argonne National Laboratory (and their Autonomie vehicle simulation model) that is described in detail in TSD Chapter 2.4. Unlike the earliest versions of the CAFE Model that relied on single effectiveness values for each technology and a small set of synergy factors to estimate the degree of improvement associated with a set of technologies, the Argonne project simulates each combination explicitly. Fuel economy improvement values in the CAFE Model represent a percentage change in fuel consumption relative to a common reference point, in all cases – the vehicle (in each technology class) with a base VVT engine and AT5 transmission, without any electrification or road load improvements.

One implication of this approach is that the set of technologies listed in Table 3-1 and Table 3-2 can be combined in hundreds of thousands of ways, where each technology along a given path (the engine path, for example) can be combined with a technology in each of the other paths. So, a single engine can be paired with each of the transmissions, and each of those combinations with one of the lower levels of electrification, and each of *those* combinations with varying levels of MR, and AERO, and so on. This means that each unique engine can be included in over 5,000 unique technology combinations, creating millions of unique technology combinations in each technology class. It also means that "technology effectiveness" can no longer be thought of as a single value; for a given technology, effectiveness is now a distribution over all of the combinations to which that technology can be added. How much improvement a given technology provides depends upon everything else that is already on the vehicle. While this approach makes communicating the relative effectiveness of a given technology more difficult, it also greatly improves the accuracy and realism of the analysis.

Figure 3-5 characterizes the technology effectiveness of the engine technologies in the CAFE Model. These parallel boxplots provide information about the distribution of effectiveness across all the combinations to which each technology could be applied, and this figure (like the others that follow it) combines all the technology classes into a single boxplot.[33] The shaded areas of the boxplot represent the middle 50 percent of observations, and the length of the lines extending from that box (the "whiskers") reflect the degree of dispersion in the values beyond

[33] For more detailed information about technology effectiveness, interested parties can download the full database of effectiveness values, the translated Autonomie outputs, and the report in the docket for this rulemaking, NHTSA-2021-0053.

that central block of observations.[34] Shorter boxes and whiskers reflect more tightly grouped effectiveness values, and longer whiskers indicate effectiveness values farther away from the center of the values.

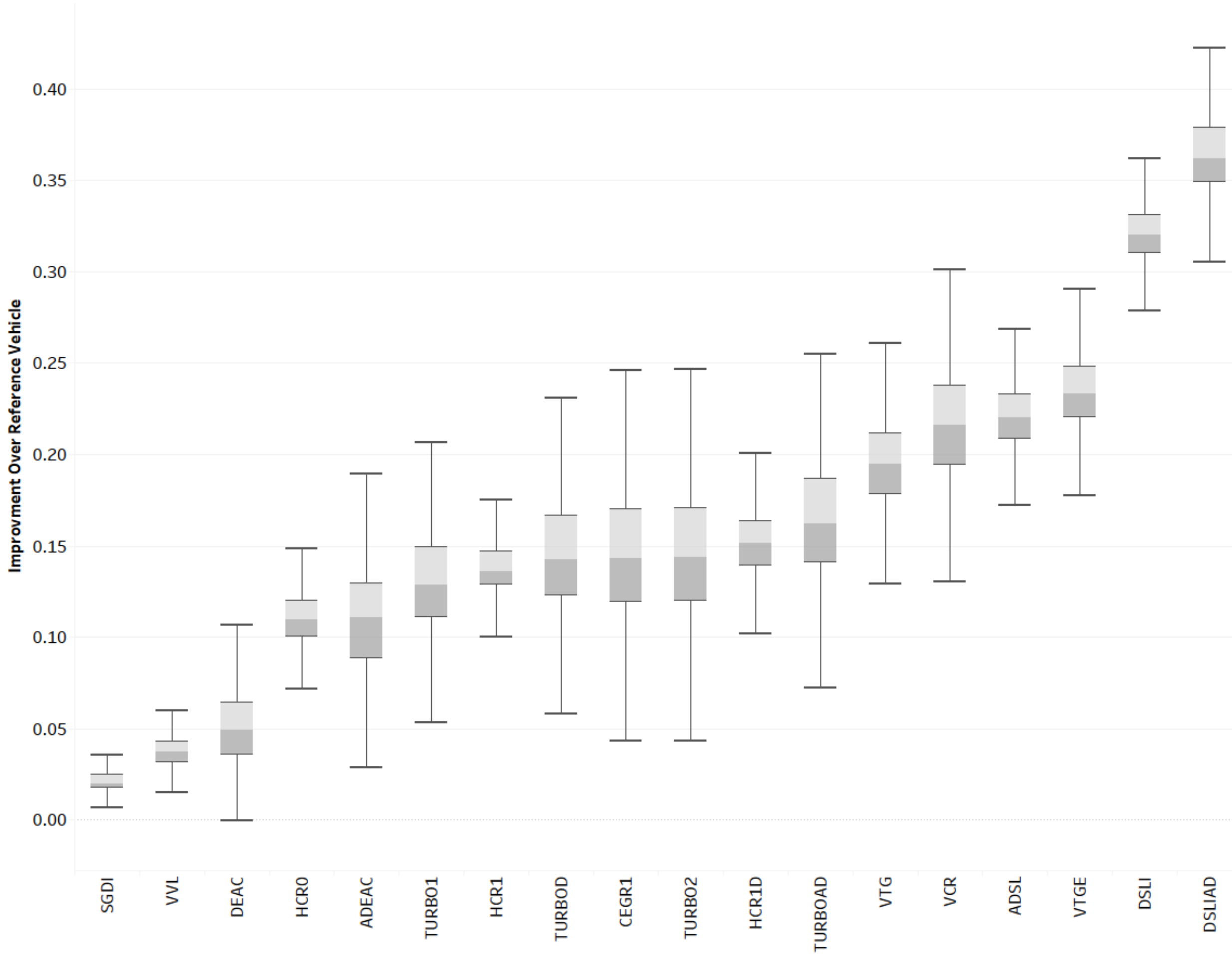

Figure 3-5 – Engine Technology Effectiveness

The boxplots have been sorted by median effectiveness and, as one would expect, the three basic engine technologies have the distributions with the smallest typical improvement over the base engine. The engines stratify into roughly three groups. The lowest level technologies (basic engine technologies and ADEAC, TURBO1, high compression ratio engine, level 0 [HCR0]) are generally between 5 and 15 percent improvement. The second group of advanced engines have effectiveness in the 10 to 20 percent improvement range. The third group is the most advanced gas engine technology and three advanced diesel (ADSL) engines (the highest of which can improve fuel economy by over 30 percent).

[34] In the case of the plots shown here, the whisker length is 1.5 times the interquartile range (the width of the shaded box).

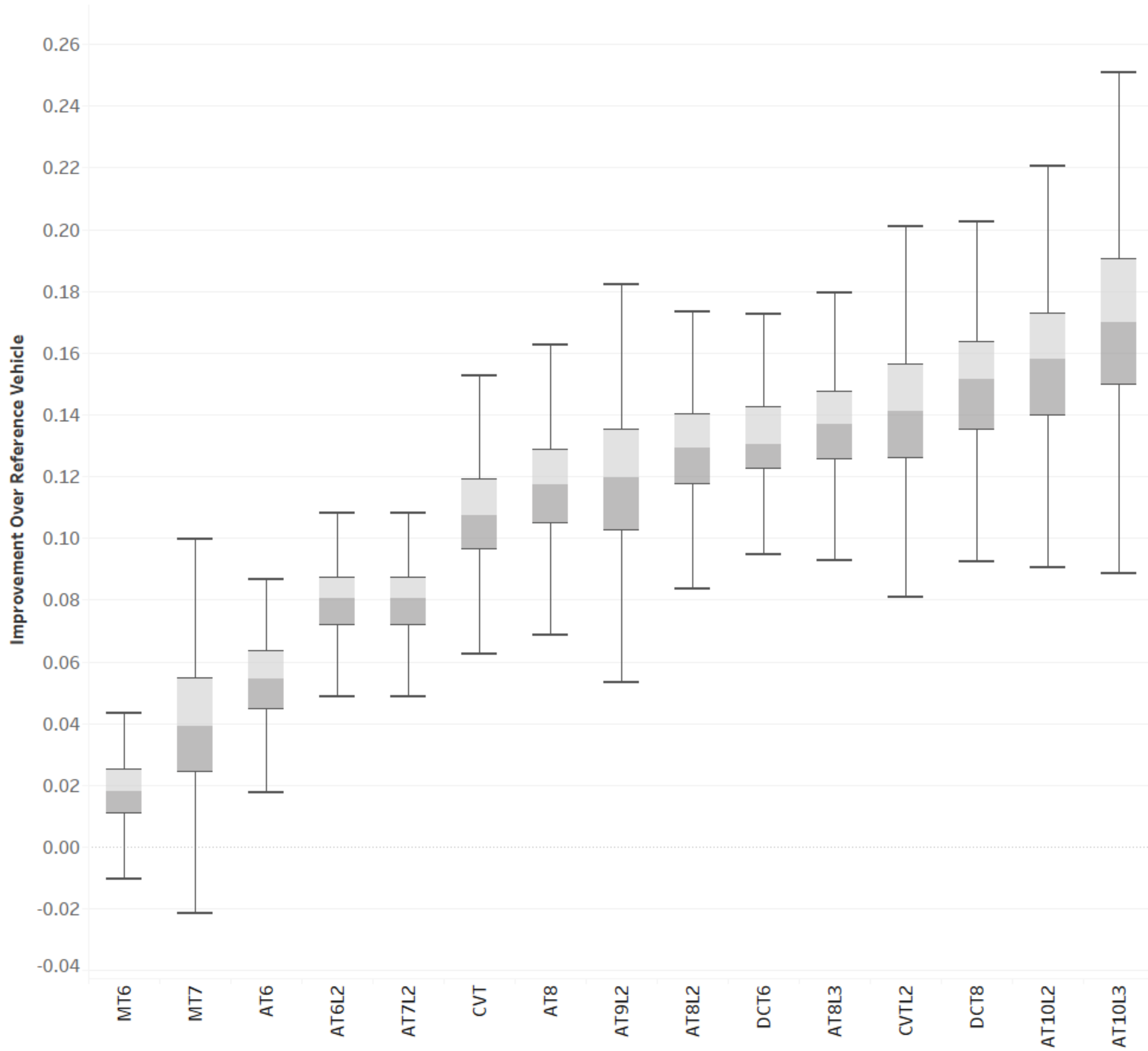

Figure 3-6 – Transmission Technology Effectiveness

Figure 3-6 illustrates the technology effectiveness of transmission technologies in the CAFE Model and, like the engine technologies, these are each distributions of effectiveness across all the combinations to which they can be applied. The lowest effectiveness is generally associated with MTs (which are applied in limited numbers in the analysis by design) and lower-gear automatic transmissions. Among automatic transmissions, effectiveness generally improves with the number of gears (and technology level, level 2 8-speed automatic transmission, AT8L2, for example). While the DCTs are among the most effective in the model, consumer acceptance in the United States has led manufacturers thus far to prefer higher gear automatic transmissions in most applications. The decision logic is structured to reflect that preference, so that only the lowest-level transmissions in the MY 2020 fleet are allowed to consider the switch to DCTs (see Figure 3-3).

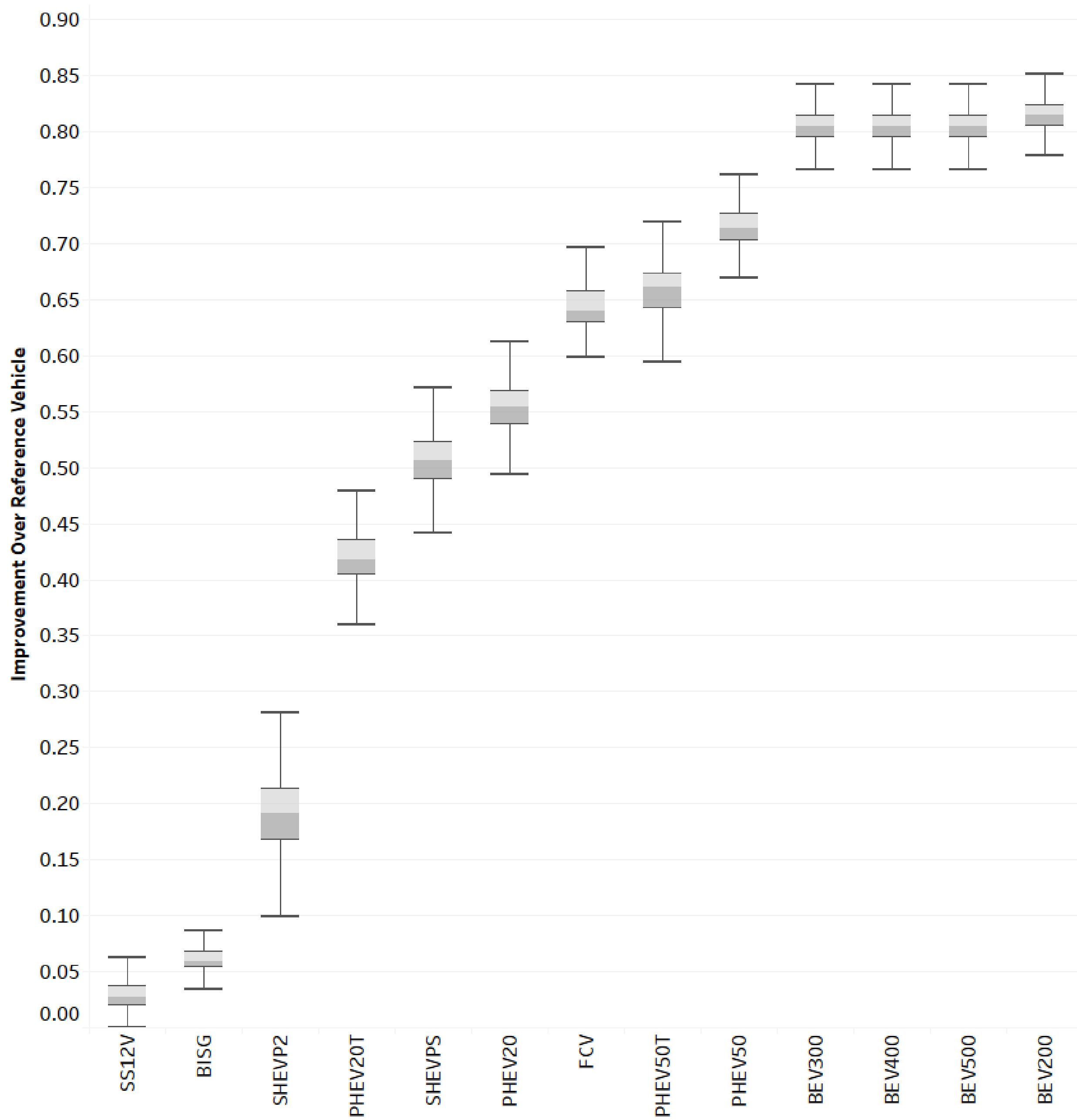

Figure 3-7 – Electrification Technology Effectiveness

The electrification technologies in Figure 3-7 are generally the most effective ways to improve fuel economy and, as Chapter 3.2.4.2 discusses, also among the most expensive. The two least transformative technologies, stop-start (12V strong hybrid/electric vehicle or SS12V) and belt integrated starter generators (BISGs), are also the least effective. However, after those two technologies, the model transitions to various degrees of hybridization. The SHEVP2 is paired with the vehicle's existing engine (or with a more advanced engine, if one is applied to the vehicle in the same model year).[35] The range in improvement shown above for SHEVP2 is on top of the improvement provided by the vehicle's existing engine. The plug-in hybrids paired with turbocharged engines are generally less effective than their Atkinson counterparts (for the same range), but may be more appropriate in higher power applications. The most effective technologies are full BEVs, of varying ranges, that can reduce the energy consumption of the reference vehicle by 80 percent or more. In the context of CAFE and GHG compliance, each of these technologies that has at least some fully electric range (as well as the fuel cell vehicle [FCV]) are heavily credited toward compliance through a variety of adjustments, ratings, and multipliers (depending upon the program). For example, in the GHG program, BEVs are treated as emitting no carbon on the test cycle (a rating of 0 grams/mile) through MY 2026. The values in Figure 3-7 represent improvements on the test cycle, but can count for considerably more improvement when considered for compliance purposes.

[35] Though not observed in today's model results, the CAFE Model could, in theory, show a vehicle adding a SHEVP2 system in the same model year the vehicle replaces an HCR2 engine with a less advanced HCR engine.

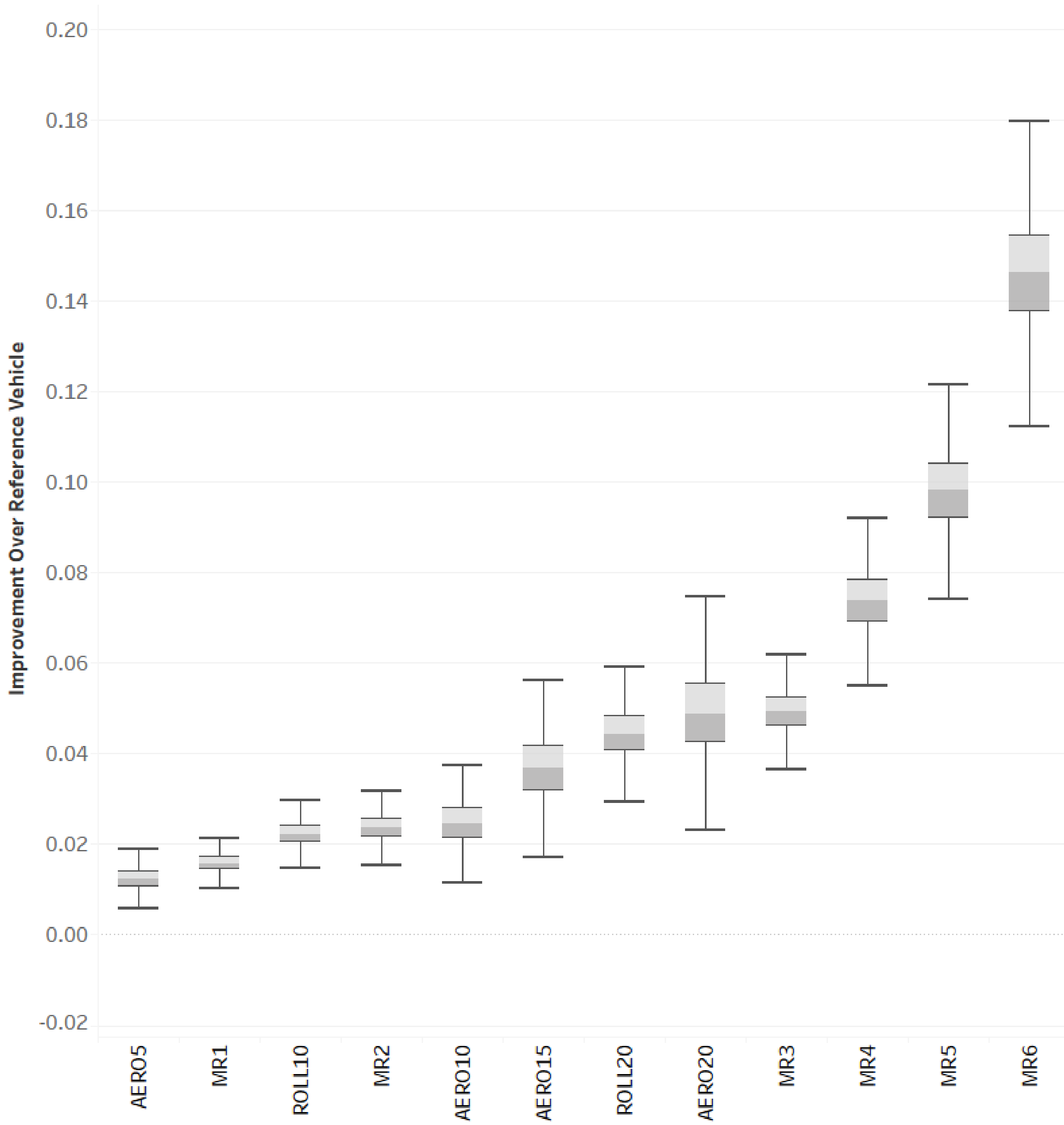

Figure 3-8 – Body-level Technology Effectiveness

The body-level technologies (related to improvements in aerodynamic drag, ROLL, and vehicle mass) are shown in Figure 3-8. As with the other graphs of technology effectiveness, the technologies are sorted by median effectiveness. One fairly consistent trend in these technologies that is not as true for the other paths is that the distribution of effectiveness tends to grow (meaning the range increases) as the median effectiveness rises. That is partially a consequence of the sequential nature of these technologies (i.e., Aero Drag Reduction, Level 1 (10 Percent Reduction) [AERO15] is naturally preceded by AERO10), but also an artifact of the portion of the test cycle affected by each change. For example, aerodynamic improvements make a larger impact on fuel economy at highway speeds than over a city driving cycle. These boxplots also represent the impact of these technologies across all ten technology classes (as they do in the other effectiveness figures), and the effectiveness of body-level technologies can scale with the size of the vehicle, further increasing the range of effectiveness values. In the case of mass reduction, some combinations will have additional optimization – in the size (and, consequently, mass) of batteries, for example – that can lead to further fuel economy improvement under higher levels of mass reduction.

3.2.4.2 Technology Cost

We estimate present and future costs for fuel-saving technologies taking into consideration the type of vehicle, or type of engine if technology costs vary by application. These cost estimates are based on three main inputs. First, direct manufacturing costs (DMCs), or the component and labor costs of producing and assembling the physical parts and systems, are estimated assuming high volume production. DMCs generally do not include the indirect costs of tools, capital equipment, financing costs, engineering, sales, administrative support or return on investment. We account for these indirect costs via a scalar markup of DMCs (the retail price equivalent, or RPE). Finally, costs for technologies may change over time as industry streamlines design and manufacturing processes. To reflect this, we estimate potential cost improvements with learning effects (LE). The retail cost of equipment in any future year is estimated to be equal to the product of the DMC, RPE, and LE. Considering the retail cost of equipment, instead of merely DMCs, is important to account for the real-world price effects of a technology, as well as market realities. Absent a government mandate, motor vehicle manufacturers will not undertake development and production efforts to implement technologies without belief that consumers would be willing to pay enough for such technology to allow for the manufacturers to recover their investment.

Technology is not applied based solely on its effectiveness; the CAFE Model considers both effectiveness and cost when choosing which technologies to apply to vehicles in order to comply with standards.

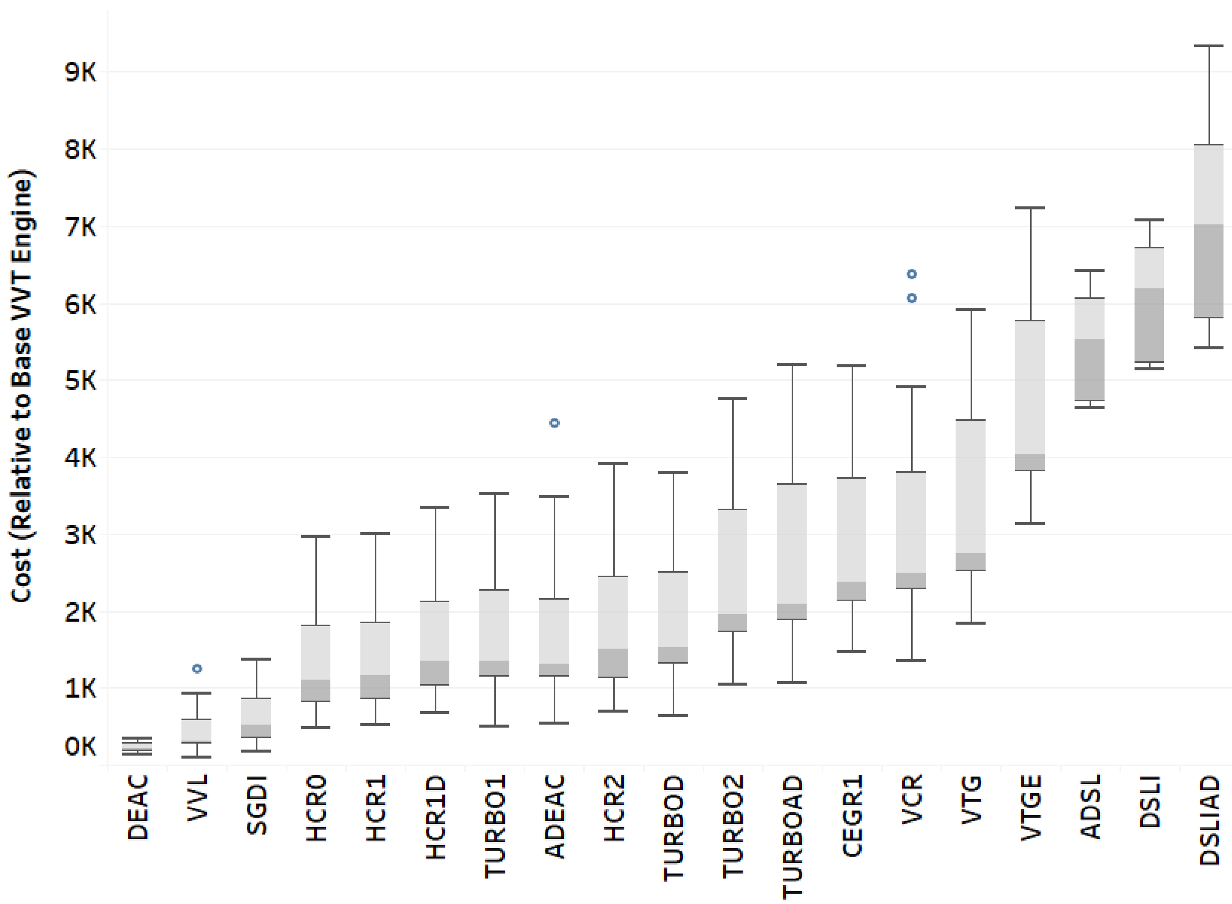

Figure 3-9 – Engine Technology Cost Distributions (Retail Price Equivalent), 2020

Figure 3-9 describes the incremental cost (over the basic VVT engine) of the engine technologies in this analysis in 2020. The cost of each engine technology varies with the size, configuration, and performance level of the engine – so the same technology will likely cost more when applied to a large engine than to a small one. This gives each engine technology a cost distribution, relative to the reference engine, over all of the possible engine sizes and configurations.[36] Consistent with Figure 3-5, describing engine technology effectiveness, the basic engine technologies improve fuel economy at the lowest cost; more common turbocharged and HCR engines have generally higher costs (across configurations); and the most advanced gas and diesel engines also carry the highest costs.

[36] For engine technologies, there are over 30 unique engine technology classes that vary in size, cam configuration, and architecture. The cost of a given engine technology may be different in each of these classes, and these differences create the distributions in the figure.

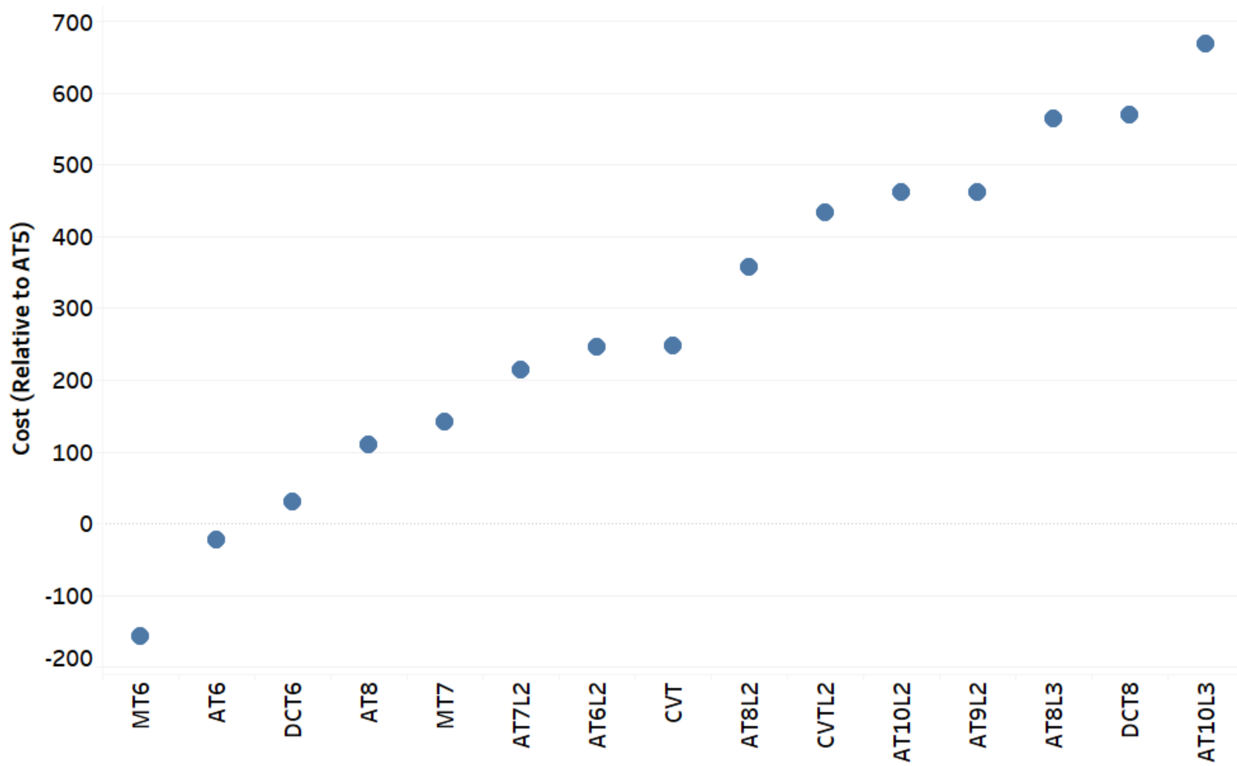

Figure 3-10 – Transmission Cost (Retail Price Equivalent), 2020

In this analysis, as Figure 3-10 illustrates, transmission costs are not distributions across either technology classes or vehicle size, but rather single cost estimates regardless of the vehicle to which they are applied. In general, cost increases with the number of transmission gears (and level of technology – L2 or L3), as does efficiency in most cases. Negative costs represent a cost savings over the reference AT5 to which these costs are incremental.

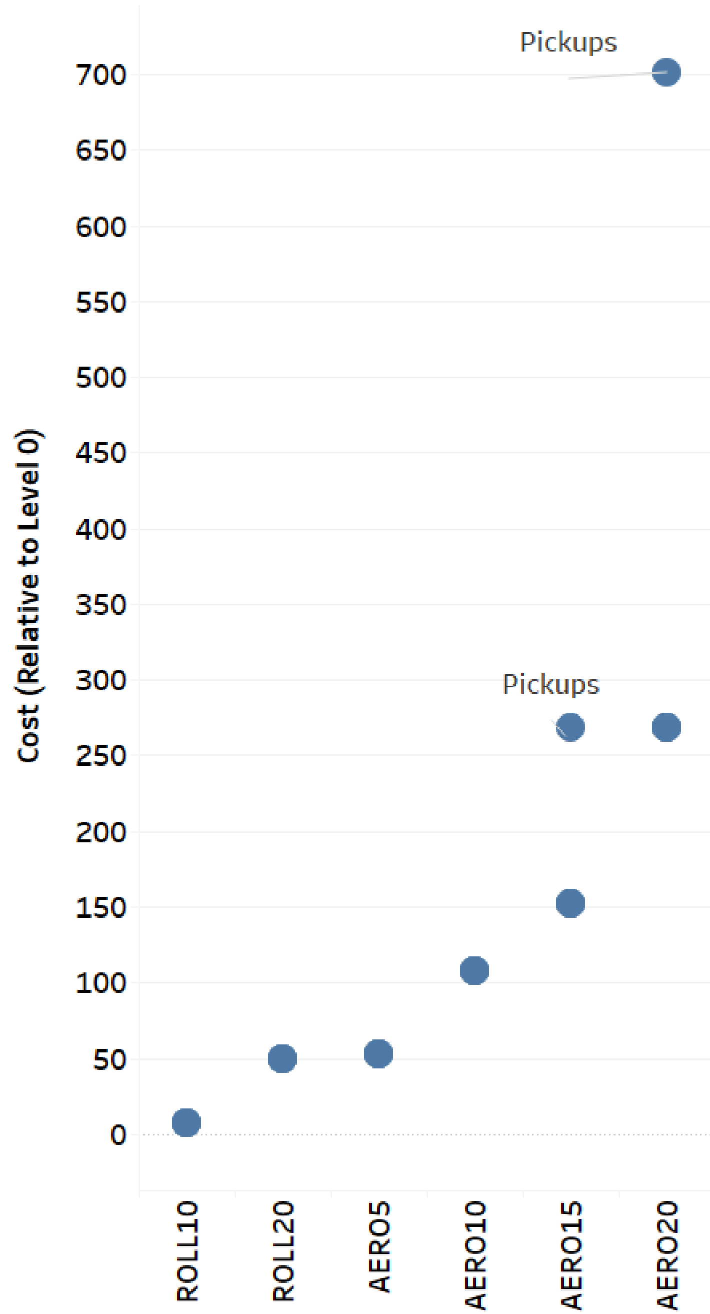

Figure 3-11 – Aerodynamic and Rolling Resistance Improvement Costs (Retail Price Equivalent), 2020

Figure 3-11 displays the cost for aerodynamic and rolling resistance improvements in 2020. These costs do not vary across regulatory classes except for higher levels of aerodynamic improvement on pickup truck bodies, which are more expensive than comparable improvements in the other technology classes due to larger frontal areas and higher ground clearances. In general, the low cost and flexibility in application – where these technologies can be applied to individual vehicle models without affecting other vehicles in the portfolio – make them attractive compared to other technology options.

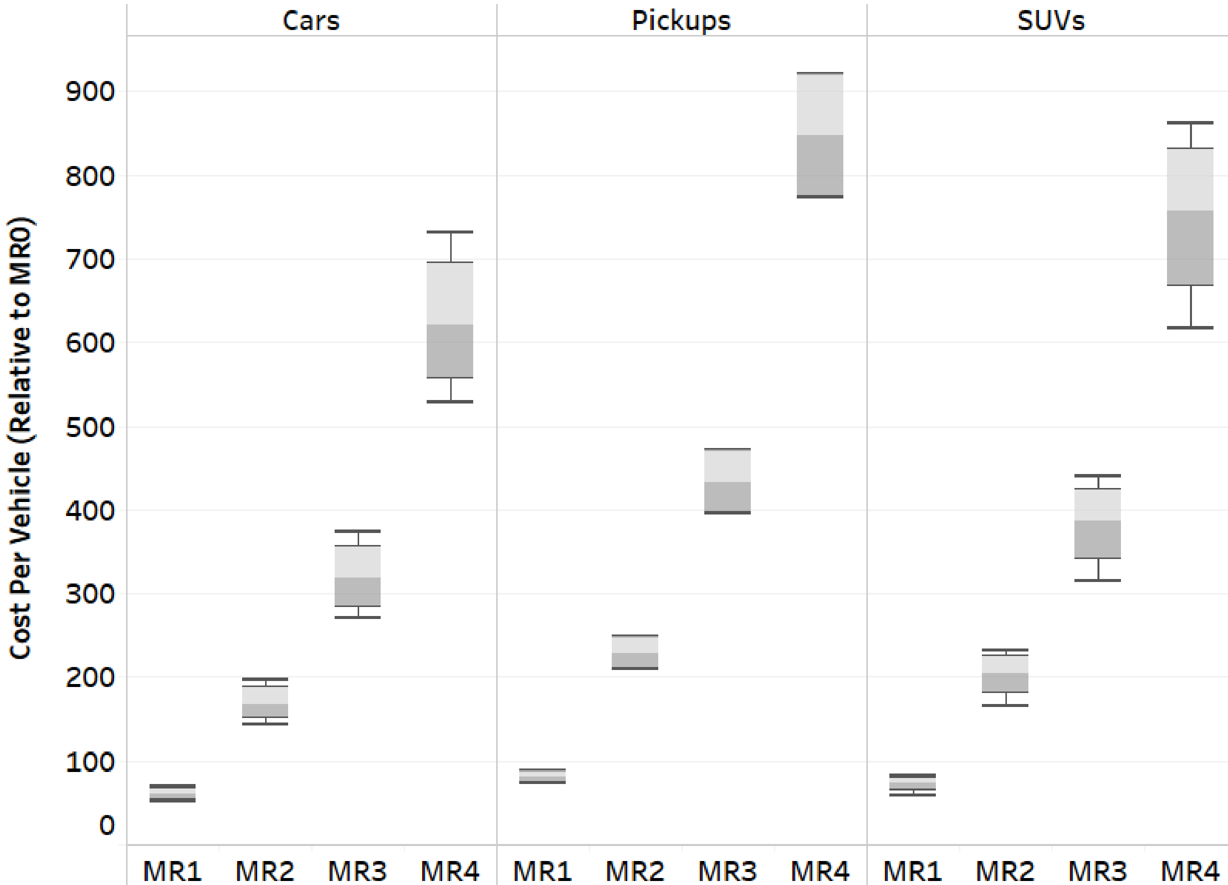

Figure 3-12 – Mass Reduction Costs (Per-Vehicle), Up to 15 Percent Reduction in Glider Weight (Retail Price Equivalent), 2020

The cost distributions of the four lowest levels of mass reduction technology are shown in Figure 3-12. The distributions in the figure represent the full range of costs across all technology classes for each level in MY 2020. Not only does the price per pound of reduction increase with higher levels of mass reduction, as each successive level becomes more dependent upon increasingly expensive materials and design choices, but the cost of each individual application depends on the number of pounds removed from the vehicle. In general, smaller vehicles are lighter and have fewer pounds to save for an identical percentage reduction in mass, but the fleet also contains heavier luxury, performance, and utility vehicles that have higher mass reduction costs per-vehicle due to their higher initial mass (e.g., given the same cost per *pound* of avoided mass, it costs more to reduce a 4,000-pound vehicle's mass by 1 percent than to reduce a 3,000-pound vehicle's mass by 1 percent).

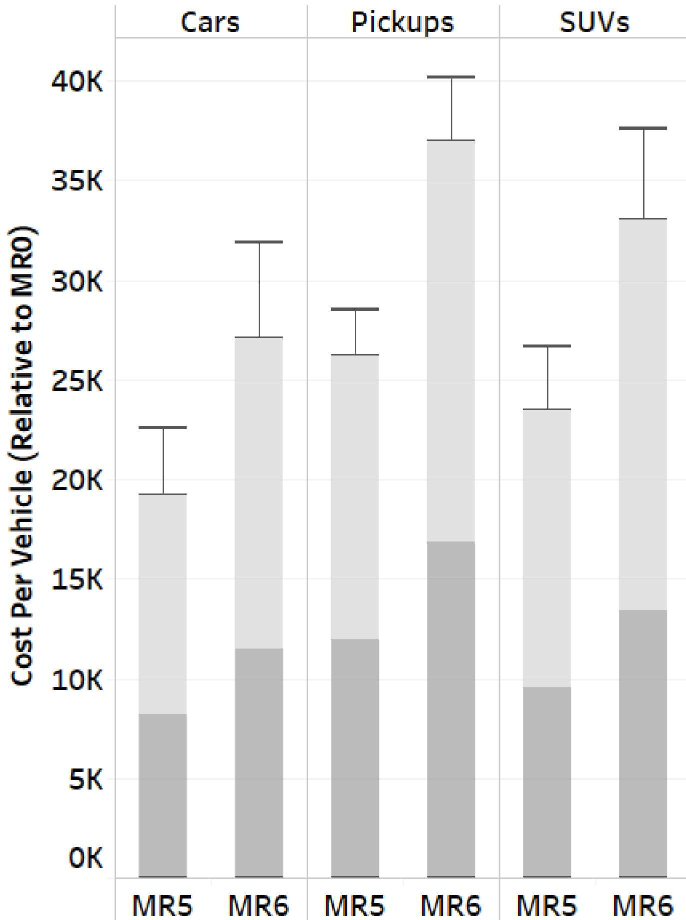

Figure 3-13 – Mass Reduction Costs (Per-Vehicle) for Highest Levels (Retail Price Equivalent), 2020

In order to display the cost distributions of the mass reduction technologies meaningfully, it was necessary to separate the mass reduction levels into two figures. Figure 3-13 illustrates the cost distribution of the highest mass reduction levels (in 2020, after which they learn down). These two levels, the most aggressive in the analysis, represent a phase shift in materials and, as a consequence, have significantly higher costs than the lower levels of mass reduction. For a more detailed discussion of mass reduction technology, see TSD Chapter 3.4.

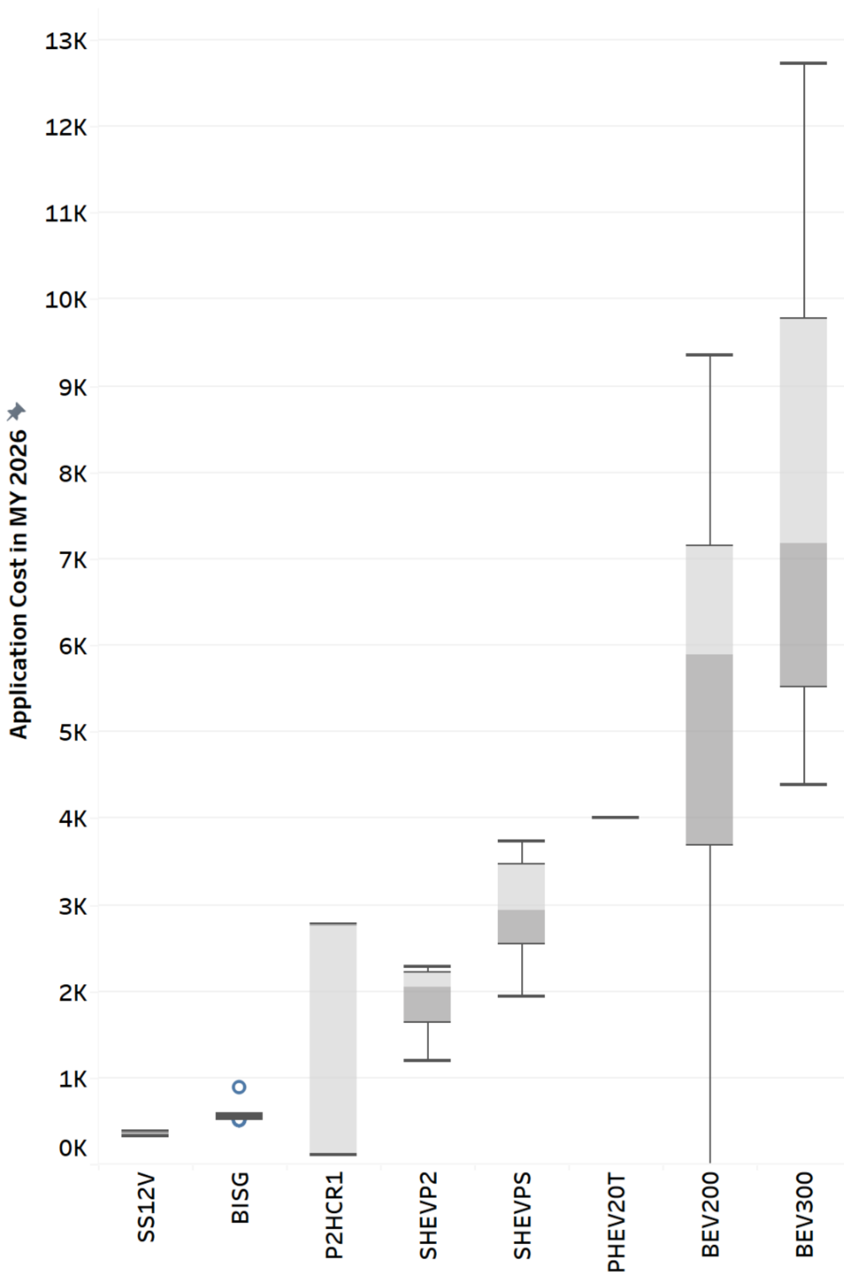

Figure 3-14 – Electrification Cost Distributions (Retail Price Equivalent), 2026

The costs of electrification technologies are not as easily described as technologies on other vehicle systems. In addition to the fixed cost components like power management systems that accompany strong hybrids (SHEVs) or plug-in vehicles, there are costs that vary with the power requirements of the powertrain they replace (like electric motor power). In addition to these system costs, the cost of the battery is significant and variable over both vehicle size and time. The size of the batteries required by most of these technologies (except for SS12V and BISG, which have fixed battery sizes) scales with both the technology class (i.e., the body-style and power requirements) of the vehicle, but also by the amount of body-level technology that has been applied to the vehicle *within* a technology class. For example, the same vehicle model would have a larger battery at MR2 than at MR4, where the energy required to move the vehicle would be inherently less due to its lower mass. Given the influence of technology content on both battery size and cost, the DMCs for batteries are also a product of the Argonne simulation study, which uses Argonne's BatPaC[37] model to estimate battery cost. Of all the technology costs in this analysis, battery costs decline the fastest over time – so the year in which the technology is applied matters more for electrification technologies than for fuel-saving technologies in other systems.

Not all of the electrification technologies included in the analysis are represented in Figure 3-14, but the figure still conveys the relevant information about the general cost of electrification in the analysis. For more detail about the specific costs of electrification technologies, and their derivations, see TSD Chapter 3.3.5. The two least effective technologies at improving fuel economy on the electrification path are also the least expensive. In this analysis, plug-in hybrid electric vehicles (PHEVs) are all paired with a specific engine (either a specific HCR engine or a specific turbocharged engine). The cost distributions in Figure 3-14 span all ten technology classes, but represent costs in a single (future) year, MY 2026, when the cost of all technologies (most especially, battery costs) have decreased due to cost LE. The costs in the figure represent costs of technologies that the model actually chose to apply under an alternative that required aggressive application of electrification technologies. As one would expect, the cost of BEVs increase with range (where 200-mile range BEV [BEV200] is less expensive than 300-mile range BEV [BEV300], and, while not pictured, 400-mile range BEV [BEV400] and 500-mile range BEV [BEV500] are each incrementally more expensive than the shorter-range version). Even by MY 2026, the cost to convert an ICE can still be several thousand dollars, depending on the technology class of the vehicle and the range of the electric vehicle (EV). By comparison, SHEVs represent lower cost solutions that may be preferred by the model if stringency increases and a manufacturer's product portfolio supports their application.

In addition to the DMCs and an RPE scalar of 1.5, technology costs "learn down" over time. As manufacturers produce more of a given technology, the analysis assumes that they improve the efficiency and cost with which they do so. More established technologies have manufacturing costs that decrease more slowly over time, while the cost of emergent technologies (like advanced ICEs and batteries) decrease quickly. These differences in learning rates can (and do) lead to situations where a given technology may not be preferred by the model in the near term, but can be very cost effective after a certain point in time – when its cost has decreased more rapidly than technologies against which it is competing. In this analysis, that is exactly what occurs with more advanced electrification technologies in the future. As the model carries forward technologies that it has already applied to future model years, it similarly adjusts the costs of those technologies based on their individual learning rates. For a more detailed discussion of technology cost learning, see TSD Chapter 2.6.4.

3.2.5 Simulating Manufacturers' Compliance Decisions

In general, the model adds technology for several reasons, which it references sequentially. First, the model applies credits associated with a manufacturer's application of OC and AC

[37] The version of BatPaC used to support this analysis is BatPaC 4.0v – 01 October, 2020.

efficiency technology (and, if simulating compliance with GHG standards, AC leakage) to the relevant year's compliance performance. If California's ZEV mandate is simulated to be in place, as it is in this analysis, the model will then add advanced technology to vehicles up to the point of compliance with ZEV.[38] The production of vehicles satisfying the ZEV mandate affects a manufacturer's CAFE compliance status – the vehicles are both fuel efficient and benefit from generous alternative fuel credit provisions (these vehicles are credited in excess of their fuel savings), both of which impact the amount of additional technology required to achieve compliance with standards. The model then applies any "forced" technologies.[39] Next, the model applies any technologies that were applied to a leader vehicle in an earlier year and must be inherited by follower vehicles (on the shared system) that are freshened or redesigned in the current year (and thus eligible to receive the updated version of the shared component). After applying forced and inherited technologies, the model evaluates the manufacturer's compliance status, applying all cost-effective technologies regardless of compliance status (essentially any technology for which the effective cost is negative). Then the model applies expiring CAFE credits (if allowed to consider credit application, either outside of standard-setting years or under the conditions of the environmental impact statement (EIS) analysis that remove those constraints). At this point, the model checks the manufacturer's compliance status again. If the manufacturer is still not compliant (and is assumed to be unwilling to pay civil penalties), the model will add technologies for which the effective cost is positive (meaning that the cost of the technology is greater than the combination of the first 30 months of fuel savings it produces and the reduction in required civil penalty payment) until the manufacturer reaches compliance. If the manufacturer exhausts opportunities to comply with the standard by improving fuel economy (typically due to a limited percentage of its fleet being redesigned in that year), the model will apply banked CAFE credits to offset the remaining deficit.

While this description of the model's logic sequence describes actions in a single year, in practice, the model considers the entire set of years simultaneously when identifying compliance actions. Rather than choosing a solution that minimizes the cost of compliance in a single year, the CAFE Model attempts to minimize the cost of compliance over the set of years in the analysis for a manufacturer and fleet. Manufacturers have repeatedly presented us with product planning information affirming that they actually engage in such multiyear planning, although their approaches and levels of sophistication are varied. This implies a consideration of standards (and changes to them) over time, as well as the changes to future compliance positions that result from actions in any single model year. The model will take lower-cost compliance actions that are not needed for CAFE compliance in an earlier year, in order to carry the technology forward into future years with fewer redesigns. It will also do this in order to earn over-compliance credits that can be applied to expected deficits in future years when standards are increasing in stringency. Alternatively, as a consequence of cost learning, some technologies will become more cost effective in future years and the model will take actions in earlier years that anticipate the eventual attractiveness of those technologies – rather than front-loading

[38] The model applies technology to vehicles in the market data file that are not currently ZEVs in order to approach compliance with California's ZEV mandate, for each manufacturer. For a full description of how ZEV compliance is modeled in this analysis, see TSD Chapter 2.3.

[39] As a practical matter, the model is coded to force the application of VVT to vehicles in the fleet that enter without it, as that is the reference point against which all technology effectiveness is measured. The current new vehicle market (MY 2020) has no vehicles that either do not already have VVT or have not progressed to higher technology states (like hybrid electric vehicles).

technology to earn over-compliance credits, it will evaluate the cost of doing so against the future (possibly lower) cost of applying more advanced technologies whose costs will have "learned down" over time. At the end of this process, the model is left with a single compliance solution over the entire period for each manufacturer and fleet. Due to the possibility of sales and fleet mix shifts as a consequence of the technology application, the CAFE Model iterates the compliance simulation again (with, possibly, new fleet volumes, standards, and achieved CAFE levels) until the technology solutions stop changing between iterations.[40]

In a given model year, the model determines applicability of each technology to each vehicle model, platform, engine, and transmission. The compliance simulation algorithm begins the process of applying technologies based on the CAFE standards specified during the current model year. This involves repeatedly evaluating the degree of noncompliance, identifying the next "best" technology (ranked by the effective cost, discussed in Chapter 3.2.5.2) available on each of the parallel technology paths described above and applying the best of these. The algorithm combines some of the pathways, evaluating them sequentially instead of in parallel, in order to ensure appropriate incremental progression of technologies. The algorithm first finds the best next applicable technology in each of the technology pathways, then selects the best among these, and reevaluates both compliance status and effective cost for all remaining technology options.

3.2.5.1 Multiple Programs Operate Simultaneously (CAFE, GHG, ZEV)

Unlike previous analyses of CAFE alternatives, the baseline for this analysis includes the simultaneous simulation of multiple programs regulating vehicles. In particular, the baseline includes California's ZEV mandate, discussed in detail in TSD Chapter 2.3, as well as California's Framework Agreements GHG emission reduction commitments made by five manufacturers. In addition to these programs, there are Federal CAFE and GHG standards in place for MYs 2020-2026 that were finalized in 2020. While the alternatives considered in this analysis involve new CAFE standards for MYs 2024-2026, the reference point against which the effects of those standards is measured is a baseline that includes three programs interacting simultaneously to shape vehicle offerings and compliance positions across the industry.

In previous analyses of new CAFE standards, the CAFE Model would consider each manufacturer's CAFE standard and identify a cost-minimizing technology pathway to achieve that standard over successive model years. For the CAFE alternatives in today's analysis, that is still how the model simulates compliance. However, with multiple programs in place simultaneously in a given year, the CAFE Model must first determine which of the standards is binding in a given year for each manufacturer and fleet. This identification process requires comparing the various compositions of the passenger car fleets, where the CAFE program distinguishes between imported and domestically produced cars (but the GHG programs do not), and light truck fleets. The initial compliance position in each program is not only a function of the MY 2020 performance level of the respective fleets, relative to their standards, but of the existing credit balances in each program as well.

[40] For more detail about the logic and mechanics of the compliance simulation algorithm, please see the CAFE Model documentation https://www.nhtsa.gov/corporate-average-fuel-economy/compliance-and-effects-modeling-system, (Accessed: February 14, 2022).

In addition, the model must account for the new ZEV vehicles that are scheduled to be produced over time (and in every alternative, regardless of CAFE stringency). These vehicles are simulated as BEVs (of varying ranges) and get the appropriate credit provisions under both the CAFE and GHG programs. For the manufacturers who entered into Framework Agreements with California (like Ford, who is used in the compliance example in Chapter 3.2.6), the model must treat the GHG emission reduction commitment as the relevant GHG constraint. However, for manufacturers that did not sign agreements with California, their GHG constraint in MY 2021-2026 still reflects the GHG standards that were finalized in conjunction with CAFE standards in 2020. This means that the CAFE Model is simulating three programs simultaneously for any single manufacturer, but actually simulates four programs simultaneously across the industry (because there are two sets of GHG constraints in place at the same time).

For manufacturers that did not adopt Framework Agreements, the CAFE standards finalized in 2020 are typically the binding constraint in the baseline, often due to the limitations on credit transfers between fleets (particularly during standard-setting years and in the "standard setting" runs, where the model is also prohibited from using credits to offset compliance deficits). The 2020 final GHG standards, while harmonized with CAFE, feature greater compliance flexibility and more favorable credit positions for most manufacturers. In the GHG programs, credit transfers between fleets are unlimited; a manufacturer is able to comply with the standard in a given year provided one fleet is sufficiently over-compliant to offset the deficit that occurs in the other fleet. The CAFE Model simulates both GHG constraints to reflect that compliance strategy – minimizing compliance costs across the combined passenger car and light truck fleets.

In addition to identifying which program represents the binding constraint in any given year, and accounting for the relevant credit positions and accounting for each program, the CAFE Model must also faithfully represent a variety of provisions that are unique to each program.[41] For example, beyond the different definitions of the standards themselves (the model uses the functions and coefficients native to each program to define the standards), there are a number of provisions related to the treatment of alternatively fueled vehicles. In the CAFE program, alternative fuel vehicles receive a compliance benefit from a compliance fuel economy adjustment called the petroleum equivalency factor (PEF) that adjusts fuel economy on electricity (or the portion of fuel economy represented by electricity, for PHEVs), E85, CNG, or hydrogen. However, in the EPA GHG program, electricity is treated as generating no GHG emissions (i.e., a rating of 0 grams/mile) until MY 2026, at which point upstream emissions are attributed to the electricity consumption. Alternatively fueled vehicles also benefit from the application of sales/production multipliers (which vary by technology and over time) in the GHG frameworks, and the CAFE Model accounts for those as well.

3.2.5.2 Tradeoffs Among Compliance Cost, Civil Penalties, and Consumer Demand for Fuel Economy Improvements

Given information about regulations, and technology cost and effectiveness, the model attempts to apply technology to each manufacturer's fleet in a manner than minimizes "effective costs."

[41] While the model has the ability to estimate and account for the number of new ZEV credits generated through the production and sale of ZEVs in the future, it does not attempt to enforce compliance with the ZEV program through any internal logic. The degree of ZEV compliance is purely a function of inputs defined by the user.

The effective cost captures more than the incremental cost of a given technology – it represents the difference between their incremental cost and the value of fuel savings to a potential buyer over the first 30 months of ownership.[42] In addition to the technology cost and fuel savings, the effective cost also includes the change in civil penalties from applying a given technology.[43]

This construction allows the model to choose technologies that both improve a manufacturer's compliance position and are most likely to be attractive to its consumers. This also means that different assumptions about future fuel prices will produce different rankings of technologies when the model evaluates available technologies for application. For example, if gasoline prices are forecasted to be high, an expensive but very efficient technology may look attractive to manufacturers because the value of the fuel savings is sufficiently high to both counteract the higher cost of the technology and, implicitly, satisfy consumer demand to balance price increases with reductions in operating cost. The model continues to add technology until a manufacturer either: (a) reaches compliance with CAFE standards (or GHG standards, depending upon the operating mode and the regulatory alternative), possibly through the accumulation and application of compliance credits, (b) reaches a point at which it is more cost effective to pay civil penalties than to add more technology, or (c) reaches a point (beyond compliance) where the cost additional fuel-saving technology begins to exceed the fuel savings projected to occur during the first 30 months (a model input discussed in the accompanying TSD) of vehicle ownership. As discussed in the TSD, this estimate reflects buyers' significant undervaluation of fuel economy relative to a strict actuarial projection of lifetime fuel savings.

If a manufacturer's fleets have not yet achieved compliance with applicable standards, the CAFE Model examines options to add specific technologies to specific vehicle model configurations. Once a manufacturer reaches compliance (i.e., the manufacturer would no longer need to pay CAFE civil penalties), the algorithm continues to apply any additional technology determined to be cost-effective (i.e., where the fuel savings in the first 30 months of ownership fully offset the cost of the technology). Conversely, if a manufacturer is assumed to be willing to pay CAFE civil penalties, the algorithm only applies technology up to the point where doing so is less costly than paying those penalties (although even for manufacturers treated as willing to pay CAFE civil penalties, the model may continue to apply technology in order to achieve compliance with CO_2 standards, for which paying civil penalties is not a plausible option). The algorithm stops applying additional technology to this manufacturer's products once no more cost-effective solutions are encountered. This process is repeated for each manufacturer present in the input fleet. It is then repeated again for each model year. Once all model years have been processed, the compliance simulation algorithm concludes.

[42] The length of time over which to value fuel savings in the effective cost calculation is a model input that can be modified by the user. This analysis uses 30 months' worth of fuel savings in the effective cost calculation, assuming that the price of fuel at the time of purchase persists for at least the next 30 months. This implies that new car buyers will behave as if the fuel price at the time of purchase reflects the fuel price he or she will face over the life of the vehicle. The accompanying TSD discusses the basis for this model input.

[43] Staff are currently considering a possible expansion of this calculation to account for tax credits and other financial incentives that could be applied to stimulate electrification.

3.2.6 Compliance Example

To better understand how the CAFE Model simulates compliance, it helps to walk through the solution for a single manufacturer, recognizing that no simulation using publicly-available inputs can predict precisely what Ford will actually do. The example that follows examines Ford's simulated compliance actions in the baseline (Alternative 0[44]) and illustrates the features of the model, given the full set of assumptions about technology cost and effectiveness (among others). Ford's voluntary compliance with California's the Framework Agreement with California through MY 2026, applied to their national fleet (as was intended by the agreement), makes the example of particular relevance to this analysis. In MYs 2021-2026, Ford faces requirements under the CAFE program (with standards finalized in 2020 for those model years), California's ZEV program that requires a particular number of ZEVs produced and sold in both California and the other states who have adopted the ZEV program, and the voluntary Framework Agreements between California and five manufacturers (including Ford) regarding the average GHG levels to be achieved by those manufacturers' national new vehicle fleets through MY 2026. These simultaneous frameworks interact to influence Ford's decisions about how to increase the fuel efficiency of its various fleets, and the pace at which it must do so.

At the start of the simulation, in MY 2020, Ford produces 30 unique engines shared across 18 unique nameplates, over 300 model variants (that differ by nameplate, technology content, curb weight, footprint, or fuel economy), and three regulatory classes (domestic and imported passenger cars, and light trucks). The CAFE Model attempts to preserve the observed level of component sharing throughout the simulation to avoid introducing additional production complexity for which we do not estimate additional cost. An even smaller number of transmissions (24) and platforms (11) are shared across the same number of nameplates, model variants, and regulatory classes.

While the CAFE Model's decisions are focused on bringing each manufacturer's fleets into compliance with the relevant standards, the actions taken to do so occur at the level of individual models offered for sale. Before considering the broader context of compliance, by program and over time, it may be helpful to follow the evolution of a specific model in Ford's portfolio as the company attempts to comply with regulations. Unlike earlier analyses that have shown aggressive improvements taking place to ICEs, early and often, under increasing CAFE stringencies, this analysis is different. Many of those actions have been taken over the last decade, and starting from MY 2020, there are fewer such opportunities remaining to manufacturers like Ford than starting from, as in 2012, MY 2010.

[44] In order to better illustrate the model's treatment of compliance credits over time, the results in this example use the EIS model runs – where the restrictions on considering alternatively fuel vehicles and credit application do not apply. In the central analysis runs for the Final Rule, the model has a setting in place to enforce those restrictions for MYs 2024-2026.

Table 3-4 – Compliance Example for Vehicles Sharing the Same Engine

Model[45]	Leader	Redesign Years	Refresh Years
Fusion Fwd	Engine	2020, 2026	2023
Transit Connect Lwb Usps (Cargo Van)	Transmission (other)	2024, 2030	2027
Transit Connect Lwb Passenger Wagon		2024, 2030	2027
Transit Connect Lwb Cargo Van		2024, 2030	2027
Transit Connect Swb Cargo Van		2024, 2030	2027

The following example follows the progression of a (specific) Ford Fusion, which shares an engine with some model variants of the Transit Connect, as shown in Table 3-4.[46] While these vehicles share an engine, a 2.5L I4 with VVT and SGDI, the Fusion (given its greater sales volume) serves as the engine leader – meaning that the engine's redesign cadence is tied to the redesign cadence of the Fusion in the CAFE Model. As the table shows, the redesigns of the Fusion and Transit Connect are out of phase (MYs 2020 and 2026 for the Fusion, and MYs 2024 and 2030 for the Transit Connect). While that engine is eligible to be upgraded in MY 2026 (and, indeed, does get upgraded in this example), those upgrades could not be inherited by the Transit Connect until MY 2027, its first redesign action after MY 2026 (a "refresh" rather than a full redesign). In MY 2026, these model variants of the Transit Connect continue to carry the legacy version of this engine until MY 2027, when they inherit the upgraded engine (the MY 2026 vintage of the engine), whether Ford needs to improve the fuel economy of those vehicles for compliance or not. While Ford could elect to accelerate changes to the Transit, doing so would presumably entail costs that would not be accounted for by current CAFE Model inputs.

For years in which none of the example vehicles is redesigned or refreshed, the models simply carry forward their technology content from the previous model year. Those years have been excluded from Table 3-5 to improve readability, and three Transit Connect models with identical technology content are represented by a single model (Transit Connect Lwb (Cargo Van)). The second column in the table contains the technology key ("Tech Key") associated with the model, and succinctly describes all the technology content on the vehicle in that model year. Differences in Tech Keys for successive years represent technology application. The grey rows in the table reflect model years where no actions are available (i.e., years where the vehicle model is not being redesigned or refreshed). In those years, one can observe the fuel economy target continue to increase as the stringency of the CAFE standard increases (between MY 2020 and MY 2026, after which they stabilize), though the compliance fuel economy ("MPG" in the table) does not change in years where no technology application occurs. While no individual vehicle ever needs to exceed its target in order for a manufacturer to achieve compliance (indeed, the Fusion model in this example does not exceed its target at any point between MY 2020 and MY 2030), the fact that targets evolve faster than measured fuel economy helps to illustrate part of the multi-year planning considerations faced by manufacturers.

[45] "Fwd" refers to front wheel drive. "Lwb" and "Swb" refer, respectively, to long and short wheelbase. "Usps" refers to the U.S. Postal Service.

[46] While these four versions of the Transit have nearly identical technology content, there are three distinct footprint sizes (and four distinct curb weights, for that matter), and consequently three unique fuel economy targets.

In MY 2023, the Fusion is expected to be refreshed (see Table 3-4) and inherits a new transmission from its transmission leader (upgrading from a 6-speed automatic transmission [AT6] to 8-speed automatic transmission [AT8]), improves the electronic accessories (IACC), and upgrades the tires (ROLL20). In MY 2024, the Transit Connects are redesigned and upgraded from an AT6 transmission to a 10-speed automatic transmission, level 2 (AT10L2) (on which it is the designated leader – meaning that vehicles who share that transmission will inherit the new AT10L2 when they are next refreshed or redesigned). However, as a follower on that engine, the Transit Connect models do not initiate a new technology variant. The Transits also improve electronic accessories (IACC) and upgrade tires (to ROLL20).

Table 3-5 – Technology Walks for Fusion and Transit Connects

Model Year	Tech Key	Target	MPG
Fusion Fwd			
2020	DOHC; VVT; SGDI; AT6; EPS; CONV; LDB; ROLL10; AERO15; MR0	41.6	32.0
2023	DOHC; VVT; SGDI; AT8; IACC; CONV; LDB; ROLL20; AERO15; MR0	43.5	36.3
2024	DOHC; VVT; SGDI; AT8; IACC; CONV; LDB; ROLL20; AERO15; MR0	44.1	36.3
2026	EFR; TURBO1; AT10L2; IACC; CONV; LDB; ROLL20; AERO15; MR1	45.5	44.8
2027	EFR; TURBO1; AT10L2; IACC; CONV; LDB; ROLL20; AERO15; MR1	45.5	44.8
2030	EFR; TURBO1; AT10L2; IACC; CONV; LDB; ROLL20; AERO15; MR1	45.5	44.8
Transit Connect Lwb Usps (Cargo Van)			
2020	DOHC; VVT; SGDI; AT6; EPS; CONV; LDB; ROLL0; AERO15; MR1	32.1	29.3
2023	DOHC; VVT; SGDI; AT6; EPS; CONV; LDB; ROLL0; AERO15; MR1	33.6	29.3
2024	DOHC; VVT; SGDI; AT10L2; IACC; CONV; LDB; ROLL20; AERO15; MR1	34.1	34.7
2026	DOHC; VVT; SGDI; AT10L2; IACC; CONV; LDB; ROLL20; AERO15; MR1	35.2	34.7
2027	EFR; TURBO1; AT10L2; IACC; CONV; LDB; ROLL20; AERO15; MR1	35.2	38.0
2030	EFR; TURBO1; AT10L2; IACC; CONV; LDB; ROLL20; AERO15; MR1	35.2	38.0
Transit Connect Swb Cargo Van			
2020	DOHC; VVT; SGDI; AT6; EPS; CONV; LDB; ROLL0; AERO15; MR1	36.1	29.3
2023	DOHC; VVT; SGDI; AT6; EPS; CONV; LDB; ROLL0; AERO15; MR1	37.8	29.3
2024	DOHC; VVT; SGDI; AT10L2; IACC; CONV; LDB; ROLL20; AERO15; MR1	38.4	34.7
2026	DOHC; VVT; SGDI; AT10L2; IACC; CONV; LDB; ROLL20; AERO15; MR1	39.6	34.7
2027	EFR; TURBO1; AT10L2; IACC; CONV; LDB; ROLL20; AERO15; MR1	39.6	38.9
2030	EFR; TURBO1; AT10L2; IACC; CONV; LDB; ROLL20; AERO15; MR1	39.6	38.9

The 2.5L I4 engine that these models all share is tied to the MY 2020 vintage of the Fusion Fwd and in MY 2026, when the Fusion is redesigned, it upgrades from DOHC; VVT; SGDI (a dual overhead cam [DOHC] engine with variable valve timing [VVT] and direct injection) to TURBO1 (a turbocharged engine with VVT, VVL, and SGDI) with reduced engine friction (EFR). The Transit Connect models, which are not scheduled for either type of design modification in MY 2026, continue using the legacy version of the shared engine until they are refreshed in MY 2027, at which point they inherit the new TURBO1 engine. As the fleet compliance example will show, Ford did not need to improve the fuel economy of these Transit Connect models in MY 2027 in order to comply with either CAFE standards or the Framework

Agreements with California. However, this inheritance occurs in the analysis to minimize the cost of producing a larger number of unique engines, for which we do not estimate additional costs.

All the technology application decisions that occur at the level of individual vehicles occur in the larger context of fleet level compliance – where the CAFE Model is identifying least-cost solutions across the fleet to bring it into compliance. The example of Ford's compliance in Alternative 0 (described in more detail in Table 3-6 for CAFE and Table 3-7 for GHG) illustrates the tradeoffs that the model makes between applying technology in a given year that creates ripple effects across the product portfolio in future years, applying banked credits, transferring credits between fleets, and generating credits in a higher-performing fleet to assist a fleet that struggles against its standard. The meaning of "compliance" is also complicated by the fact that three frameworks – CAFE (2020 final standards), ZEV, and the Framework Agreements – all operate simultaneously in MYs 2021-2026.[47] As the example demonstrates, no one framework represents the binding constraint in all model years.

The compliance simulation begins with Ford's compliance status in MY 2020, in each fleet, for all frameworks, relative to the MY 2020 standards that were finalized in 2012. In this case, Ford faces a number of binding constraints, but the CAFE Model does not apply technology to the MY 2020 fleet; it is the starting point of the simulation and is based on compliance data submitted by the manufacturer. The initial credit banks reflect prior transactions between manufacturers and earned credits by the same manufacturer in prior model years. In Ford's case, there are existing CAFE credits that can be applied to deficits in the DC fleet and expiring GHG credits that are transferred into the fleet. However, the application of these credits varies by framework.

Under CAFE standards, Ford's DC fleet is bound by the MDPCS (40.9 MPG in MY 2020), which is 4 MPG higher than Ford's estimated compliance value for that fleet. By statute, Ford is not able to use CAFE credits from another fleet (whether earned by Ford in another fleet or another manufacturer) to resolve the deficit with respect to the minimum standard; civil penalties must be paid. The CAFE Model simulates the penalties associated with the deficit (the "Fines" column in Table 3-6). However, after resolving the deficit associated with the minimum standard, a manufacturer may use credits to resolve any *remaining* deficit that occurs as a consequence of its calculated standard (41.9 MPG, in this case). As expected, the CAFE Model transfers credits into the DC fleet in MY 2020 ("Credits In"), in an amount that offsets the remaining compliance deficit. The imported car (IC) fleet is also under its standard, and the model estimates the penalties associated with the deficit. Despite the nearly 10 MPG gap between the standard and compliance value, the sales volumes in the IC fleet are modest, and the size of the penalty payment modest as well. In practice, it is more likely that Ford acquires IC credits from another manufacturer or shuffles credits between fleets in a way that differs from the simulation. Longer term, discontinuing the single model/configuration in Ford's IC fleet would be an option, as might applying AWD to potentially shift the vehicle into Ford's light

[47] In principle, there are four simultaneous programs in place in the example, but the GHG standards associated with the CA agreement supersede EPA's 2020 final GHG standards, as they are more stringent in every year (until 2027, where the standards of the CA agreement are assumed to revert to EPA's standards).

truck fleet. Ford's light truck fleet exceeds its standard in MY 2020 and generates credits, which the CAFE Model accrues for use in future years.

Under the GHG standards, Ford's passenger car fleet (the union of its DC and IC fleets in CAFE) is similarly out of compliance with its standard. However, Ford has a sufficient number of compliance credits available and applies a quantity that exactly offsets the passenger car deficit in MY 2020 (2,701,639 credits, the "Credits In" column in Table 3-7). The light truck fleet earns 2.2 million credits, and transfers those into the bank for future use. Because credit transfers between fleets are uncapped, earned GHG credits essentially live in a common bank that is not specific to either fleet, only the model year in which they were earned. As such, Ford is able to take expiring credits and push them into the passenger car fleet in MY 2020, while simultaneously taking earned truck credits in that year and carrying them forward. In this way, a manufacturer is able to renew expiring credits as long as a single fleet performs sufficiently better than its standard. In CAFE compliance, this is not the case. Because the earned credits are tied to both a specific fleet and a specific model year, the credits must be used to offset deficits in the fleet in which they were earned (or be transferred to another fleet, and be subject to required adjustments that could significantly erode their value, even before the transfer cap applies). The CAFE Model accounts for both of these credit accounting regimes, simultaneously, while simulating compliance with the two programs simultaneously.

In MY 2021, despite the continued under-performance of Ford's passenger car fleet on GHG standards, the light truck fleet over-complies by enough to offset the deficit – and the same crediting behavior that was observed in MY 2020 continues with a small difference. The combined fleets comply in GHG space (if the model were to shift credits simultaneously from light truck to passenger car), but the CAFE Model still applies expiring credits to offset the passenger car deficit and carries forward the credits earned by the light truck fleet. Thus, in MY 2021 (as in MY 2020) CAFE is still the binding standard. Both passenger car fleets are non-compliant, and the domestic fleet still accrues penalties relative to the domestic minimum standard. The model accrues the penalties associated with underperformance in the DC fleet but applies banked credits to sufficiently offset the deficit in the IC fleet. As in MY 2020, the light truck fleet exceeds its standard and generates credits for future use.

Table 3-6 – Simulated CAFE Compliance (Alternative 0), Ford

Model Year	Regulatory Class	Min. Std. (mpg)	Standard (mpg)	CAFE (mpg)	Fines	Credits Earned	Credits Out	Credits In
2020	Domestic Car	40.9	41.9	36.8	194,553,321	(21,311,574)	-	7,089,840
2020	Imported Car		48.0	38.8	35,797,222	(2,616,756)	-	-
2020	Light Truck		29.2	29.8	-	7,438,992	22,669	-
2021	Domestic Car	39.9	42.5	37.3	353,811,170	(26,482,872)	-	-
2021	Imported Car		48.7	38.9	-	(3,250,170)	-	3,250,170
2021	Light Truck		29.7	31.7	-	28,913,160	-	-
2022	Domestic Car	40.6	43.2	44.2	-	5,584,410	-	-
2022	Imported Car		49.5	39.1	1,387,192	(3,601,624)	-	3,502,468
2022	Light Truck		30.1	32.7	-	39,248,352	30,448	30,448
2023	Domestic Car	41.1	43.8	47.6	-	21,175,842	-	-
2023	Imported Car		50.2	79.1	-	9,684,390	-	67,021
2023	Light Truck		30.6	34.5	-	56,967,456	24,979	24,979
2024	Domestic Car	41.8	44.5	47.7	-	17,705,152	-	-
2024	Imported Car		51.0	79.1	-	9,117,888	-	64,898
2024	Light Truck		31.0	35.2	-	59,406,102	24,538	24,538
2025	Domestic Car	42.4	45.2	47.8	-	14,292,226	-	-
2025	Imported Car		51.8	79.1	-	8,600,046	-	63,004
2025	Light Truck		31.5	35.3	-	52,180,536	22,669	22,669
2026	Domestic Car	43.1	45.8	50.1	-	23,719,918	-	-
2026	Imported Car		52.5	79.1	-	8,252,650	-	-
2026	Light Truck		32.0	36.2	-	56,800,044	-	-
2027	Domestic Car	41.9	45.8	50.3	-	24,904,440	-	-
2027	Imported Car		52.5	79.1	-	8,178,702	-	-
2027	Light Truck		32.0	36.2	-	56,290,122	-	-
2028	Domestic Car	41.9	45.8	50.4	-	25,547,664	-	-
2028	Imported Car		52.5	79.1	-	8,048,894	-	-
2028	Light Truck		32.0	36.3	-	56,715,839	-	-
2029	Domestic Car	41.9	45.8	50.6	-	26,681,232	-	-
2029	Imported Car		52.5	79.1	-	7,929,460	-	-
2029	Light Truck		32.0	36.3	-	55,873,555	-	-

In MY 2022, Ford's DC fleet exceeds its CAFE standard by 1 mpg, and the deficit in the IC fleet is largely offset by applying banked credits (as was the case in MY 2021). As in the previous two model years, the light truck fleet exceeds its standard and generates credits that are banked for later use. Ford's passenger car fleet makes considerable progress toward its GHG constraint, but still does not comply. However, as in the previous model years, Ford has sufficient banked credits to exactly offset the deficit in the passenger car fleet and, like MY 2021, complies in total when considering over-compliance in the light truck fleet. However, as in the previous years, the CAFE Model preserves the newly generated light truck credits, carrying them forward into future years and applies banked credits instead.

MY 2023 is the first year when the California Framework Agreements begin to represent a binding constraint over the CAFE standards in the simulation (for Ford; this could easily happen earlier or later for another manufacturer). In MY 2023, the single vehicle in Ford's IC fleet is redesigned and exceeds its standard from that point forward (significantly, because Ford's IC fleet includes only the front-wheel drive version of the Ecosport, leaving application of SHEVPS as apparently the best remaining option in MY 2023). Ford's DC fleet also improves, as the GHG standards force broad changes to the passenger car fleet. While the passenger car fleet still does not comply with its GHG constraint, the deficit is closer than in earlier years. The light truck fleet continues to exceed its standard, but by a smaller amount. As in previous years, the CAFE Model attempts to use expiring credits to the fullest extent allowable, but must allow some credits to expire – as the MY 2024 standard forces more technology application in MY 2023 so that it can be carried forward into the next compliance year. This is evidence of the multi-year planning behavior discussed in Chapter 3.2.5. On balance, Ford's combined fleet exceeds its GHG constraint for the first time in the simulation of Alternative 0. As the ZEV columns in Table 3-7 illustrate, some of the improvements in Ford's compliance position in MYs 2022 and 2023 are due to the increase in production of ZEVs, which result in Ford earning more ZEV credits than its estimated target throughout the remainder of the simulation.

Table 3-7 – Simulated GHG Compliance (Alternative 0), Ford

Model Year	Regulatory Class	Standard (g/mi)	Rating (g/mi)	Credits Earned	Credits Out	Credits In	ZEV Target	ZEV Credits
2020	Passenger Car	194	225	(2,701,639)	-	2,701,639		
2020	Light Truck	289	281	2,240,277	2,240,277	-		
2020	TOTAL	264	266	(461,362)	2,240,277	2,701,639	36,091	3,801
2021	Passenger Car	183	223	(4,236,846)	326,524	4,563,370		
2021	Light Truck	269	261	2,612,188	2,612,188	326,524		
2021	TOTAL	246	251	(1,624,658)	2,938,712	4,889,894	53,753	33,186
2022	Passenger Car	177	187	(1,158,056)	-	1,158,056		
2022	Light Truck	258	254	1,363,820	1,158,056	-		
2022	TOTAL	235	235	205,764	1,158,056	1,158,056	68,693	107,688
2023	Passenger Car	170	166	461,424	-	115,356		
2023	Light Truck	249	240	2,969,297	115,356	-		
2023	TOTAL	226	219	3,430,721	115,356	115,356	78,578	107,400
2024	Passenger Car	164	166	(228,746)	-	800,609		
2024	Light Truck	240	235	1,597,352	800,609	-		
2024	TOTAL	218	215	1,368,606	800,609	800,609	87,879	108,890
2025	Passenger Car	158	166	(907,904)	-	1,309,823		
2025	Light Truck	231	234	(930,454)	1,309,823	2,240,277		
2025	TOTAL	209	214	(1,838,358)	1,309,823	3,550,100	96,876	108,098
2026	Passenger Car	152	157	(568,854)	-	568,854		
2026	Light Truck	222	228	(1,832,735)	568,854	2,612,188		
2026	TOTAL	201	207	(2,401,589)	568,854	3,181,042	95,917	108,401
2027	Passenger Car	174	166	912,553	-	-		
2027	Light Truck	260	229	9,384,120	-	-		
2027	TOTAL	234	210	10,296,673	-	-	95,391	108,710
2028	Passenger Car	174	166	914,840	-	-		
2028	Light Truck	260	229	9,235,205	-	-		
2028	TOTAL	234	210	10,150,045	-	-	94,409	109,016
2029	Passenger Car	174	165	1,029,241	-	-		
2029	Light Truck	260	228	9,391,539	-	-		
2029	TOTAL	233	208	10,420,780	-	-	93,439	109,047

From MY 2024, the simulation shows Ford generating large CAFE credit surpluses as it attempts to comply with the Framework Agreements. We note here that the final CAFE standards issued today will likely reduce the opportunity to build such sizable credit surplus against lower standards in those years. Under the GHG constraint, the model simulates behavior similar to prior years: Ford's passenger car fleet still falls short of compliance, the light truck fleet exceeds its standard, and the model applies credits to offset the passenger car deficit while banking credits earned by the light truck fleet. In both MY 2025 and MY 2026, the CAFE Model simulates the same behavior: Ford complies with standards in neither fleet, but uses banked credits to offset the deficits in both. The reliance on banked credits for these final two model years is an artifact of the specification for Alternative 0. In the No-Action Alternative, the Framework Agreements are assumed to expire after MY 2026, at which point the standards revert to the EPA GHG standards that were finalized in 2020. This is illustrated in Table 3-7, where Ford's passenger car and light truck standards revert from 152 g/mi and 222 g/mi in MY

2026, to 174 g/mi and 260 g/mi, respectively, in MY 2027. The CAFE Model sees this relaxation in stringency looming in future years, and applies only enough technology in earlier years to generate the credits needed to comply with the short series of high stringency years before the standards relax. While this may not be how the real world plays out, it reflects DOT's (and thus, the CAFE Model's) understanding of the regulatory landscape as would exist in that time frame if standards were to remain at levels in place when DOT began working toward these updates to CAFE standards.

3.3 Simulating the Economic and Environmental Effects of CAFE and GHG Standards

The CAFE Model tracks and reports each manufacturer's compliance decisions, for every year, in every alternative. Those decisions alter the cost and efficiency of the new vehicle fleet, which then becomes a part of the on-road vehicle population. Through the simulation of the on-road vehicle population, and the energy consumption resulting from its usage, the CAFE Model simulates the physical outcomes that drive economic and environmental effects from alternative fuel efficiency standards.

3.3.1 Representing the Economic Effects of CAFE

The economic framework of the benefit cost analysis is discussed in detail in Chapter 4. In general, changes to standards create streams of benefits and costs that accrue to vehicle producers when they build and sell vehicles, owners when they purchase and use vehicles, and the rest of society as they interact with a population of vehicles that has been influenced in some way by the standards.

As manufacturers apply technology to their vehicle offerings in order to comply with more stringent standards, the CAFE Model explicitly simulates the price impacts in the new vehicle market. In particular, based on the assumption that all costs related to compliance (the cost of technology or civil penalties) are passed through to buyers of new vehicles, the model uses a price elasticity to adjust aggregate new vehicle sales, relative to the baseline. The price elasticity acts on an adjusted average price increase, by calculating the average price increase net of some portion of realized fuel savings (the first 30 months in this analysis). While the value of the elasticity is a user-defined input, this analysis assumes an elasticity equal to -0.4. The assumption is discussed in greater detail in the context of estimating the response of sales to higher prices and increased fuel economy, in TSD Chapter 4.2.1 and Section III.E.1 of the preamble.

This portion of the sales response only creates deviations from the baseline vehicle sales forecast, which is a function of macroeconomic inputs and historical sales over time. The change in new vehicle sales has another component that changes the mix of vehicles sold, rather than the total sales of all vehicles, referred to as the dynamic fleet share (DFS). This module reacts to changes to attributes of vehicles (fuel economy, curb weight, and horsepower, the last of which does not change in the analysis) and fuel prices to modify the shares of passenger cars and light trucks in the new vehicle market. For today's sensitivity analysis, we have modified the CAFE Model to consider alternative specifications of the DFS model.

These two models work together to modify the total number of new vehicles, the share of passenger cars and light trucks, and, as a consequence, the number of each given model sold by a given manufacturer. Changes to higher levels of sales (either total sales or passenger car/light-truck body styles) are distributed to individual manufacturers and vehicle models based on their observed shares in the MY 2020 fleet. While we have experimented with fully-integrated consumer choice models, their performance has yet to satisfy the requirements of a rulemaking analysis. For more detail on both components of the sales response, please see TSD Chapter 4.2.1.

In addition to capturing the influence of changes to average new vehicle prices on total new vehicle sales, the model also accounts for expected changes to the used vehicle population as a consequence of those price increases (and fuel savings). In particular, the CAFE Model dynamically estimates the probability that used vehicles of a given age remain in service each year. It uses this function to dynamically retire portions of older vehicle cohorts in a manner that is responsive to both macroeconomic conditions and simulated price changes in the new vehicle market that influence used vehicle transaction prices and residual value. As new vehicles enter the registered population, their retirement rates are governed by this equation, but so are the vehicles already registered. To the extent that a given set of CAFE standards accelerates or decelerates the retirement of those vehicles, additional fuel consumption and social costs may accrue to those vehicles under that standard. The CAFE Model accounts for those costs and benefits, as well as tracking all of the standard benefits and costs associated with the lifetimes of new vehicles produced under the rule. For more detail about the derivation of the scrappage functions, see TSD Chapter 4.2.2.

Another critical element of the economic response to changes in CAFE standards is the effect on demand for travel. As new vehicles become more efficient, the cost-per-mile of driving them decreases, which is assumed to spur additional demand for travel. The exclusive mechanism by which this occurs is the so-called "rebound effect," the change in vehicle miles traveled (VMT) demanded for a given percentage change in fuel economy. The CAFE Model contains a travel demand function that governs total light-duty travel demand, absent rebound-induced demand, given a set of economic conditions related to travel. The function itself is the light-duty VMT forecasting model that Federal Highway Administration (FHWA) uses to generate forecasts, though the inputs to that model are consistent with the assumed macroeconomic conditions of this analysis rather than any specific inputs used to generate official FHWA forecasts.

The implementation in the CAFE Model uses this function to define a constraint on "non-rebound" VMT that is held constant across regulatory alternatives, and implicitly includes any changes to both fuel prices over time and the average efficiency of the on-road fleet (as newer more efficient vehicles replace older ones over time). It is our perspective that the total demand for VMT should not vary excessively across alternatives; the basic travel needs for an average household are unlikely to be influenced heavily by the stringency of the CAFE standards (i.e., by the impact of CAFE standards on new vehicle prices and fuel economy levels), as the daily need for a vehicle will remain the same. That said, it is reasonable to assume that fleets with differing age distributions and inherent cost of operation will have slightly different annual VMT (even without considering VMT associated with rebound miles); however, the difference could conceivably be small. Based on the structure of the CAFE Model, the combined effect of the sales and scrappage responses can create small percentage differences in total VMT across the range of regulatory alternatives if steps are not taken to constrain VMT. Because VMT is related to many of the costs and benefits of the program, even small magnitude estimated differences in VMT across alternatives can have meaningful impacts on the incremental net benefit analysis.

This methodology constrains the model so that the only estimated differences in VMT among the alternatives is a direct consequence of the degree of fuel economy improvement relative to MY 2020 and the magnitude of the rebound effect assumption. However, this also implies that, as fleet composition varies by alternative (the most aggressive alternatives may also produce on-road fleets with higher average ages), some of the total VMT demanded is redistributed from the new vehicle fleet to the newer vehicles in the used fleet. And this redistribution creates additional costs and benefits that are associated with the regulatory alternative. For more detail about the treatment of VMT in the CAFE Model, see TSD Chapter 4.3.

3.3.2 Representing the Physical and Environmental Effects of CAFE and GHG Standards

The CAFE Model carries a complete representation of the registered vehicle population in each calendar year, starting with an aggregated version of the most recent available data about the registered population for the first year of the simulation. In the case of this analysis, the first model year considered is MY 2020, and the registered vehicle population enters the model as it appeared at the end of CY 2019. The initial vehicle population is stratified by age (or model year cohort) and body style (passenger cars, sport utility vehicles [SUVs], and pickup trucks). Once the simulation begins, new vehicles are added to the population from the new vehicle market and age throughout their lives during the simulation, with some fraction of them being retired (or scrapped) in each year along the way. For example, in CY 2021, the new vehicles (age 0) are MY 2021 vehicles (added by the CAFE Model simulation and represented at the same level of detail used to simulate compliance). The age 1 vehicles are MY 2020 vehicles (added by the CAFE Model simulation), and the age 2 vehicles are MY 2019 vehicles (inherited from the registered vehicle population and carried through the analysis with less granularity). This national registered fleet is used to calculate both annual and lifetime: fuel consumption (by fuel type), VMT, pollutant emissions, and safety impacts under each regulatory alternative.

Rather than rely on the compliance values of fuel economy for either historical vehicles or vehicles that go through the full compliance simulation, the model applies an "on-road gap" to represent the expected difference between fuel economy on the laboratory test cycle and fuel economy under real-world operation. While the model currently allows the user to specify an on-road gap that varies by fuel type (gasoline, E85, diesel, electricity, hydrogen, and compressed natural gas [CNG]), it does not vary over time, by vehicle age, or by technology combination. As discussed in the accompanying TSD, today's analysis uses input values range that from 24 to 29 percent, depending on the fuel type as shown in Table 3-8. It is possible that the "gap" between laboratory fuel economy and real-world fuel economy has changed over time, that fuel economy degrades over time as a vehicle ages, or that specific combinations of fuel-saving technologies have a larger (or smaller) discrepancy between laboratory and real-world fuel economy than others.

Table 3-8 - "Gap" between Test and On-Road MPG (by Fuel Type)

Gasoline	24%	24%	24%	24%
Ethanol-85	24%	24%	24%	24%
Diesel	24%	24%	24%	24%
Electricity	29%	29%	29%	29%
Hydrogen	29%	29%	29%	29%
Compressed Natural Gas	24%	24%	24%	24%

The product of on-road fuel economy and VMT determines the fuel consumption, by fuel type, of each vehicle and cohort in the analysis (vehicles produced after MY 2019 are simulated at the model level and all older vehicles as body-style/age cohorts). All of the physical and environmental impacts in the analysis are the consequence of either fuel consumption or VMT. The CAFE Model accumulates these totals on an annual (calendar year) basis, but can also compute the lifetime totals of any physical quantity by model year cohort. Importantly, the calendar year totals for quantities like fuel consumed or miles traveled include both the new vehicle fleet (produced after MY 2019) and the legacy fleet (produced before MY 2020). While some concessions were necessary to represent these model years in the CAFE Model (for example, the CAFE Model only accounts for vehicles until age 40, while the actual on-road fleet has a nontrivial number of vehicles older than that), even with these concessions, it is reasonable to compare calendar year totals of physical quantities to observed values in earlier years and some projections from other sources.

Because the model produces an estimate of the aggregate number of gallons sold in each calendar year, it is possible to calculate both the total expenditures on motor fuel and the total contribution to the Highway Trust Fund (HTF) that result from that fuel consumption. The Federal fuel excise tax is levied on every gallon of gasoline and diesel sold in the United States, with diesel facing a higher per-gallon tax rate. The model uses a national perspective, where the state taxes present in the input files represent an estimated average fuel tax across all U.S. states. It is therefore not possible to use the CAFE Model to reasonably estimate potential losses to state fuel tax revenue from increasing the fuel economy of new vehicles, but doing so for the HTF is possible.

In addition to the tailpipe emissions of CO_2 and other pollutants, each gallon of gasoline produced for consumption by the on-road fleet has associated "upstream" emissions that occur in the extraction, transportation, refining, and distribution of the fuel. The model accounts for these emissions as well (on a per-gallon basis) and reports them accordingly. Similar calculations occur for the upstream component of electricity consumption (by BEVs), though these calculations do not reach as far up the fuel cycle. For more detail about the upstream emissions inputs in the analysis, see TSD Chapter 5.2.

The CAFE Model uses the entire on-road fleet, calculated VMT (discussed above), and emissions factors (which are an input to the CAFE Model, specified by model year and age) to calculate tailpipe emissions associated with a given alternative. Just as it does for additional GHG emissions associated with upstream emissions from fuel production, the model captures criteria pollutants that occur during other parts of the fuel life cycle. While this is typically a function of the number of gallons of gasoline consumed (and miles driven, for tailpipe criteria pollutant emissions), the CAFE Model also estimates electricity consumption and the associated upstream emissions (resource extraction and generation, based on U.S. grid mix).

3.3.3 Costs and Benefits to Producers, Consumers, and Society

As the CAFE Model simulates manufacturer compliance with regulatory alternatives, it estimates and tracks a number of consequences that generate social costs and benefits. The most obvious cost associated with the program is the cost of additional fuel saving technology that is added to new vehicles as a result of the alternatives considered in this analysis. For each technology that the model adds to a given vehicle, it accumulates cost. As the model carries forward technologies that it has already applied to future model years, it similarly adjusts the costs of those technologies based on their individual learning rates.

The other costs that manufacturers incur as a result of CAFE standards are civil penalties resulting from non-compliance with the standards. The CAFE Model applies the real dollar fine rate based on statute, accumulating costs of about $14 per 1/10-MPG under the standard, multiplied by the number of vehicles produced in that fleet, in that model year.[48] The model reports as the full "regulatory cost" the sum of total technology cost and total fines by the manufacturer, fleet, and model year.

The costs and benefits of each alternative are defined relative to the baseline, or No-Action Alternative (Alternative 0 in this analysis). For example, the CAFE Model reports absolute values for the amount of money spent on fuel in the baseline, then reports the amount spent on fuel in the alternatives relative to the baseline. So, if the baseline standard were fixed at the current level, and an alternative achieves 100 MPG by 2025, the total expenditures on fuel in the alternative would be lower, creating a fuel savings "benefit."

The CAFE Model also enforces a constraint on benefit-cost accounting that spans the alternatives. When applying technology to reach compliance, multi-year planning considers as many years as possible to smooth out the costs of the optimal compliance pathway. However, for years close to the present, this has the potential to create different simulations for the same historical year. For example, the market data are based on MY 2020 and this Final Rule is published after MY 2021 production is effectively complete. If the CAFE Model did not impose the constraint that MY 2021 be identical across alternatives (and, in fact, identical to the No-Action Alternative for that year), the multi-year planning algorithm would reach back into MY 2021 to apply more technology under more stringent alternatives. In this analysis, we assume that manufacturers are unable to modify product offerings in either MY 2021 (which is effectively complete) or MY 2022 (which has been fully planned, if not yet completely produced). The technology outcomes of the compliance simulation in MY 2021 and MY 2022 under Alternative 0 are forced in those years for the other alternatives as well. As a result, the CAFE Model simulates no incremental costs or benefits for those years across alternatives.

Other social costs and benefits emerge as the result of physical phenomena, like tailpipe emissions or highway fatalities, which are the result of changes in the composition and use of the on-road fleet. The social costs (in dollars) associated with those quantities represent an

[48] The rate at which fines are assessed increases over time with inflation.

economic estimate of the social damages associated with the changes in each quantity. The model tracks and reports each of these quantities by: model year and vehicle age (the combination of which can be used to produce calendar year totals), regulatory class, fuel type, and social discount rate. The list of social costs and benefits is presented in Table 3-9, as well as the population of vehicles that determines the size of the factor (either new vehicles or all registered vehicles) and the mechanism that determines the size of the effect (whether driven by the number of miles driven, the number of gallons consumed, or the number of vehicles produced).

Table 3-9 – Social Costs and Benefits in the CAFE Model

Cost/Benefit	Population	Mechanism
Technology Cost	New vehicles	Production volume
Consumer Surplus	New vehicles	Production volume
Retail Fuel Savings	All Vehicles	Fuel Consumption
Fuel Tax Revenue	All Vehicles	Gallons
Benefit of Additional Mobility	New vehicles	Miles
Benefit of Less Frequent Refueling	New Vehicles	Gallons
Energy Security Cost	All Vehicles	Gallons
Congestion and Noise costs	All Vehicles	Miles
Non-Fatal Injuries	All Vehicles	Miles
Fatalities	All Vehicles	Miles
Criteria Pollutant Damages (CO, NO_X, SO_X, PM)	All Vehicles	Miles, Fuel Consumption
Greenhouse Gas Emissions Damages (CO_2, CH_4, N_2O)	All Vehicles	Fuel Consumption

3.3.4 Representing the Safety Effects of CAFE Standards

There are three avenues by which raising CAFE standards are evaluated to assess any effect with respect to fleet-wide safety. First, by raising prices for new vehicles and reducing their sales, and by reducing retirement rates for used vehicles, it redistributes VMT from newer cars and light trucks toward older ones, and between new passenger cars and new light trucks as sales shares change over time.[49] Because the safety of new vehicles has gradually improved over time, redistributing VMT from newer to older vehicles increases fatalities and injuries slightly. We measure this effect by projecting differential fatality and injury rates for cars and light trucks of different vintages (i.e., model years) and ages during future calendar years, and applying these rates to estimates of the redistribution of total VMT by model year and age that results from reduced sales of new models and slower retirement of older vehicles.

Second, by increasing VMT of the new cars and light trucks that continue to be sold via the rebound effect, raising CAFE standards exposes their drivers and passengers to increased risks of being involved in crashes. Despite the fact that new cars and light trucks produced during each

[49] We find that price increases from the new standards could depress new vehicle sales slightly (e.g., by about 0.7 percent during MYs 2023-2029) because these price increases are expected to be somewhat greater than the value purchasers are estimated here to place on the fuel outlays they will realize as they operate new vehicles.

successive model year are anticipated to be safer than their predecessors, their increased use thus results in slightly more crashes, and slightly larger numbers of fatalities and injuries. We measure this effect as the product of the increase in driving in new cars and light trucks over their lifetimes, and the per-mile risks that their occupants will suffer fatal and non-fatal injuries in crashes. Given that the additional driving is a choice by individuals cognizant of the injury and fatality risk, we assume that drivers internalize 90 percent of the increased safety risk and experience an off-setting benefit of this magnitude.

Finally, manufacturers are expected to reduce the mass of some of their vehicle models as a strategy to comply with higher CAFE standards, since doing so can sometimes offer a low-cost strategy to improve their fuel economy. Depending on how the initial weight of those models compares to other vehicles in the fleet and how much manufacturers elect to reduce it, this can modify the risk that their passengers will be injured if these vehicles become involved in crashes. We estimate this effect as the change in the risk that occupants of these vehicles will be injured or killed in crashes, multiplied by the number of miles they are driven each year over their expected lifetimes.

These three effects occur simultaneously and interactively within the simulation – where a given vehicle model has a base fatality rate that is a function of its age, but also may see that rate modified due to changes in vehicle mass, and then be driven more or fewer miles as its retirement probability is simulated. For a detailed discussion of how the model measures safety outcomes, see TSD Chapter 7.

4. Economic Analysis of Regulatory Alternatives

This chapter describes NHTSA's approach for measuring the economic costs and benefits that will result from establishing alternative CAFE standards for future model years. It presents the economic theory underlying the measures of benefits and costs that the agency estimates and describes the inputs and assumptions that the agency uses to calculate each category of costs and benefits. The agency's empirical estimates of costs and benefits likely to result from the alternatives it considered appear in Chapter 6 of this FRIA. The economic inputs and assumptions the agency uses in its analysis are important because they directly determine the estimated dollar values of each regulatory alternative's benefits and costs, and any uncertainty about their correct values will affect the reliability of our estimated benefits and costs. We chose these economic inputs based on extensive review of empirical research and selected values that reflect the broader literature rather than basing them on individual studies or deriving them from speculative assumptions, and carefully considered the range and effect of uncertainty that surrounds each value.

As OMB Circular A-4 states, benefits and costs reported in regulatory analyses should be defined and measured consistently with economic theory, and should also reflect how alternative regulations are anticipated to change the behavior of producers and consumers from a baseline scenario.[50] The following sections illustrate how our measures of benefits and costs from adopting higher CAFE standards are derived from economic theory describing how markets for

[50] White House Office of Management and Budget, *Circular A-4: Regulatory Analysis*, September 17, 2003 (https://obamawhitehouse.archives.gov/omb/circulars_a004_a-4/\), Section E. (Accessed: February 14, 2022).

new and used vehicles, car and light truck owners' decisions about how much to drive, and supplies of petroleum and gasoline are likely to respond to higher fuel economy. As this discussion shows, raising CAFE standards is likely to change the behavior of vehicle manufacturers, buyers of new cars and light trucks, owners of used vehicles, and suppliers of petroleum and refined fuel. The agency's analysis describes how the behavior of each of these actors is likely to change compared to a baseline.

4.1 Overview of Effects from Increasing Fuel Economy Standards

Figure 4-1 shows the inputs to the model, the behaviors influenced by fuel economy standards, and the resulting benefits and costs in the markets generated throughout the U.S. economy. Vehicle manufacturers respond to increases in required fuel economy by accelerating the pace at which they apply existing and new technology to improve the fuel efficiency of their fleet. Because additional technology is costly to produce and integrate into a vehicle's design, doing so will increase manufacturers' costs to produce those models they redesign, and they will attempt to recover their additional technology costs and maintain profitability by raising some models' prices. This may result in potential tradeoffs with other vehicle attributes that could create an opportunity cost for some consumers. In addition to fuel economy, potential buyers of new cars and light trucks value other features such as their seating and cargo-carrying capacity, ride comfort, safety, and performance. Changing some of these other features, however, can affect vehicles' fuel economy, so manufacturers will carefully consider any tradeoffs among them when deciding how to comply with stricter CAFE standards. NHTSA's analysis holds vehicle attributes constant, and thereby isolates the costs associated with improvements to fuel economy.

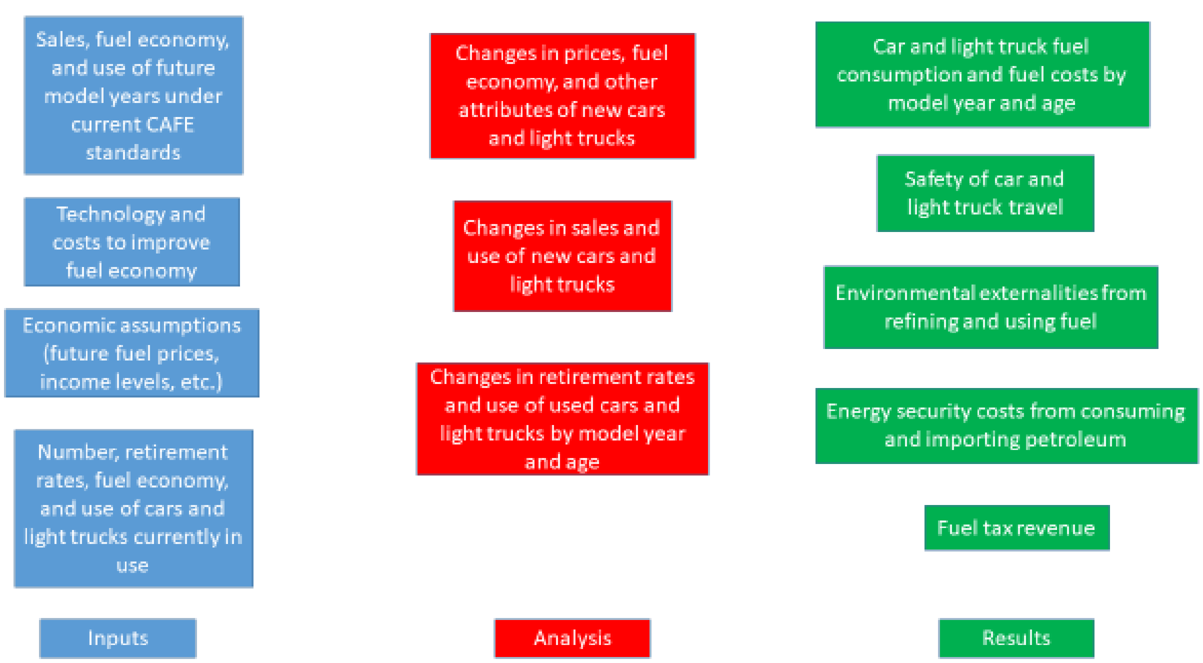

Figure 4-1 – Overview of NHTSA's Analysis of Changes in Fuel Economy Standards

In the absence of CAFE standards, manufacturers design their vehicle models to offer levels of fuel economy, other features, and selling prices they believe will make them most attractive to buyers, and thus maximize their sales and profits.[51] Increasing the stringency of CAFE standards is intended to require manufacturers to raise their vehicles' fuel economy levels from this market-determined baseline to levels beyond those they would otherwise provide, in accordance with the statutory mandate to set maximum feasible standards to enhance fuel economy. The agency believes that doing so will provide benefits to new car and light buyers – as well as to the general public – that exceed the costs of increasing fuel economy. Of course, manufacturers will change vehicle attributes while complying with the fuel economy standards, both to facilitate fuel economy improvements and to enhance the attractiveness of their vehicles to consumers. Manufacturers may design vehicles with "less" of other attributes to facilitate greater fuel economy if doing so would reduce compliance costs and maximize profits. If they do so, there would be a reduced—if any—effect on vehicle prices relative to baseline (and lower compliance costs relative to those estimated here). Conversely, some fuel economy technologies may deliver enhancements in other vehicle attributes. The combination of improvements in fuel economy, changes in vehicles' other features, and prices is likely to affect sales of new cars and light trucks. The size of the market response (and even possibly its direction) depends on how potential buyers value the future savings in fuel costs that result from improving fuel economy, how they value accompanying changes in other attributes, and how they weigh purchase prices against these changes. Manufacturers presumably will make improvements in fuel economy (beyond what current standards require) when they believe investing in fuel economy technologies will maximize their profits, but raising CAFE standards is specifically intended to require producers to increase fuel economy beyond its market-determined level. However, doing so could marginally reduce sales of new cars and light trucks if consumers do not recognize the full value of fuel saved, since if manufacturers could increase sales, and, by extension, profits by increasing fuel economy beyond the levels they currently provide, they would presumably do so even in the absence of higher CAFE standards.[52]

Much of the response of new vehicle sales will be determined by how the combination of prices changes, improved fuel economy, and changes in other features influence buyers' choices between new and used models, since acquiring or keeping a used vehicle can often substitute for buying a new one. If vehicle prices increase as a result of the standards, as NHTSA projects here, and if consumers do not recognize the full value of fuel savings, some would-be new vehicle buyers are likely to purchase used cars or light trucks instead, while others may simply decide to retain their used vehicles for longer, and still others may elect to remain carless; in combination, these responses will increase demand for used vehicles. Higher demand will increase the market value of used cars and light trucks because their supply is limited (although it is not fixed, as will be discussed in detail later), so some that would otherwise have been retired will instead be kept in working condition and driven longer. The combination of reduced sales

[51] Of course, manufacturers must offer fuel economy levels that also meet prevailing CAFE standards.

[52] Note, however, that a variety of market failures, such as information asymmetries and market power, may prevent consumers from demanding that manufacturers supply the level of fuel economy that would ultimately deliver the most welfare to consumers. Furthermore, as EPA has explored, given the uncertainties and large fixed costs involved in technological innovation and adoption, without the incentive of government standards, manufacturers may be more likely to focus on only small, incremental innovations to fuel economy rather than pursuing more major advances that may have greater potential to improve both fuel economy and performance simultaneously. *See* Draft TAR at 4-32.

of new vehicles and slower retirement of used ones will in effect transfer some travel from new to older vehicles: a larger share of more of total miles will be driven in used cars and light trucks when CAFE standards are raised than if prevailing standards remained in effect.

As Figure 4-1 shows, these responses will in turn generate other economic consequences. Improving new vehicles' fuel economy reduces their operating costs and increases the number of miles they are driven via the fuel economy "rebound effect," offsetting a modest fraction of the expected fuel savings from higher CAFE standards. New cars and light trucks featuring higher fuel economy will have extended driving ranges and require less frequent refueling, thus reducing the inconvenience from locating stations and economizing on their drivers' and passengers' time. Despite their increased use, the total amount of fuel new cars and light trucks consume over their lifetimes will decline and result in cost savings to their owners, and, while increased fuel use by older vehicles will offset an additional portion of the anticipated savings, total fuel use will decline. Finally, while new vehicles have become progressively safer over time, there continues to be a strong association between vehicles' age and their involvement in crashes, so shifting travel from newer to older vehicles will affect the safety of drivers and their passengers.

Reducing the volume of fuel refined (or imported), distributed, and consumed throughout the United States will lower emissions of GHGs and criteria air pollutants, thus reducing the costs that potential climate-related impacts and adverse health effects from air pollution impose on the public. Lowering the volume of fuel refined or imported may also reduce costs that result from U.S. petroleum consumption and imports, including revenue transfers from consumers to suppliers of petroleum products and potential costs to businesses and households that rely on gas prices when determining their level of activity. These costs fall broadly across the U.S. economy, so reducing them by curtailing fuel consumption represents an economy-wide benefit of raising CAFE standards that extends well beyond the immediate savings in fuel costs and other benefits to buyers of new cars and light trucks.

4.2 Measuring Benefits and Costs from Raising CAFE Standards

In theory, the economic benefits and costs resulting from higher CAFE standards are measured by changes in consumers' and producers' welfare in all markets that are ultimately affected, plus any accompanying changes in externalities generated by production or consumption of the products traded in those markets. Our evaluation of this final action estimates these benefits and costs arising in four different markets that are likely to be affected either directly or indirectly. These include the market for new cars and light trucks, the market for used cars and light trucks, markets for transportation fuels (including those refined from petroleum and, increasingly, electricity), and the market for crude petroleum. The agency examines benefits and costs in these markets in the order they arise: raising CAFE standards affects the market for new cars and light trucks directly, and its consequences for the fuel economy, prices, and sales of new vehicles in turn generate indirect impacts on new vehicles' use, the number of used cars and light trucks in service and how much they are driven, production and consumption of gasoline and other transportation fuels, and U.S. production, imports, and refining of crude petroleum.[53]

Insofar as possible, the agency's analysis estimates theoretically correct measures of changes in economic welfare in the affected markets, which consist of changes in consumer and producer surplus plus any changes in the value of externalities arising from production or consumption. Throughout its analysis, however, we make various assumptions that simplify measuring these benefits and costs. The most important of these is that the supplies of new cars and light trucks as well as transportation fuels are "perfectly elastic," so that changes in demand do not lead to changes in their prices. While acknowledging that this is a simplification of real-world production conditions, the agency believes that this assumption is likely to have little effect on its estimates of benefits and costs from the final action.[54]

Similarly, the agency's analysis generally assumes that the magnitude of any externalities varies proportionally with changes in production or consumption activity that generates them; in other words, the value of externalities per unit of activity (such as per mile driven or gallon of fuel consumed) is assumed to be unaffected by changes in production or consumption levels. Again, the agency acknowledges that in some cases this assumption simplifies real-world conditions but believes any effect on its estimates of benefits or costs from changes in the relevant externalities is likely to be modest.

4.2.1 Private versus "External" Benefits and Costs

Throughout this regulatory analysis, the agency distinguishes carefully between the costs and benefits from raising CAFE standards that are experienced by private parties, and those likely to fall more broadly on the public or throughout the U.S. economy. The former include private businesses that produce cars and light trucks, households that purchase and use them, and suppliers of transportation fuels and crude petroleum. We also report estimated costs and benefits of this final action (and the alternatives it considers) in a format that clearly distinguishes between benefits and costs it would create for households and businesses, and those that would be distributed more widely throughout the U.S. population and economy. This distinction highlights the fact that most benefits and costs that result from raising CAFE standards would be experienced by the private households and businesses whose decisions it affects, while the final action's more widely distributed monetized benefits and costs are likely to be smaller.

4.2.2 Perspective for Measuring Benefits and Costs

OMB's guidance on regulatory analysis directs agencies to measure the benefits and costs of their regulatory actions against a baseline alternative that represents "the best assessment of the

[53] Some gasoline consumed in the United States may also be imported in already-refined form, rather than refined domestically.
[54] More specifically, the agency's analysis implicitly assumes that the *sum* of changes in consumer and producer surplus in each affected market is likely to vary relatively little under alternative assumptions about the extent to which supply is inelastic and prices change because of changes in demand of the magnitude likely to result from imposing higher CAFE standards.

way the world would look absent the proposed action."[55] Where that future world includes existing government regulations, OMB's guidance further advises that a baseline should reflect "changes in regulations promulgated by the agency or other government entities, and the degree of compliance by regulated entities with other regulations," and that "[f]or review of an existing regulation, a baseline assuming no change in the regulatory program generally provides an appropriate basis for evaluating regulatory alternatives."[56]

In accordance with OMB's guidance, we are using the CAFE standards established previously for MY 2022-2026 cars and light trucks as the baseline alternative for this regulatory analysis (also referred to as the No-Action Alternative). The baseline the agency uses for this analysis also reflects specific assumptions about the administration of EPA's GHG standards to reduce GHG emissions from cars and light trucks, as well as California's Framework Agreements with some manufacturers to reduce their vehicles' emissions, and ZEV mandates. Since the agency has not previously issued CAFE standards beyond MY 2026, the agency assumes for the baseline that the standards previously established for MY 2026 would be extended to apply to subsequent model years. Regulatory alternatives are compared against the baseline.

This analysis relies on many economic assumptions and forecasts, and while these do not vary between the baseline scenario and the various regulatory alternatives, they nevertheless contribute to benefits and costs of each regulatory alternative when those are measured by comparison to the regulatory baseline. Forecasts of overall U.S. economic activity, personal income, and other macroeconomic variables, which affect the projections of new vehicle sales and retirement rates of used vehicles, are taken from the U.S. Energy Information Administration (EIA)'s *Annual Energy Outlook 2021* (AEO 2021).[57] This is also the source for the forecasts of U.S. fuel prices, global petroleum supply and prices, and U.S. imports of crude petroleum and refined fuel that are used in this analysis.[58] Finally, the agency relies on U.S. DOT guidance for valuing travel time when assessing benefits from less frequent refueling and costs of increased congestion delays.[59]

When assessing potential buyers' likely response to requiring manufacturers to meet higher fuel economy targets, we assume that buyers of new cars and light trucks value fuel costs over the first 30 months they own and use them. This assumption implies that in a competitive automobile industry, manufacturers will voluntarily make any improvements in fuel economy that repay their initial costs within that 30-month period, since they will be able to recover their costs for doing so from buyers by raising the prices they charge. Thus, new cars and light trucks will incorporate these lower-cost improvements in fuel economy even without increases in CAFE standards. Potential further improvements in fuel economy that would require more than 30 months to repay their initial costs in the form of savings in fuel expenses may remain, but

[55] OMB Circular A-4, p. 15.
[56] *Id.*
[57] U.S. Energy Information Administration, Annual Energy Outlook 2021, Reference Case Table 20 (https://www.eia.gov/outlooks/archive/aeo21/tables_ref.php). (Accessed: March 28, 2022).
[58] U.S. Energy Information Administration, Annual Energy Outlook 2021, Reference Case Tables 11 and 12 (https://www.eia.gov/outlooks/archive/aeo21/tables_ref.php). (Accessed: March 28, 2022).
[59] U.S. Department of Transportation, Office of the Assistant Secretary for Transportation Policy, "Revised Departmental Guidance on Valuation of Travel Time in Economic Analysis" https://www.transportation.gov/office-policy/transportation-policy/revised-departmental-guidance-valuation-travel-time-economic, (Accessed: February 14, 2022).

manufacturers are unlikely to offer them if they believe that buyers are unwilling to pay higher prices to purchase models that feature them.

When estimating social benefits from raising CAFE standards, however, the agency assumes that buyers and subsequent owners of new cars and light trucks will benefit from the resulting savings in fuel costs over those vehicles' *entire lifetimes*, rather than just the first 30 months they own and drive them. Requiring manufacturers to improve fuel economy beyond the levels they would voluntarily offer by raising CAFE standards may thus produce fuel savings that ultimately repay their initial costs, even if those improvements require longer than 30 months to do so. Consequently, imposing stricter CAFE standards can provide fuel savings and other benefits that exceed the costs to achieve them, making society better off as a result.

4.3 Impacts on the Market for New Cars and Light Trucks

Raising CAFE standards requires manufacturers to improve the fuel economy of some – and perhaps most – car and light truck models, and by doing so will increase manufacturers' costs to produce them. These direct impacts are the initial source of all costs and benefits that ultimately result from imposing higher standards. Of course, potential buyers are also sensitive to new vehicles' purchase prices, and these are likely to rise as manufacturers attempt to recover the costs for improving fuel economy to sustain their profitability. Imposing higher CAFE standards may cause manufacturers to scale back or even forego planned improvements in other features, if by doing so they can optimize profits. The analysis presented here holds other vehicle attributes constant, thereby isolating the costs of meeting enhance fuel economy standards. Finally, gradual technological progress in vehicle design and production methods enables manufacturers to improve vehicles' fuel economy slowly over time, thereby reducing their incremental costs for further increasing fuel economy to meet higher CAFE targets.

The economic cost of meeting higher CAFE standards includes changes in consumer welfare (or "consumer surplus") stemming from the difference between higher purchase prices and the perceived value of fuel savings for new cars and light trucks, together with any losses in manufacturers' profits ("producer surplus") stemming from their inability to recover increases in production costs by charging higher prices for new cars and light trucks. Without detailed models of manufacturers' costs to produce vehicles with different combinations of fuel economy and other features, and how vehicles' prices and features affect sales and market shares of competing models, we are unable to estimate the actual economic cost of requiring manufacturers to meet more demanding CAFE standards as the information necessary to do so is closely held by manufacturers and not publicly available. Instead, the agency makes several simplifying assumptions that enable it to approximate the economic costs and benefits of imposing alternative CAFE standards for future model years.

First, we assume that car and light truck manufacturers will be able to recover their full incremental costs for producing vehicles that meet higher CAFE targets in the form of higher selling prices. The agency does not attempt to estimate price increases for specific car and light truck models, and instead simply assumes that their average price will rise sufficiently that increased sales revenue will fully cover manufacturers' increased costs. Our analysis does not attempt to project improvements in vehicles' other attributes that manufacturers would make if they were not compelled to meet higher fuel economy targets, or to value any changes in those other features that producers make to meet more demanding CAFE standards. Our analysis holds other vehicle attributes constant in order to isolate the costs of complying with the fuel economy standards. Our analysis does not account for gradual improvements in the fuel economy of future new cars and light trucks that might occur under current CAFE standards as a result of continuing improvements in vehicle technology, or for how such technological progress might reduce manufacturers' incremental costs to meet higher standards. It does, however, account for fuel economy improvements manufacturers would voluntarily make in response to anticipated increases in future fuel prices and their effect on car and light truck buyers' demands for higher fuel economy.

Manufacturers' use of more advanced technology to improve fuel economy may also increase owners' maintenance or repair expenses.[60] Although some slight deterioration in vehicles' fuel economy as they age and accumulate use appears normal, owners must respond to any unexpected decline by undertaking the maintenance or repairs necessary if they wish to preserve their expected savings in fuel costs. More frequent or costly maintenance and repairs to sustain vehicles' original fuel economy represents an additional cost of requiring new cars and light trucks to meet higher fuel economy targets, and while we do not attempt to estimate it, doing so would increase the costs of meeting higher CAFE standards.

The agency's analysis first assembles data on sales, prices, fuel economy, and other attributes of the car and light truck models each manufacturer produced during MY 2020 (the "reference fleet"). It then projects baseline values of these variables for future model years under the assumption that previously adopted standards remain in effect, including fuel economy improvements that manufacturers would make to "catch up" with prevailing standards, in response to increased market demand for fuel economy, or to take advantage of improvements in engine technology that enable higher fuel economy. Using this regulatory baseline, the agency's CAFE Model simulates the combination of fuel economy improvements each manufacturer could make to specific models in its reference fleet that would minimize its total incremental costs for complying with higher CAFE standards in future model years. Because it does not allow for any fuel economy increases that would result from normal technological progress under the baseline, the agency may overstate manufacturers' costs for improving the fuel economy of their reference fleets to meet higher CAFE standards. At the same time, it omits any opportunity costs imposed on buyers by manufacturers' decisions to redeploy additional technology to increase the reference fleet's fuel economy rather than improve other features of vehicles that buyers also value, and this omission may understate the economic costs of meeting higher standards—although such compliance strategies would also reduce compliance costs, which would have a countervailing effect. It is difficult to anticipate the net effect of these omissions, but the agency's view is that they are likely to have modest effects on the true economic costs of meeting stricter CAFE standards.

[60] Some significant changes in technology, such as converting from internal-combustion power to batter-electric drive, may reduce maintenance costs.

4.3.1 Near-Term Effects of Raising CAFE Standards in the Market for New Cars and Light Trucks

This section describes how we estimate the effects of higher CAFE standards on new vehicle sales and the used car market. The changes in selling prices, fuel economy, and any other features of cars and light trucks produced during future model years will affect both sales of individual models and the total number of new vehicles sold. On balance, the changes in prices and fuel economy resulting from manufacturers' efforts to comply with higher CAFE standards are likely to reduce total sales of new cars and light trucks during future model years, because we assume that at the time they decide which models to purchase, buyers value those improvements at less than manufacturers' costs to make them.

The logic underlying this assertion is simple: if manufacturers believed that potential buyers valued fuel economy (and adjusted purchasing decisions accordingly) sufficiently that improving it – while raising vehicle prices to cover their incremental costs for doing so – would increase sales, they would do so even in the absence of higher standards because their profits would rise.[61] Conversely, the observation that manufacturers do not voluntarily provide the levels of fuel economy this final rule will require suggests that they believe being required to do so will reduce their sales and profits.[62] However, the relative importance of prices, fuel economy, and vehicles' other attributes to potential buyers both at the time of purchase and subsequently is not fully understood and is also likely to vary widely among consumers, so their combined effect on sales of new car and light truck models – and even on the mix of those two categories – is difficult to anticipate. The following sections detail our approach to estimating changes in new car and light truck prices, the response of sales, and their implications for consumer welfare.

Figure 4-2 illustrates the final rule's likely near-term effect on total sales of new cars and light trucks. Under the baseline scenario, total demand for new cars and light trucks is shown by the demand curve D_0, which shows the number that will be purchased at each price. The industry-wide supply curve – which depicts the number produced and offered for sale at each price – is shown by S_0 in the figure; in the baseline, demand and supply interact to result in total sales of Q_0 vehicles at a price of P_0. Increasing the amount of fuel economy-improving technology that manufacturers must employ by raising CAFE standards increases their costs to produce new vehicles, and this effect is shown as an upward shift in the industry-wide supply curve to S_1. To preserve their profitability, manufacturers would charge higher prices that reflected their increased costs (on average across their entire model lineups, if not for each individual model), and if there were no accompanying change in demand, annual sales would decrease to the level corresponding to Q_0*.

[61] Note that some market failures, like information asymmetries and the first-mover disadvantage, could disrupt standard assumptions about the balancing of supply and demand.

[62] If manufacturers absorb some costs to increase fuel economy to avoid losing sales, the resulting losses in consumer welfare will be smaller. Insofar as this occurs, however, manufacturers' profits will decline, and this represents an additional cost of requiring higher fuel economy. The sum of losses in consumer and producer welfare is likely to vary relatively little under alternative assumptions about the extent to which manufacturers can recover their increased costs by increasing prices.

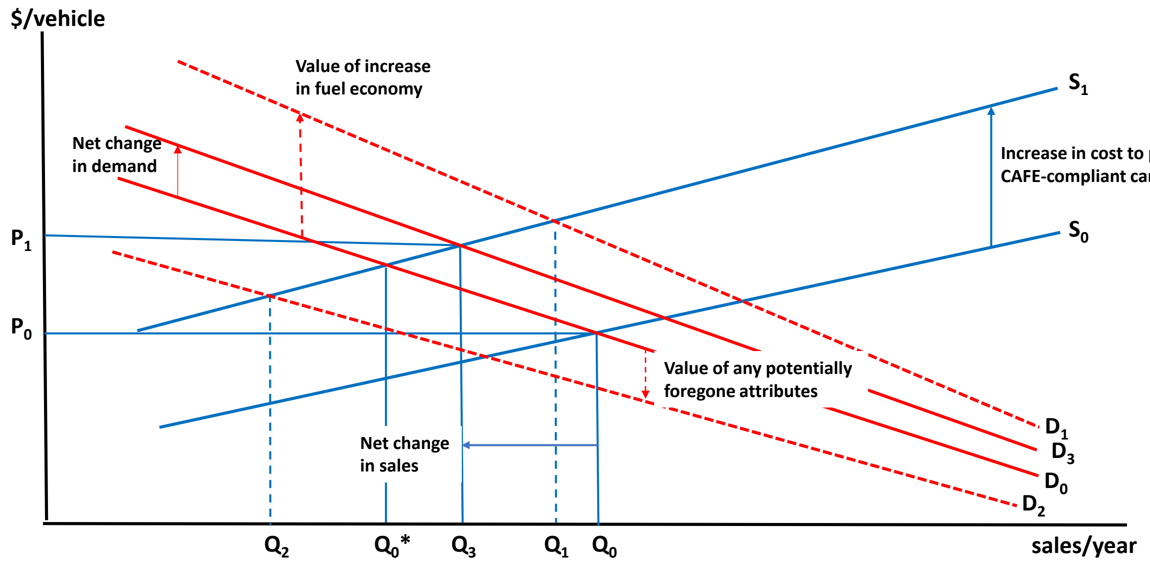

Figure 4-2 – Effect of Changes in Prices, Fuel Economy, and Other Attributes on Demand and Sales of New Cars and Light Trucks

As indicated in the previous section, however, the combination of fuel economy and other features of some new car and light truck models will also change, as their manufacturers employ more advanced technology and may potentially forgo some improvements they would otherwise have made in those models' other desirable features as they optimize profit. Both changes will affect consumer demand for new vehicles, but they are likely to do so in opposite directions.[63] On one hand, improving vehicles' fuel economy reduces their operating costs, which improves their appeal to potential buyers; by itself, this would shift demand for new vehicles upward – for illustrative purposes, to the level shown by the demand curve D_1 in Figure 4-2. The changes made to enhance fuel economy may also enhance other vehicle attributes, which could make vehicles more attractive. The specific form of the upward shift in demand shown in the figure reflects a distribution of buyers' valuations of higher fuel economy, with those toward the upper (or left) end of D_1 willing to pay the most for increased fuel economy, and buyers showing progressively lower values of higher fuel economy moving down and to the right along D_1.

In conjunction with price increases that reflect manufacturers' higher costs, the increase in demand caused by the improvement in fuel economy would limit the decline in sales to Q_1, if no other changes in vehicles' attributes occurred.[64] At the same time, however, any accompanying reduction in improvements to their other features will reduce new models' desirability to potential buyers; this would reduce market demand, as illustrated in Figure 4-2 by the downward shift in the demand curve to D_2. In conjunction with higher prices that fully recovered

[63] Note, however, that many technologies can both increase fuel economy and improve other vehicle attributes.
[64] Whether potential buyers correctly value the future savings in fuel costs they would experience from purchasing models with higher fuel economy is uncertain, and empirical research on this question shows mixed results. If shoppers correctly valued those savings and they exceeded manufacturers' costs to improve fuel economy, however, manufacturers could profit by doing so and sales would increase even with price increases that reflected their higher costs.

manufacturers' costs, any sacrifice in improvements to vehicles' other desirable features would reduce their sales to Q_2 if it were not accompanied by improvements in their fuel economy.

The net effect of these two changes on demand for new cars and light trucks is difficult to anticipate, because it depends on the specific changes in fuel economy and vehicles' other features that manufacturers make, as well as on the distributions of values that buyers attach to fuel economy and those other attributes. As Figure 4-2 shows, if buyers view the combination of higher fuel economy and more modest improvements in vehicles' other features (compared to the combinations of attributes manufacturers would have offered under the No-Action Alternative) as making future models more desirable on balance, demand for new vehicles will ultimately settle at a position such as D_3 and their price will rise to P_1. Consequently, sales will decline to the level Q_3 shown in the figure, because the effect of higher prices will outweigh the increase in new vehicles' overall desirability.[65] More generally, sales of new cars and light trucks will decline as long as potential buyers find that the combination of higher prices and foregone improvements in vehicles' other features outweighs the value of their improved fuel economy, which the agency concludes is the most likely response.[66] Our analysis also assumes that the increase in new car and light truck prices occurs at the outset of the model year when higher CAFE standards take effect, and that the resulting decline in their sales occurs throughout the period when that model year is on sale.[67]

4.3.2 Near-Term Effects on the Used Vehicle Market

By affecting the fuel economy, selling prices, and other features of new cars and light trucks, raising CAFE standards will affect not only new vehicle sales, but also the demand for used models. This is because used cars and light trucks – especially those produced during recent model years – offer a potential substitute for new models, so changes in prices and other attributes of new car and light truck models will influence demand for used versions. This will affect the market value and selling prices of used vehicles, which in turn will influence some owners' decisions about whether to make the repairs necessary to keep their used models in service and how much to drive them. Regulations on new cars can also affect their durability and retirement rates directly—by making them costlier to repair and maintain— and affecting their owners' decisions about how long to keep them in use. Changes in the number of used vehicles kept in service and how much they are driven can have important consequences for fuel consumption, safety, and emissions of GHGs and criteria air pollutants, so it is important for the agency to consider how raising CAFE standards will affect the number and use of older vehicles. The effect that regulations that raise prices for new vehicles can have on the size and utilization

[65] It is also possible that buyers will regard the combination of higher fuel economy and lesser improvements to vehicles' other features will on balance make future models less desirable, in which case D_3 will lie below the original demand curve D_0 shown in the figure. Sales will also decline in that case, despite a smaller price increase.
[66] Again, if manufacturers could increase sales and profits by improving fuel economy and raising prices enough to recover their higher costs, they would do so voluntarily.
[67] Again, to simplify the analysis, the agency assumes that vehicles produced during a model year are sold entirely within the contemporaneous calendar year.

of the used vehicle fleet has been well documented and is the subject of extensive empirical research, and is often referred to as the "Gruenspecht effect."[68]

Figure 4-3 illustrates the immediate effects of higher CAFE standards on the market for used cars and light trucks. Faced with higher prices for new models that feature improved fuel economy (and perhaps less desirable combinations of other features), some households and businesses will rely on used cars or light trucks as an alternative to purchasing a new one. Their decisions will increase demand for used cars and light trucks, shifting the demand curve for used models in the figure from its original position at D_0 outward to D_1. Shifts in demand for used cars and light trucks of different ages in response to changes in the prices and attributes of new models are likely to mirror how closely they substitute for their new counterparts. Nearly new vehicles offer the closest substitute for new ones, so their demand is likely to be most responsive to changes in prices and other characteristics of new ones, while the outdated features and accumulated usage of older vehicles make them less satisfactory substitutes. Demand for nearly new cars and light trucks is likely to increase significantly when prices for new models rise, while increases in the demand for older vehicles are likely to be progressively smaller.

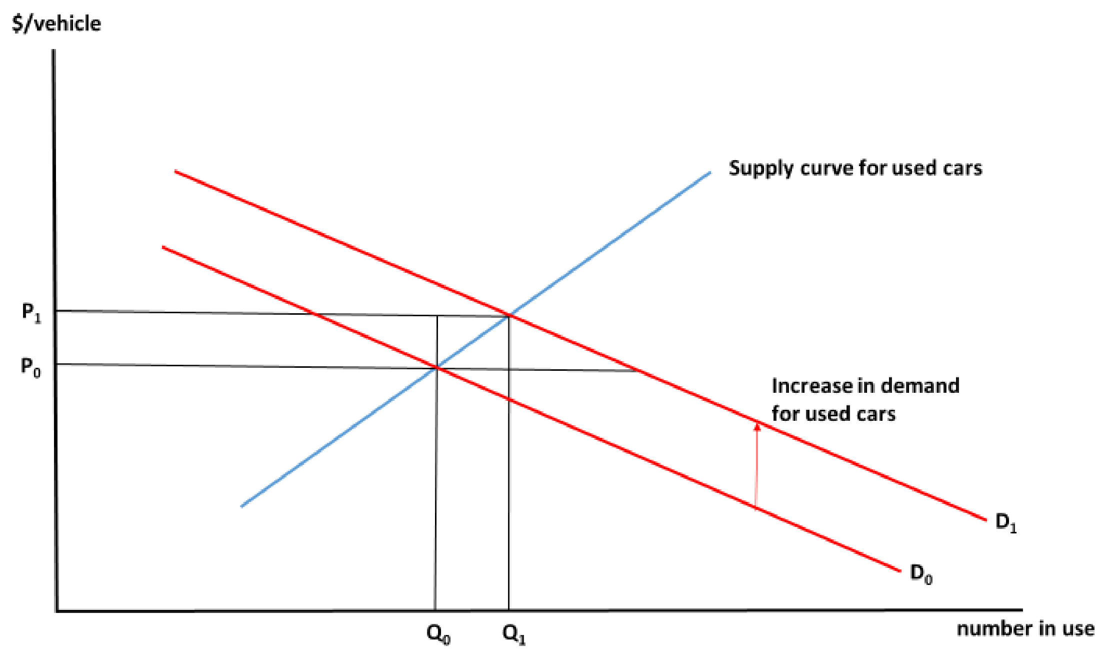

Figure 4-3 – Effect of Increasing CAFE Standards on the Market for Used Cars

In Figure 4-3 the position of the supply curve for used vehicles reflects the initial size of the used vehicle fleet at the outset of the period, which in the agency's analysis is the current new-car model year and calendar year. The supply of used vehicles is likely to be relatively insensitive to changes in their price (or "inelastic"), but it is not fixed, because owners can increase the number

[68] Gruenspecht, Howard. "Differentiated Regulation: The Case of Auto Emissions Standards." American Economic Review, Vol. 72(2), pp. 328-31 (1982).

that are available by spending more on the maintenance and repairs necessary to keep older models in service rather than retiring them. This is shown by the upward-sloping supply curve in Figure 4-3, which reflects the fact that the repairs and maintenance necessary to increase the number of used vehicles in usable condition are likely to become progressively costlier as more of those that would otherwise have been retired are instead kept in use.

The interaction of increased demand for used car and light truck models and their inelastic supply will cause their average market value and selling price to rise, from P_0 to P_1 in the figure. Some owners who would previously have retired their used vehicles will find that their higher market value justifies the expense of any maintenance and repairs necessary to keep them in service longer, so the increase in their price will raise the number kept in service, from Q_0 to Q_1. Because the market for used vehicles is very active – sales of used cars and light trucks have averaged nearly 40 million in recent years, nearly three times the number of new models sold annually – these responses are likely to occur rapidly, probably within the same model year as those in the new car market shown previously in Figure 4-2.

These indirect effects of raising CAFE standards on the used vehicle market will continue as long as standards continue to be raised. In effect, this process will slow the "turnover" of the nation's light-duty vehicle fleet from its pace under the baseline, by reducing the rate at which new cars and light trucks enter the fleet to replace the used vehicles that are retired each year. Coupled with the reduction in sales of new cars and light trucks likely to result from raising CAFE standards, the resulting rise in the number of used models kept in service will in effect "transfer" some travel that would have been done in new vehicles to older models. As emphasized throughout this regulatory analysis, this shift of travel toward older cars and light trucks has important implications for fuel consumption, safety, and the environmental externalities associated with fuel supply and use.

4.3.3 Longer-Term Effects on New and Used Vehicle Markets

Because new and used car and light truck models can substitute for one another in meeting households' demands for transportation services, the change in used vehicle prices will have secondary effects in the market for new cars and light trucks, as Figure 4-4 illustrates. Higher prices for used cars and light trucks in turn increase demand for new models, and this effect is shown in Figure 4-4 as a shift in demand for new cars and light trucks outward from D_3, its final near-term position shown previously in Figure 4-2, to D_4. In conjunction with the upward-shifted supply curve shown previously in Figure 4-2, which reflects manufacturers' increased costs to produce CAFE-compliant new cars and light trucks, this secondary increase in demand raises their prices further from their ultimate level P_1 in Figure 4-2 to P_2 in Figure 4-4.

At the same time, however, the further outward shift in the demand curve for new cars and light trucks mitigates the near-term decline in sales of new vehicles; in Figure 4-4, new car and light truck sales ultimately settle at Q_4, a level higher than their near-term equilibrium level Q_3 shown previously in Figure 4-2, although still lower than their original level Q_0. Thus, the longer-term effect of raising CAFE standards on sales of new cars and light trucks is likely to be more modest than it would have been if new and used vehicles were not substitutable and there were no interactions between markets for the two. In contrast, the ultimate effect on new car and light truck prices may be larger than the immediate effect, although the secondary effect caused by higher used car prices is likely to be modest, as Figure 4-4 suggests.

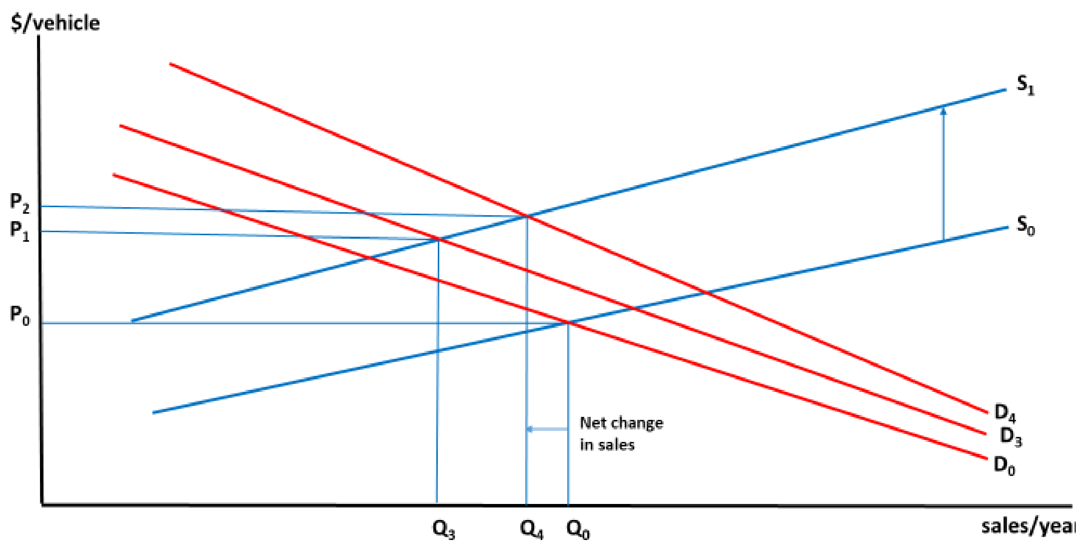

Figure 4-4 – Longer Term Effects on Sales and Prices of New Cars and Light Trucks

Finally, there are also likely to be secondary impacts on the market for used cars and light trucks. First, the secondary increase in prices for new cars and light trucks will raise demand for their used counterparts, again because – within limits imposed by changes in their design over time and the effects of accumulated use – the two can substitute for each other in providing transportation services for households and businesses. At the same time, the decline in sales of new cars and light trucks during the current model year reduces the supply of used models available in future years, and this effect accumulates over time, particularly if CAFE standards are raised year after year. This occurs simply because fewer new cars are initially produced and sold during each model year subject to higher standards, so fewer remain in use at the outset of any subsequent calendar year and available to be maintained in (or restored to) working condition when their market values rise. While the effect of higher new-car prices on demand for used vehicles is likely to be felt within the current model year, the reduction in their supply resulting from lower new vehicle sales will accumulate slowly over time.

Figure 4-5 illustrates these longer-term effects. The secondary increase in prices for new cars and light trucks increases demand for used cars further relative to the near-term effect of higher new car prices, shifting the demand curve from its previous position at D_1 in Figure 4-3 further outward to D_2 in Figure 4-5. At the same time, the reduction in sales of new cars and light trucks reduces the supply of used versions available in future years, and this effect – which accumulates over time, as noted above – is represented in Figure 4-5 as an inward shift in the supply curve for used vehicles, from S_0 to S_1. Increased demand and reduced supply interact to raise the average price for used cars and light trucks further beyond its near-term increase to P_1 shown previously in Figure 4-3, to the slightly higher level P_2 in Figure 4-5. In response to this further increase in their market value, the number remaining in working condition adjusts further; depending on the relative magnitudes of the shifts in demand and supply, the final equilibrium size of the used vehicle fleet can be larger or smaller than in the nearer term. Figure 4-5 illustrates the case where the effect of reduced supply outweighs that of increased demand and the number of used vehicles in service (Q_2) declines relative to the near term (Q_1), but the more certain and important effect is that the final equilibrium size of the used vehicle fleet (Q_2 in Figure 4-5) is larger than it would have been if CAFE standards were not raised (Q_0).

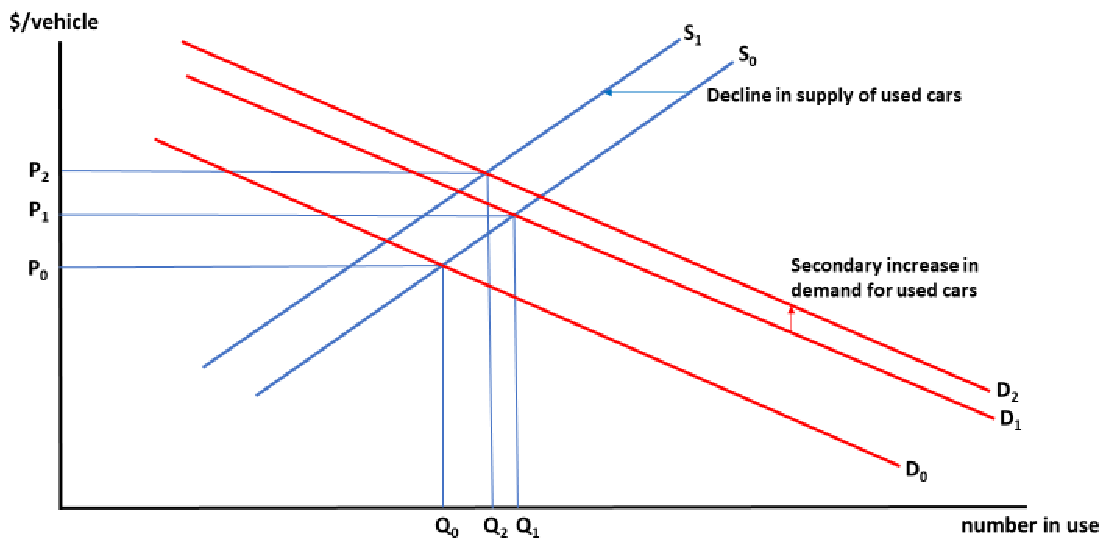

Figure 4-5 – Longer Term Effects on Prices and for Used Cars and Light Trucks and the Number Remaining in Service

In theory, these reciprocal responses of new- and used-car demand to increasing prices for each other continue until markets for the two jointly reach a new equilibrium, although in practice these further adjustments seem likely to "dampen out" relatively quickly. It is difficult to anticipate exactly how long these complex adjustments will continue, but most of the ultimate change in new car and light truck prices and sales should be largely complete within the same model year when higher CAFE standards take effect. However, the complete effects on prices and sales of used vehicles shown in Figure 4-5 are likely to require considerably longer to be fully felt, because they depend in part on the longer-term cumulative effect of lower new vehicle sales on the supply of used models.

4.3.4 Estimating Impacts in the new and Used Vehicle Markets

We use an econometric model that captures the historical relationship of sales to their average price, disposable personal income, and other economic conditions to estimate the change in total sales of new vehicles when CAFE standards increase during future model years. The agency estimates the shares of future sales accounted for by cars and light trucks using a model developed by the U.S. Energy Information Administration as part of its National Energy Modeling System (NEMS), which relates those shares to fuel prices, the relative fuel economy levels of new cars and light trucks, other attributes that differ between the two, and their recent historical shares of total sales. This process is described in detail in Chapter 4.2.1 of the TSD accompanying this final rule.

To estimate the effects of raising CAFE standards on the used vehicle fleet, we use a detailed econometric model relating prices, fuel economy, and other characteristics of new cars and light trucks to retirement rates for each vintage of used vehicles making up the current fleet. This model also controls for the increasing durability of new vehicles over time, fuel prices, macroeconomic conditions, maintenance and repair costs, and other factors that influence year-to-year variation in used vehicles' retirement rates. Our development and use of this model is described in Chapter 4.2.2 of the TSD accompanying this final rule.

4.4 Welfare Effects in the New and Used Vehicle Markets

The likely decline in sales of new cars and light trucks during future model years when stricter CAFE standards take effect produces two sources of economic costs. Figure 4-6 illustrates these costs for the simplified case where demand for new cars and light trucks increases (from D_0 to D_1) as their manufacturers improve fuel economy to comply with stricter standards but make no accompanying sacrifices in their models' other attributes.[69] Although the upward shift in the demand curve in response to improved fuel economy by itself would increase sales, higher prices – which rise from P_0 to P_1 as producers attempt to recoup their higher costs for producing vehicles meeting the stricter standard – suppress sales by more than enough to offset this gain. On balance, sales of new cars and light trucks decline to Q_1. On one hand, this example provides a conservative estimate of costs, because if manufacturers forego any improvements in vehicles' other features as part of their effort to increase fuel economy, the decline in sales will be larger than Figure 4-6 shows, as the discussion of Figure 4-2 above indicated. On the other, the assumption of "perfectly elastic" supply (indicated by the horizontal supply curve shown in the figure) may slightly exaggerate the increase in prices. Under the perhaps more realistic assumption of inelastic supply of new cars and light trucks manufacturers would absorb some of

[69] Unlike in Figure 4-2 and Figure 4-4 above, the industry supply curve for new cars and light trucks is shown in Figure 4-2 as "perfectly elastic," meaning that additional vehicles can be produced at constant incremental costs, and this same assumption of elastic supply is used to analyze most other impacts of raising CAFE standards. We use this assumption mainly to simplify the presentation of how benefits are measured, and also partly because the alternative assumption of inelastic supply complicates the measurement of welfare impacts by requiring changes in producer surplus as well as in consumer surplus to be estimated empirically. Assuming inelastic supply of new cars and light trucks would affect the agency's analysis because some of the increased costs to produce vehicles meeting a higher CAFE standard would be absorbed by producers rather than passed through to buyers in the form of higher prices, so the decline in sales would be slightly smaller than the agency estimates. We do not believe that this treatment would significantly affect its estimates of costs and benefits, although it would lead to different conclusions about their distribution among producers and buyers of new cars and light trucks.

their increased costs to meet a stricter standard, so the increase in prices and resulting decline in sales would be slightly smaller than Figure 4-6 shows.[70]

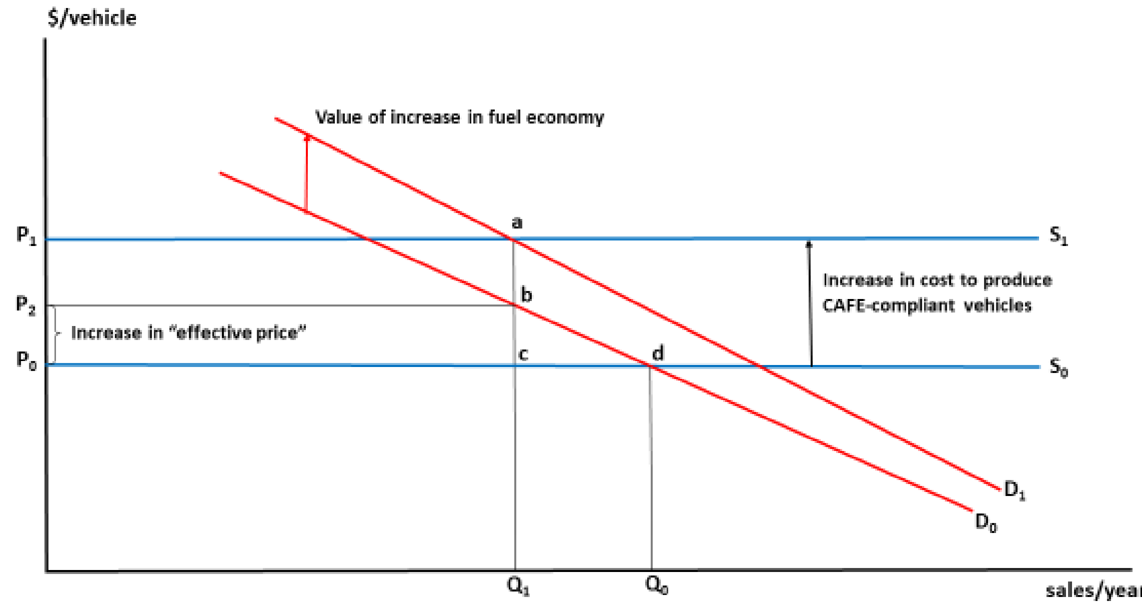

Figure 4-6 – Welfare Effects in the Market for New Cars and Light Trucks

First, although buyers who purchase new cars and light trucks even at their higher price are those with the highest values of improved fuel economy, they are collectively likely to experience some loss in welfare from the combination of higher prices and improved fuel economy. Their net loss in welfare is measured by their increased outlays to purchase Q_1 new vehicles, shown as rectangle P_1acP_0 in Figure 4-6 (its area is the increase in price multiplied by the number that continue to be sold), minus the value they attach to the savings in fuel costs that result from higher fuel economy. This latter value is the smaller rectangle P_1abP_2, since its area equals the value of improved fuel economy (the distance ab, or the upward shift in the demand curve) multiplied by the number of new vehicles that continue to be sold (Q_1). Together, these partly

[70] This would result in a loss in manufacturers' short-term profits or "producer surplus," while the loss in consumer surplus would be smaller than shown in Figure 4-6. With the magnitude of the sales price elasticity the agency uses to estimate changes in new vehicle sales, the sum of these losses in producer and consumer surplus would be very similar in magnitude to the loss in consumer surplus the agency reports. Producer surplus, a welfare measure analogous to consumer surplus, is equal to the difference between sales revenue that suppliers receive from selling increased output and their short-run incremental costs for producing it; this measure corresponds to suppliers' short-term gain in profit on the increased output. For a complete discussion, see Richard E. Just, Darrel L. Hueth, and Andrew Schmitz, *The Welfare Economics of Public Policy*, Northampton MA, Edward Elgar Publishing, Inc., 2004, Sections 4.2 and 4.3.

offsetting impacts leave net losses to continuing buyers equal to rectangle P_2bcP_0.[71,72] Another way to view this result is that the "effective price" of new vehicles – the difference between the actual increase in their price and the increase in their value due to their higher fuel economy – increases only from P_0 to P_2, so the loss to "continuing" buyers is equal to the product of this effective price increase and the number of vehicles that continues to be sold.

Second, some buyers who would have purchased new cars and light trucks under the baseline fuel economy standard will decide not to do so once stricter CAFE standards take effect, and these buyers experience smaller losses in welfare. On average, their valuation of higher fuel economy is slightly lower than those who continue to purchase new vehicles, and consequently the increase in average prices deters their purchases and reduces the number sold from Q_1 to Q_0. The welfare loss to buyers who forego purchases they would otherwise make because of new vehicles' higher "effective price" is represented by triangle bcd in Figure 4-6.

The consequences of the effects of higher CAFE standards in the used car market discussed previously for economic welfare are complex. Higher prices for used vehicles result in a loss of consumer surplus to their potential buyers, which is shown in Figure 4-3 below (a simplified version of the previous Figure 4-5) as the area P_2abP_0. However, much of this loss is simply a transfer to suppliers of used cars and light trucks, who are a combination of retail dealers and individual owners selling used vehicles on the private market. Collectively, they experience a gain in "producer surplus" equal to area P_2acP_0 in Figure 4-7, which offsets much of the loss in consumer surplus to buyers; the remaining uncompensated loss in consumer surplus is the triangle abc. Estimating the value of this loss would require detailed data on prices for used cars and light trucks of different ages, together with estimates of both the elasticity of their supply (which would also be expected to vary with age) and the "cross-elasticities" of demand for used cars and light trucks of varying ages with respect to the prices of new models.[73]

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[71] Again, the agency is unable to quantify any changes in other features that are likely to accompany the increase in new vehicles' fuel economy, or to estimate the value those features would have provided to car and light truck buyers.

[72] As indicated previously, there is presumably some distribution of values of higher fuel economy among potential new-car buyers rather than a uniform value, and that distribution is reflected in the increasing divergence between the demand curves D_0 and D_1 at quantities below Q_1 in Figure 4-3. The distance (P_1-P_2) or ab measures the value of fuel economy only for the marginal buyer (the buyer of the Q_1st vehicle) after the standard is imposed or raised, so (P_2-P_0) or bc is the effective price increase only as viewed by that marginal buyer. Losses to other continuing buyers will be smaller, because their values of fuel economy exceed (P_1-P_2) or ab and thus offset more of the increase in the "unadjusted" price (which is the distance P_1-P_0, or ac) than is the case for the marginal buyer. As a result, the agency's measure of welfare losses to continuing buyers will overstate their actual loss to the extent that the value they collectively attach to the increase in fuel economy exceeds $(P_1-P_2)*Q_1$ or the area P_1abP_2, since this will make their total loss smaller than the area $(P_2-P_0)*Q_1$ or P_2bcP_0 by that same amount. Without knowing the distribution of values of fuel economy among potential buyers, it is difficult to anticipate the magnitude of this overstatement; however, interpreting the estimates of (P_1-P_2) and (P_2-P_0) as average values is consistent with the approach used throughout the agency's analysis.

[73] While the estimated coefficients of the "scrappage model" described in Chapter 4.2.2 of the TSD could be used to develop elasticities of supply for used cars and light trucks, we do not have access to the remaining information necessary to calculate this welfare loss.

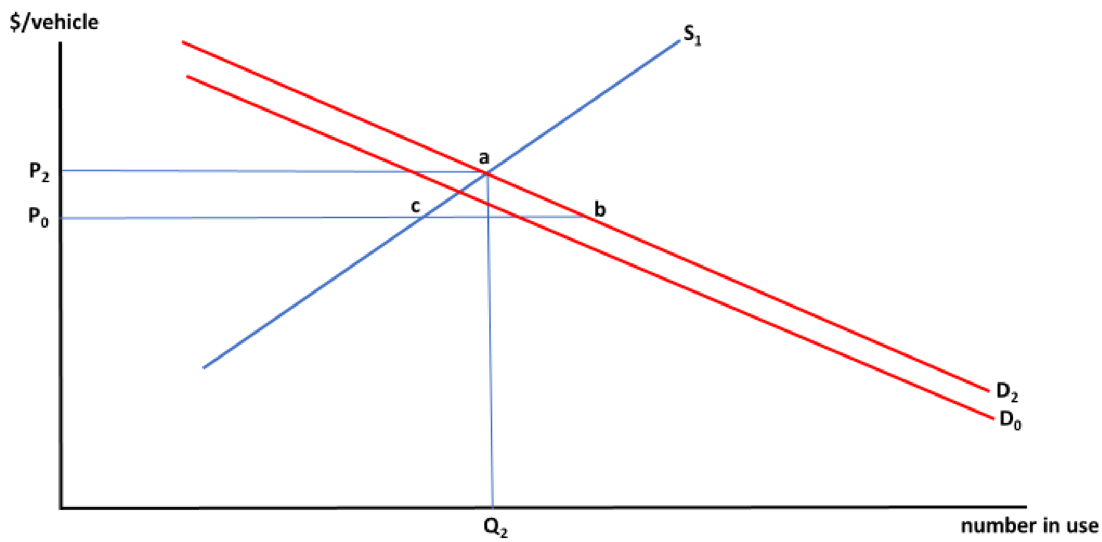

Figure 4-7 – Welfare Effects in the Market for Used Vehicles

As discussed previously, however, the increase in used car prices that creates these welfare effects in the used car market causes an increase in demand for new cars and light trucks, which will ultimately be incorporated in the longer-run upward shift of the new-car demand curve (D_4) shown previously in Figure 4-4. Although not shown explicitly there, the further increase in new-car demand that occurs in response to higher prices for used vehicles acts much like the improvement in new cars' fuel economy, by limiting the decline in their sales and the accompanying loss in consumer surplus to their would-be buyers. Under reasonable assumptions, this reduction in the welfare loss to new vehicle buyers will approximately offset the net loss in welfare in the market for used vehicles.[74] Hence our analysis omits both effects, under the assumption that including them would have little effect on the comparison of total costs and benefits from imposing higher CAFE standards.

4.5 Effects of Higher CAFE Standards on Vehicle Use

The fuel economy rebound effect – a specific example of the well-documented energy efficiency rebound effect for energy-consuming capital goods – refers to the tendency of motor vehicles' use to increase when their fuel economy is improved and the cost of driving each mile declines as a result. Increasing CAFE standards will lead to higher fuel economy for new cars and light

[74] These assumptions are that the effect of used car prices on the demand for new cars and the reverse effect of new car prices on demand for used cars are approximately equal, and that the real income effects of those price changes are minor. For a fuller explanation and example, see Anthony Boardman, David Greenberg, Aidan Vining and David Weimer. 2018. *Cost-Benefit Analysis: Concepts and Practice*, Cambridge, U.K., Cambridge University Press, Chapter 7. A different explanation that arrives at the same conclusion is Herbert Mohring, *Transportation Economics*, Cambridge MA, Ballinger Publishing Co., 1976, Chapter 5.

trucks, thus reducing the amount of fuel they consume per mile. The resulting decline in the cost to drive each mile will lead to an increase in the number of miles they are driven each year over their lifetimes. For its analysis of this final rule, we use a value of 10 percent for the fuel economy rebound effect, which implies that for a 10 percent increase in fuel economy will produce a 1 percent increase in average annual driving.[75]

4.5.1 The Fuel Economy Rebound Effect and Vehicle Use

Figure 4-8 illustrates the effect of new vehicles' higher fuel economy on the number of miles they are driven annually. As it shows, vehicles' per-mile operating costs include the cost of fuel they consume, the expected cost associated with potential crashes, maintenance and repair outlays, operating costs other than fuel (oil, tire wear, etc.), and the value of their occupants' travel time.[76] Requiring new cars and light trucks to achieve higher fuel economy will reduce the amount of fuel they consume each mile they are driven, thus reducing their per-mile driving cost; this is shown in the figure as a reduction in the total cost of driving each mile from C_0 to C_1. If the use of new cars and light trucks remained unchanged, their owners' total savings in fuel costs would be the rectangle C_0abC_1, whose area is the product of the reduction in per-mile fuel costs and the number of miles driven.[77] However, the decline in driving costs leads to a downward movement along the demand curve for vehicle use, increasing the average number of miles that new cars and light trucks are driven annually from M_0 to M_1.

[75] For a detailed review of recent empirical evidence on the magnitude of the rebound effect and a discussion of our choice of the 10 percent value, see Chapter 4.3.3 of the TSD accompanying this final rule.
[76] Drivers presumably consider only the fraction of costs they and their passengers expect to bear in the event they are involved in a crash when they decide to make additional trips or drive longer distances; these are shown as the private cost of crash risk in Figure 4-8. The remaining fraction of these costs is borne by occupants of other vehicles (as well as pedestrians and others using the road) and is thus an "external" cost of their decisions. It is included with other external costs drivers impose in Figure 4-9.
[77] Of course, this savings would decline over time as these once-new vehicles are driven progressively less and begin to be retired, but the savings in fuel costs for each successive model year required to meet the higher standards would be equal to this same area during the year it was initially sold.

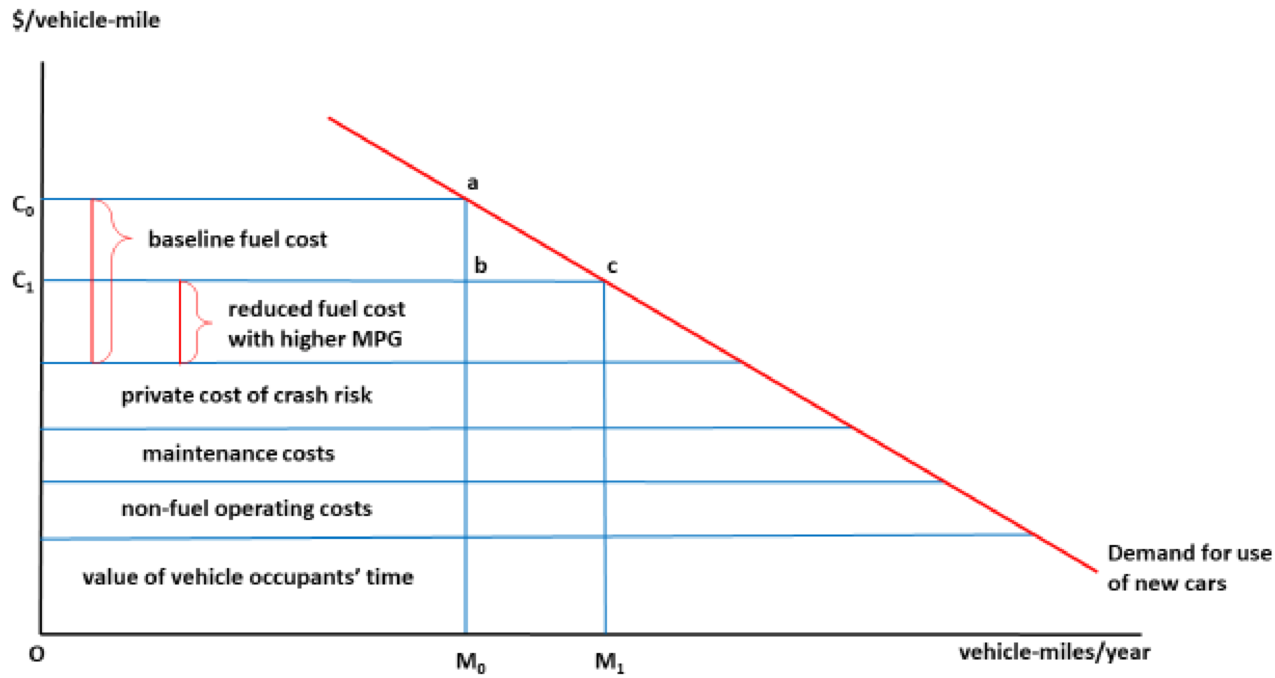

Figure 4-8 – Effect of Relaxing CAFE/GHG Standards on New Car and Light Truck Use

Two direct economic benefits (as well as a variety of indirect economic benefits and costs, which are discussed in subsequent sections) will result from the increase in new vehicles' fuel economy. First, car and light truck buyers' annual outlays for fuel will decline throughout the lifetimes of the models they purchase, as raising CAFE standards leads to higher fuel economy levels and reduces fuel consumption. The magnitude of this benefit depends on how much new vehicles' average fuel economy increases when future standards are raised, how much they are driven each year, and future retail prices for fuel. During the year they are initially sold, it is measured by the difference between drivers' annual driving costs with higher standards in effect, area C_1cM_1O in Figure 4-8, and their driving costs with the lower baseline CAFE standards in effect, or C_0aM_0O. This difference – which is negative, indicating that it represents a net savings – is also equal to the cost of fuel consumed by additional driving (area M_0bcM_1) minus the savings in fuel costs on the amount of driving that would have been done under the baseline resulting from the improvement in fuel economy (area C_0abC_1).[78]

The agency estimates this savings using improvements in the fuel economy of individual cars and light truck models projected to result from raising CAFE standards, assumptions about how much they will be used with and without the increased driving due to the rebound effect of higher fuel economy, and forecasts of fuel prices from the EIA's *Annual Energy Outlook 2021*. As indicated above, this savings declines over vehicles' lifetimes as they are driven less and gradually retired from use, although its normal decline can be partly or completely offset by rising fuel prices. The savings in fuel costs for each model year required to meet higher CAFE

[78] Figure 4-8 exaggerates the scale of the increase in driving (M1-M0) for illustrative purposes, which makes it difficult to see that this will necessarily be a savings.

standards will equal this same area during the year it is initially sold and decline similarly over its lifetime in the fleet.

Second, the additional mobility associated with increased driving provides benefits to new car and light truck buyers. These benefits must be more than sufficient to offset the costs of their additional driving, including fuel expenses, vehicle depreciation, other operating costs, maintenance, the value of travel time, and the increased safety risks they assume; if they were not, no additional driving would occur.[79] In Figure 4-8, mobility benefits from increased driving are equal to the area M_0acM_1, which exceeds the cost of the additional driving, area M_0bcM_1. The amount by which they do measures the net benefit (or gain in "consumer surplus") to buyers of new cars and light trucks from additional driving; it is shown as the area abc in Figure 4-8. Following the usual procedure, we estimate the dollar value of this welfare gain assuming the demand curve for vehicle use is linear over the relevant range, so its annual value can be calculated as one-half of the product of the decline in driving costs ($C_0 – C_1$) and the increase in vehicle use ($M_1 – M_0$).

4.5.2 Externalities from Increased Rebound-Effect Driving

Vehicle use generates external costs via increased traffic congestion and roadway noise, higher accident risks, adverse health effects from air pollution, and climate-related damages caused by emissions of GHGs. Although these external costs are small for *individual* cars and light trucks, the increase in *total* driving that occurs in response to improved fuel economy can increase these costs significantly. The increase in their total value represents an additional cost of requiring new cars and light trucks to meet higher fuel economy targets Figure 4-9 illustrates how we estimate these costs; like the preceding figure, it shows the demand for travel using new cars and light trucks and illustrates the effect of the reduction in per-mile driving costs on their increased use that occurs when their fuel economy improves. For simplicity, however, Figure 4-9 omits the detailed breakdown of total driving costs shown previously, and instead shows the combined external costs imposed by new vehicles' contributions to traffic congestion, road noise, injuries and property damage from crashes, air pollution, and climate-related damages.[80] We assume that the per-mile value of these costs is unaffected by the change in vehicle use estimated to occur in response to improved fuel economy.

[79] If increases in new vehicles' per-mile depreciation (which rises in proportion to their higher purchase prices), maintenance, or other costs offset part of the decline in their fuel costs, empirical estimates of the effect of fuel costs on vehicle use that do not control for these other cost components (which is typically the case) are likely to incorporate any association between fuel and these other costs. Nevertheless, those estimates cannot simply be applied to the overall change in vehicles' per-mile driving cost (including fuel and depreciation) to estimate the resulting change in driving.

[80] As indicated previously, drivers consider only some (unknown) fraction of potential crash-related costs when they decide to make additional trips or drive longer distances. The remaining fraction of these costs – the portion that drivers do not consider because it is likely to be borne by other road users – is an "external" cost of their decisions.

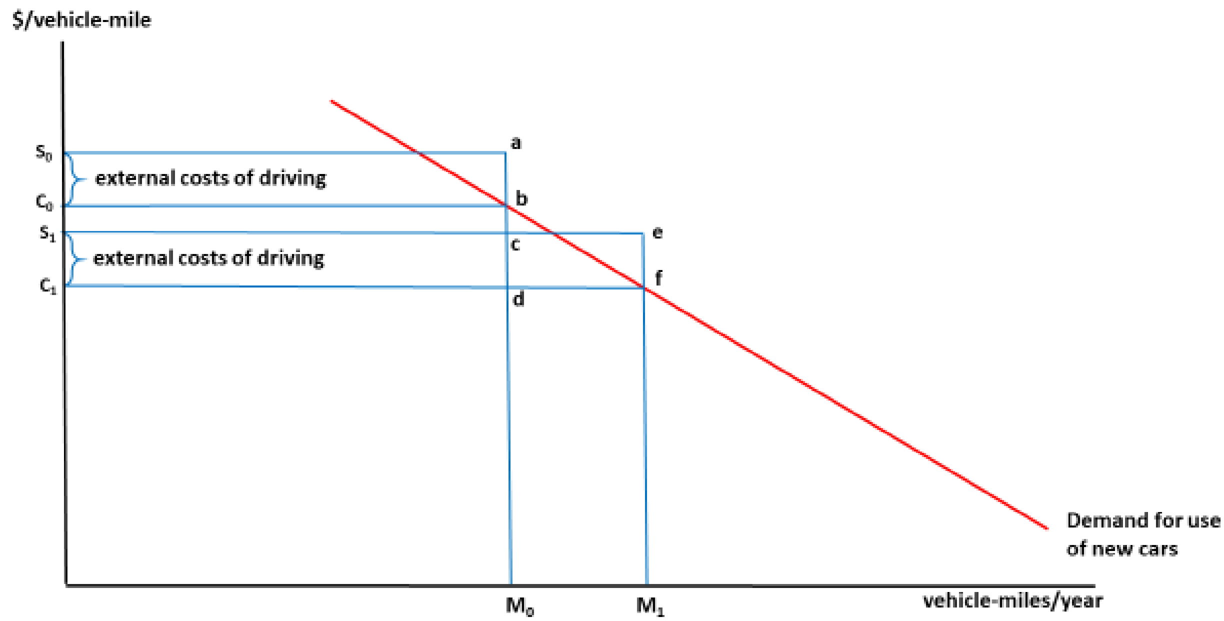

Figure 4-9 – Externalities Resulting from Changes in New Car and Light Truck Use

As in Figure 4-8 previously, Figure 4-9 denotes private costs as C_0 prior to the increase in fuel economy and C_1 with improved fuel economy; per-mile external costs are added to these to estimate the social costs associated with each mile driven, denoted S_0 and S_1. At the level of new car and light truck use that would occur with the baseline standards in effect, these external costs are equal to the product of their per-mile value (shown as the distance $S_0 - C_0$ in Figure 4-9) and the initial level of vehicle use M_0, or the rectangular area S_0abC_0. At the increased level of driving that results when fuel economy increases (M_1 in Figure 4-9), the total cost of these externalities is again the product of their per-mile value ($S_1 - C_1$) and this higher level of use M_1, or the rectangular area S_1efC_1. If the per-mile value of these externalities is unaffected by the increase in new vehicles' use, as the figure assumes, total external costs will increase by the area of the rectangle cefd, which is equal to the increase in the number of miles driven ($M_1 - M_0$), multiplied by the per-mile value of external costs ($S_1 - C_1$).[81] In words, this additional cost is the difference between the total cost of driving-related externalities caused by new cars and light trucks with higher CAFE standards in effect, and the value of those costs if the baseline CAFE standards had remained in effect. It is a direct consequence of additional driving assumed to be caused by the fuel economy rebound effect.

Our analysis calculates the increase in each of these external costs resulting from more intensive use of new cars and light trucks separately. The increase in GHG emissions from additional driving and fuel use is already reflected in the net reduction in total GHG emissions from raising CAFE standards, since this net reduction reflects the decline in fuel production and use after

[81] The largest quantified external cost that might increase significantly with added driving is congestion, since delays depend on the volume of traffic. For the added driving likely to result from raising CAFE standards, however, any increase in delays and congestion costs is likely to be negligible on a per-mile basis. Thus, the increase in total external costs is likely to be proportional to the increase in driving via the rebound effect.

accounting for increased driving. Increases in emissions of criteria air pollutants are calculated from additional driving by new cars and light trucks, together with per-mile emission factors for future model year vehicles derived from EPA's Motor Vehicle Emission Simulator (MOVES) model (which reflect future changes in emission standards). Increases in costs of congestion and road noise are calculated using incremental per-mile contributions of car and light truck use to delays and noise originally estimated by the FHWA and updated for this analysis.[82] Finally, we assume that drivers consider only 90 percent of the costs of injuries and property damage resulting from crashes, so 10 percent of the increase in these costs also represents an external cost of added rebound-effect driving.

4.5.3 Measuring the Fuel Economy Rebound Effect

In recent rulemakings, we have used values of the rebound effect ranging from 10 percent to 20 percent to analyze the effects of changes in CAFE standards on new vehicles' use. Based on an extensive review of recent research on the fuel economy rebound effect that includes additional research and explicitly incorporates uncertainty surrounding empirical estimates of its magnitude, the agency has elected to use a rebound effect of 10 percent to analyze the effects of the alternative increases in CAFE standards considered for this final rule. Chapter 4.3.3 of the TSD accompanying this final rule describes our updated review of empirical evidence on the magnitude of the rebound effect and explains the agency's choice of the 10 percent value.

4.6 Effects of Higher CAFE Standards on Fuel Consumption

Requiring new cars and light trucks to achieve higher fuel economy will significantly reduce demand for transportation fuels. Because gasoline and diesel – which account for the vast bulk of energy consumed to power light-duty vehicles – are refined from petroleum, U.S. demand for petroleum will decline, and this will be reflected in some combination of reduced consumption of U.S. produced or imported crude oil.[83] Extracting and refining petroleum into transportation fuels and distributing them for retail sale produces additional emissions of criteria air pollutants and GHGs beyond those from vehicles' consumption of fuel, so reducing the volume of fuel supplied will generate additional benefits in the form of reductions in the climate and health damages these emissions cause. Finally, reduced spending for fuel by drivers of cars and light trucks will lower tax revenues to both Federal and state governments, which typically fund spending on transportation infrastructure or other programs.[84]

[82] Federal Highway Administration, 1997 Highway Cost Allocation Study, Chapter V (https://www.fhwa.dot.gov/policy/hcas/final/five.cfm), Tables V-22 and V-23. These values were updated to 2016 dollars using the change in the Implicit Price Deflator for U.S. Gross Domestic Product, reported in U.S. Bureau of Economic Analysis, National Income and Product Accounts, Table 1.1.9. (Accessed: February 14, 2022).(https://www.bea.gov/iTable/iTable.cfm?reqid=19&step=2#reqid=19&step=3&isuri=1&1921=survey&1903=13). (Accessed: February 14, 2022).

[83] Accounting for the normal 10 percent ethanol content in most gasoline sold at retail and the lower energy density of ethanol compared to "pure" gasoline, petroleum-based fuels currently account for more than 90 percent of total energy used by light-duty vehicles, and this figure is projected to remain well above 80 percent for the foreseeable future; see U.S. Energy Information Administration, Annual Energy Outlook 2021 (https://www.eia.gov/outlooks/archive/aeo21/tables_ref.php), Table 38. (Accessed: March 28, 2022).

[84] States impose a combination of excise and general sales taxes on fuel and use the revenue those taxes raise to fund a variety of transportation and non-transportation spending programs.

4.6.1 Impacts on Fuel Use and Spending

Imposing more stringent CAFE standards will reduce U.S. demand for petroleum-based transportation fuels, shown in Figure 4-10 as a downward shift in the demand curve for fuel. Cars and light trucks subject to the higher standards will save fuel throughout their lifetimes, while added rebound-effect driving and the shift of some driving to used cars will partly offset this, but on balance, total fuel demand will decline. The U.S. domestic supply of refined transportation fuels appears to be extremely "price-elastic" – that is, increasing production does not exert significant upward pressure on refining costs and fuel prices – so reducing demand is not expected to lower fuel prices, as the figure indicates. Because of lower demand, total fuel consumption will decline from G_0 to G_1 in Figure 4-10, and spending on fuel will be reduced by the rectangular area G_1beG_0.[85] The dollar value of this area is equal to the retail price of fuel per gallon, labeled P_{retail} in the figure, multiplied by the decline in the number of gallons consumed, or $G_1 – G_0$.

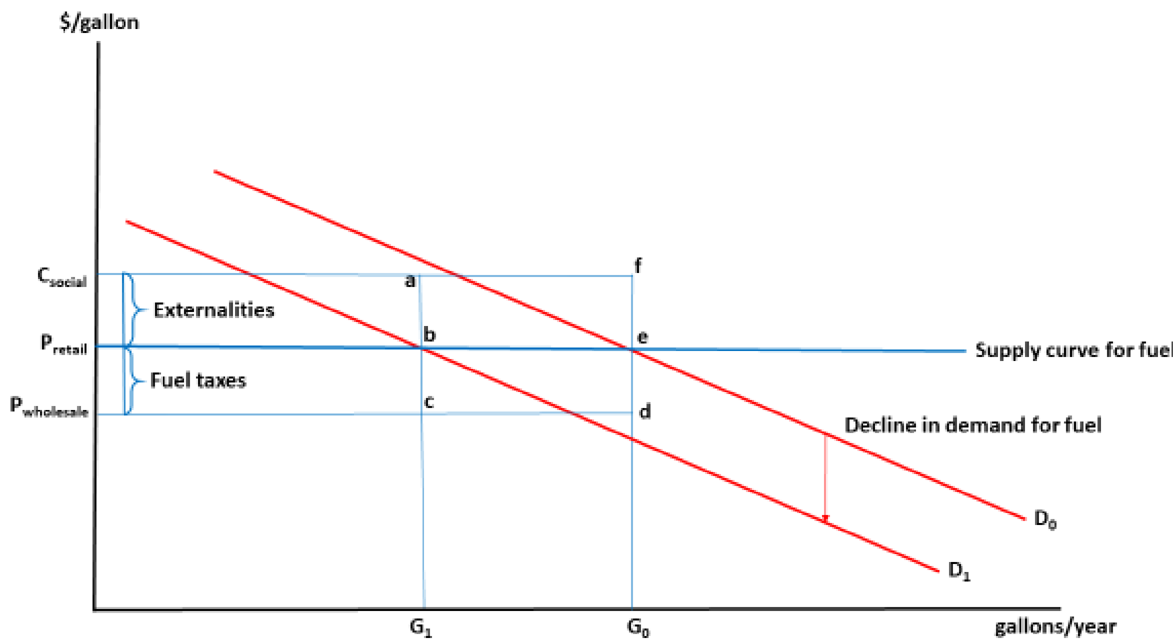

Figure 4-10 – Effect of the Final Rule on Fuel Consumption and Expenditures

Savings in fuel spending by car and light truck owners are measured using retail fuel prices, which include a significant tax component – Federal, state, and some local governments impose taxes on gasoline and diesel that together average approximately $0.50 per gallon.[86] Thus, some

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[85] The decline in total fuel consumption reflects the net effect of fuel savings as new cars and light trucks achieve higher fuel economy, fuel consumption from added rebound-effect driving, and increased fuel use as some driving shifts to older cars and light trucks.

[86] Federal taxes on gasoline and diesel are $0.184 and $0.244 per gallon, while state taxes average $0.281 per gallon on gasoline and $0.296 per gallon on diesel; see Federal Highway Administration, Highway Statistics 2020, Tables FE-101a (https://www.fhwa.dot.gov/policyinformation/statistics/2020/pdf/fe101a.pdf) and MF-205 (https://www.fhwa.dot.gov/policyinformation/statistics/2020/pdf/mf205.pdf). (Accessed: February 14, 2022). Local

fraction of the savings in fuel costs – shown as the rectangle cbed in Figure 4-10 – represents lower tax payments; their dollar value is the product of average fuel taxes per gallon and the decline in the number of gallons consumed annually with higher CAFE standards in effect. However, the loss in benefits from lower spending on programs funded from fuel tax revenue is exactly offset by the component of private savings in retail fuel costs that represents lower fuel tax payments, so on balance it leaves net social benefits from requiring higher fuel economy unaffected.

4.6.2 Externalities from Refining and Consuming Fuel

Extracting and transporting crude petroleum, refining it to produce transportation fuels, and distributing fuel generate additional emissions of GHGs and criteria air pollutants beyond those from cars and light trucks' use of petroleum-derived fuels. By reducing the volumes of these fuels that are produced and consumed, adopting higher CAFE standards mitigates global climate-related economic damages caused by accumulation of GHGs, as well as the more immediate and localized health damages caused by exposure to criteria pollutants. Because they fall broadly on the United States – and globally, in the case of climate damages –population and economy, reducing them represents an external benefit from requiring higher fuel economy.

In Figure 4-10, the economic costs of climate and health damage externalities is shown as the difference between the social cost of supplying fuel C_{social} and its retail price P_{retail}, and these costs are assumed to be constant on a per-gallon basis. The reduction in economic costs of climate and health damages resulting from lower fuel consumption is the area bafe in the figure, which is equal to the product of their per-gallon value and the reduction in the number of gallons of fuel supplied and consumed.

We calculate the reduction in GHG emissions throughout the global fuel supply chain ("upstream" emissions) directly from the estimated savings in the volume of fuel refined and consumed, using emission rates derived from Argonne's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model and procedures described in Chapter 6.2 of the TSD accompanying this final rule. As with GHG emissions resulting from fuel use itself, the agency uses unit damage costs of GHG emissions reported in recent draft guidance issued by the Federal Interagency Working Group on the Social Costs of Greenhouse Gases (IWG) to convert these reductions in GHG emissions to economic benefits.[87]

Our evaluation also accounts for benefits from reducing domestic emissions of criteria air pollutants that occur during fuel refining and distribution, again using emission rates for different fuels derived from Argonne's GREET model. Health damage costs resulting from increased population exposure to harmful accumulations of these pollutants were obtained from recent EPA analyses; these costs differ between vehicle and upstream emissions, reflecting differences

taxes vary widely but average about $0.06 per gallon on gasoline and $0.07 per gallon on diesel, bringing the total tax burden to approximately $0.53 per gallon on gasoline and $0.60 per gallon on diesel; see American Petroleum Institute, "State Motor Fuel Taxes: Summary," April 2019.

[87] Interagency Working Group on Social Cost of Greenhouse Gases, U.S. Government, *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide, Interim Estimates under Executive Order 13990*, February 2021.

in their geographic dispersal, accumulation, and resulting population exposure. Detailed descriptions of the sources used to develop these inputs also appear in Chapter 6.2 of the TSD.

4.6.3 Effects on Petroleum Consumption and U.S. Energy Security

Reducing U.S. fuel consumption will reduce the nation's demand for crude petroleum, and the United States accounts for a large enough share of global oil consumption that lower domestic demand could reduce total petroleum demand enough to lower its global price slightly. This would reduce the transfer of revenue to global oil producers, since consumers worldwide would pay lower prices; some analysts assert that this transfer is an economic externality resulting from domestic consumption of petroleum products, and that reducing it represents an additional benefit from raising U.S. CAFE standards. Reducing U.S. petroleum consumption via higher fuel economy will also reduce the exposure of U.S. consumers to sudden increases in oil prices. If households and businesses that use petroleum products do not bear all of these costs (that is, if they are partly "external" to consumers), reducing them could provide wider benefits to the U.S. economy. Finally, reducing U.S. demand for imported petroleum and reducing the exposure of U.S. consumers to global oil shocks might also enable reductions in military spending to secure oil supplies from unstable regions of the globe.

These three effects are usually referred to collectively as "energy security externalities" caused by U.S. petroleum consumption and reducing them is often cited as a potential economic benefit of lowering U.S. oil demand. These effects represent potential benefits of our regulatory action. Chapter 6.2.4 of the TSD assesses the extent to which lowering domestic gasoline use will directly reduce each of these effects, whether reducing it represents a net economic benefit, and whether and how such benefits could be measured. Briefly, it concludes that only reducing potential external costs from sudden increases in petroleum prices, something consumers are currently experiencing in the United States, represents a net and measurable economic benefit from tightening CAFE standards. This benefit can be significant. We thus include the reduction in the probability-weighted or "expected" value of those external costs as its measure of the improvement in U.S. energy security from imposing stricter CAFE standards.

4.7 Discounting Future Costs and Benefits

OMB Circular A-4 recommends as defaults that Federal agencies discount future benefits and costs of regulatory actions that affect opportunities for business investment using a 7 percent rate and to discount the economic effects of regulations that will primarily affect households' future consumption opportunities at a 3 percent rate. [88] Increases in costs to produce new cars and light trucks that meet higher CAFE targets will initially be borne by vehicle manufacturers, but we assume that they will protect their profitability by passing these cost increases on to buyers by raising selling prices for some models. Fuel savings and most other benefits from tightening standards will be experienced directly by owners of vehicles that offer higher fuel economy, and benefits or costs that are experienced more widely will also primarily affect future consumption.

[88] Note, however, Circular A-4 indicates that discounting at the consumption rate of interest is the "analytically preferred method" when effects are presented in consumption-equivalent units. NHTSA concurs that in light of Circular A-4's instructions on applying a lower discount rate when a regulation primarily and directly impacts private consumption, it would be inappropriate to use an opportunity cost of capital rate for estimating the social cost of greenhouse gases.

Although this guidance appears to suggest that future costs and benefits anticipated to result from our regulatory action should be discounted using a 3 percent rate, with the exception noted immediately below we report benefits and costs discounted at both 3 percent and 7 percent rates.

One important exception is reductions in climate damages resulting from lower GHG emissions. In this Final Rule, NHTSA has not selected a primary discount rate for the SC-GHG and instead presents all other costs and benefits of the final rule discounted at 3 and 7 percent, together with estimates of the SC-GHG valued at each of the discount rates provided by the interim guidance from the IWG. This approach was selected because, as NHTSA pointed out in the notice of proposed rulemaking (NPRM), the IWG does not specify which recommended discount rate should be considered the agency's primary estimate, and NHTSA agrees that all three discount rate approaches and the 95th percentile value discounted at 3 percent provide important information to decision-makers.[89] The agency's analysis showing our primary non-GHG impacts at 3 and 7 percent alongside climate-related benefits discounted at each rate recommended by the IWG may be found in FRIA Chapter 6.5.6. For the sake of simplicity, most tables throughout today's analysis pair both the 3 and the 7 percent discount rates with a 3 percent value for the social costs of greenhouse gases.

Because there is some uncertainty about whether and how completely cost savings will be passed through to buyers rather than redeployed by manufacturers to other investment opportunities, however, the 7 percent rate may still be relevant for discounting some future economic consequences of this action. To acknowledge this uncertainty, we also report the anticipated future costs and benefits of this action, except for climate effects, discounted using a 7 percent rate. Benefits and costs are discounted using both rates to their present values as of 2020 and are expressed in constant dollars reflecting economy-wide price levels prevailing during 2018.

4.8 Reporting Benefits and Costs

We believe it is important to report the benefits and costs of our regulation in a format that illustrates *how* the action will generate the economic impacts described throughout this Regulatory Impact Analysis (RIA) and their incidence on households, private businesses, and the remainder of the U.S. economy. Table 4-1 presents the economic benefits and costs of NHTSA's Final Rule establishing higher CAFE standards for MYs 2024-2026. For both costs and benefits, the table distinguishes between those experienced by private businesses and households (labeled private costs and benefits), and those experienced throughout the U.S. economy (labeled "external" costs and benefits). The agency believes it is important to distinguish these categories because private households and businesses can readily obtain most or all of the benefits from the higher fuel economy levels this final rule requires by purchasing car and light truck models that are now available, so the main motivation for requiring higher fuel economy must be to provide benefits of enhanced energy conservation to the broader population and U.S. economy. Alternative versions of Table 4-1 that include dollar estimates of costs and benefits for the regulatory alternatives we considered before adopting the standards this

[89] Interagency Working Group on Social Cost of Greenhouse Gases, U.S. Government, *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide, Interim Estimates under Executive Order 13990*, February 2021.

Final Rule establishes appear in Chapter 6.5.6 of this regulatory analysis, reflecting differing perspectives for measuring benefits and costs, time horizons, and discount rates.

Table 4-1 – Benefits and Costs Resulting from the Agency's Regulatory Action

Entry	Location of Explanation in RIA
Private Costs	
Technology Costs to Increase Fuel Economy	Chapter 4.3.1
Increased Maintenance and Repair Costs	Chapter 4.3.1
Sacrifice in Other Vehicle Attributes	Chapter 4.3.1
Consumer Surplus Loss from Reduced New Vehicle Sales	Chapter 4.4
Safety Costs Internalized by Drivers	Chapters 4.5.2, 5.3
Subtotal - Private Costs	Sum of above entries
External Costs	
Congestion and Noise Costs from Rebound-Effect Driving	Chapter 4.5.2
Safety Costs Not Internalized by Drivers	Chapters 4.5.2, 5.3
Loss in Fuel Tax Revenue	Chapter 4.6.1
Subtotal - External Costs	Sum of above entries
Social Costs	Sum of private and external costs
Private Benefits	
Savings in Retail Fuel Costs[90]	Chapter 4.6.1
Benefits from Additional Driving	Chapter 4.5.1
Less Frequent Refueling	Chapter 4.1 and 4.2.2
Subtotal – Private Benefits	Sum of above entries
External Benefits	
Reduction in Petroleum Market Externality	Chapter 4.6.3
Reduced Climate Damages	Chapters 4.5.2 and 4.6.2
Reduced Health Damages	Chapters 4.5.2 and 4.6.2
Subtotal - External Benefits	Sum of above entries
Social Benefits	Sum of private and external benefits
Net Private Benefits	Private Benefits – Private Costs
Net External Benefits	External Costs – External Benefits
Net Social Benefits	Social Benefits – Social Costs

As the table shows, many impacts of the regulatory action will fall directly on private businesses and individuals, including manufacturers of cars and light trucks, buyers and subsequent owners of the new models they produce, and owners of used cars and light trucks – that is, vehicles produced during model years prior to those covered by this action. The largest category of costs is car and light truck producers' expenses for added technology to enable their models to meet higher fuel economy targets, although as indicated previously the agency assumes these increased costs will ultimately be reflected in higher purchase prices and borne by new car and light truck buyers. Table 4-1 also includes entries for increased maintenance and repair costs necessary to ensure that their higher fuel economy is sustained throughout these vehicles' lifetimes (since estimated fuel savings assume this will be the case), and for changes in attributes

[90] Since taxes are transfers from consumers to governments, a portion of the Savings in Retail Fuel Costs includes taxes avoided. The Loss in Fuel Tax Revenue is completely offset within the Savings in Retail Fuel Costs.

other than fuel economy. Including entries for them is intended to emphasize that they could be real economic costs of requiring manufacturers to comply with higher CAFE standards, but that the agency lacks sufficient information to confidently estimate them, rather than to suggest that their true value has been determined to be zero. Other privately borne costs include losses in consumer surplus to would-be new car and light truck buyers who are deterred by their higher prices and the economic cost of safety risks that drivers consider when deciding whether to travel additional miles.

External costs include the contributions of additional rebound-effect driving to traffic congestion, delays, and to roadway noise. Although these costs are largely or completely borne by drivers (and their passengers) as a whole, it is unlikely that the individual drivers whose decisions impose them consider these costs when making additional trips. Those drivers may not consider all of the safety risks they create by making additional trips, and the economic value of risks they do not consider represent external costs they impose on other vehicles' passengers, pedestrians, and other road users. Losses in fuel tax revenue reduce the ability of government agencies who collect them to fund road maintenance and other programs with broad-based benefits, so these are another cost of ensuring higher fuel economy for buyers of new cars and light trucks. Since taxes are transfers from consumers to governments, a portion of the savings in retail fuel costs includes taxes avoided. The loss in fuel tax revenue is completely offset within the savings in retail fuel costs.

By far the largest category of benefits from raising CAFE standards is the cost of fuel that would be saved by buyers of cars and light trucks that achieve higher fuel economy, which as Table 4-1 shows is a private benefit. Those same buyers experience additional benefits from the increased mobility that added rebound-effect driving provides, as well as from the convenience of having to refuel less frequently because they can travel farther before needing to do so. Reducing fuel use also provides some benefits to the broader population. These external benefits include less frequent or severe disruptions to economic activity from sudden increases in fuel prices, some reduction in future economic damages caused by climate change, and improved health from less frequent exposure to harmful levels of air pollution.

Finally, the table reports social costs, or the sum of private and external costs, and social benefits, the sum of private and external benefits from requiring higher fuel economy. Net social benefits are simply the difference between social benefits and costs with positive values indicating that raising CAFE standards generates benefits exceeding its social costs, and negative values suggesting the opposite. It also reports net private benefits, the difference between private benefits and private costs, as well as net external benefits, the difference between population and economy-wide or external benefits and external costs. Reporting the private and external components of net benefits separately enables readers of this FRIA to see the extent to which the economic value of NHTSA's action depends on providing benefits to buyers of new cars and light trucks they could readily obtain for themselves by purchasing higher fuel economy models that are now available in today's vehicle market and likely to remain available even without more stringent CAFE standards.

5. Impacts on Motor Vehicle Safety

The primary objective of CAFE standards is to achieve maximum feasible fuel economy, thereby reducing fuel consumption. In setting standards to achieve this intended effect, the potential of the standards to affect vehicle safety is also considered. As a safety agency, NHTSA has long considered the potential for adverse safety consequences when establishing CAFE standards. Safety consequences include all impacts from motor vehicle crashes, including fatalities, nonfatal injuries, and property damage.

Safety trade-offs associated with increases in fuel economy standards have occurred in the past—particularly before CAFE standards became attribute-based—because manufacturers chose to comply with stricter standards by building smaller and lighter vehicles.[91] In cases where fuel economy improvements were achieved through reductions in vehicle size and mass, the smaller, lighter vehicles did not protect their occupants as effectively in crashes as larger, heavier vehicles, on average. Although we now use attribute-based standards, in part to reduce the incentive to downsize vehicles to comply with CAFE standards, the agency continues to be mindful of the possibility of safety-related trade-offs.

This safety analysis includes the comprehensive measure of safety impacts from three factors:

1. Changes in Vehicle Mass. Similar to previous analyses, we calculate the safety impact of changes in vehicle mass made to reduce fuel consumption and comply with the standards. Statistical analysis of historical crash data indicates reducing mass in heavier vehicles generally improves safety, while reducing mass in lighter vehicles generally reduces safety. Our crash simulation modeling of vehicle design concepts for reducing mass revealed similar effects.

2. Impacts of Vehicle Prices on Fleet Turnover. Vehicles have become safer over time through a combination of new safety regulations and voluntary safety improvements. The agency expects this trend to continue as emerging technologies, such as advanced driver assistance systems (ADAS), are incorporated into new vehicles. Safety improvements will likely continue regardless of changes to CAFE standards.

   As discussed in Chapter 4.3 through Chapter 4.8, technologies added to comply with fuel economy standards have an impact on vehicle prices and operating costs, therefore possibly altering the acquisition of newer vehicles and retirement of older ones. A change in fleet turnover resulting from higher new vehicle prices and lower fuel costs is assumed to affect safety by changing the penetration of new safety technologies into the fleet.

   The standards also influence the composition of the light-duty fleet. There is evidence that upsizing has been occurring in the United States since the footprint adjustment was made in 2005 (Whitefoot and Skerlos, 2012; Jacobsen, 2013; Ito and Sallee, 2014; Killean, 2017; Neil, 2018). It is not entirely clear how much of the upsizing is due to

[91] Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards (NRC, 2002).

regulatory incentive and how much is due to greater consumer interest in seating capacity, leg room, crush space, trunk space, and cargo-carrying capability. As the safety provided by light trucks, SUVs and passenger cars responds differently to technology that manufacturers employ to meet the standards—particularly mass reduction—fleets with different compositions of body styles will have varying numbers of fatalities, so changing the share of each type of light-duty vehicle in the projected future fleet affects the projected safety outcomes. However, the agency's projections of changes in the composition of the vehicle fleet rely on a fleet share model whose shortcomings make these projections uncertain, and this uncertainty is also reflected in the anticipated safety consequences of changes in the vehicle fleet.

3. Increased driving because of better fuel economy. The "rebound effect" predicts consumers will drive more when the cost of driving declines. More stringent standards reduce vehicle operating costs, and in response, some consumers may choose to drive more. Additional driving increases exposure to risks associated with motor vehicle travel, and this added exposure translates into higher fatalities and injuries.

The contributions of the three factors described above generate the differences in safety outcomes among regulatory alternatives.[92] The agency's analysis makes extensive efforts to allocate the differences in safety outcomes between the three factors. Fatalities expected during future years under each alternative are projected by deriving a fleet-wide fatality rate (fatalities per vehicle mile of travel) that incorporates the effects of differences in each of the three factors from baseline conditions and multiplying it by that alternative's expected VMT. Fatalities are converted into a societal cost by multiplying fatalities with the DOT-recommended value of a statistical life (VSL) supplemented by economic impacts that are external to VSL measurements. Traffic injuries and property damage are also modeled directly using the same process and valued using costs that are specific to each injury severity level.

All three factors influence predicted fatalities, but only two of them—changes in vehicle mass and in the composition of the light-duty fleet in response to changes in vehicle prices—affect risks to drivers and passengers that are not compensated for by accompanied by benefits of increased mobility. In increased driving associated with the rebound effect is a consumer choice that reveals the benefit of additional travel. Consumers who choose to drive more have apparently concluded that the utility of additional driving exceeds the additional costs for doing so—including the crash risk that they perceive additional driving involves. As discussed in Chapter 7 of the accompanying TSD, the benefits of rebound driving are accounted for by offsetting a portion of the added safety costs.

The agency categorizes safety outcomes through three measures of light-duty vehicle safety: fatalities to occupants occurring in crashes, serious injuries sustained by occupants, and the number of vehicles involved in crashes that cause property damage but no injuries. Counts of fatalities to occupants of automobiles and light trucks are obtained from the Fatal Accident

[92] The terms safety performance and safety outcome are related but represent different concepts. When we use the term safety performance, we are discussing the intrinsic safety of a vehicle based on its design and features, while safety outcome is used to describe whether a vehicle has been involved in a crash and the severity of the accident. While safety performance influences safety outcomes, other factors such as environmental and behavioral characteristics also play a significant role.

Reporting System (FARS). Estimates of the number of serious injuries to drivers and passengers of light-duty vehicles are tabulated from the General Estimates System (GES), an annual sampling of motor vehicle crashes occurring throughout the United States. Weights for different types of crashes were used to expand the samples of each type to estimates of the total number of crashes occurring during each year. Finally, estimates of the number of automobiles and light trucks involved in property damage-only (PDO) crashes each year were also developed using GES.

5.1 Safety Baseline

To estimate the impact of the standards on safety, the agency uses statistical models that explicitly incorporate variation in the safety performance of individual vehicle model years. The agency uses separate models for fatalities, non-fatal injuries, and property damage to vehicles, each of which tracks vehicles from when they are produced and sold, enter the fleet, gradually age and accumulate usage (and for most vehicles, change in ownership as they age), and are ultimately retired from service. We also consider how newer technologies are likely to affect the safety of both individual vehicles and the combined fleet. The overall safety of the light-duty vehicle fleet during any future calendar year is determined by the safety performance of the individual model year cohorts comprising it at the ages they will have reached during that year, the representation of each model year cohort in that (calendar) year's fleet, and a host of external factors that fluctuate over time, such as driver demographics and behavior, economic conditions, traffic levels, and emergency response and medical care. Combining forecasts of future crash rates for individual model year cohorts at different ages with the composition of the vehicle fleet produces baseline forecasts of fatalities, non-fatal injuries, and vehicles incurring property damage. Regulatory alternatives that establish new CAFE standards for future model years change these forecasts by altering the representation of different model year cohorts making up the future light-duty fleet.

Using this same approach, we designed separate models for fatalities, non-fatal injuries, and property damaged vehicles.

To simplify forecasting baseline future rates for fatalities, non-fatal injuries, and involvement in PDO crashes, we utilize the versions of each model that include fixed effects for safety regimes, vehicle age and its squared value, the time trend measure (including any significant change in the trend), and indicator variables for recession years. Specifically, we use model 10 from Table 7-9, Table 7-10, and Table 7-11 in the accompanying TSD Chapter 7.1.9. Starting with the relevant rate for the latest model year when it was new (e.g., the fatality rate for MY 2019 during CY 2019, when most vehicles from that model year were sold and placed into service), we apply estimates of the shares of new vehicles produced during future model years that will be equipped with various crash avoidance technologies and the effectiveness of each of those technologies in reducing crashes (fatal, non-fatal, or property damage, as appropriate). The nature of these technologies, projections of the shares of new cars and light trucks that will be equipped with each of them, and estimates of the effectiveness of those technologies in preventing these three different types of crashes are discussed in the following section.

During each future calendar year, the appropriate new model year is assumed to be incorporated into the fleet, with its forecast rate (of fatalities per billion miles, for example). At the same time, the rate for each earlier model year making up the fleet during that calendar year is increased to reflect the aging effect implied by the coefficients on the variables age and age-squared in the relevant model. Any remaining vehicles originally produced during the model year that would have reached age 41 in a future calendar year are assumed to be retired from service or driven so little that they contribute negligibly to overall safety. Finally, the rates (again, fatality, non-fatal injury, or property damage) for these earlier model years are also adjusted downward to reflect continuation of their historical downward trends, which were estimated as part of the models discussed previously.

This produces estimates of fatality, non-fatal injury, and property damage crash involvement rates for each model year making up the fleet during each future calendar year, and the process is continued until CY 2050. Multiplying these rates by the estimated number of miles driven by cars and light trucks of each model year in use during a future calendar year produces baseline estimates of total fatalities, non-fatal injuries, and cars and light trucks involved in property damage-only crashes. As an example, Figure 5-1 illustrates the recent history and baseline forecast of the overall fatality rate for occupants of cars and light trucks. The sharp rise in the fatality rate for 2020 coincided with the steep drop in car and light truck VMT during that year due to the coronavirus disease of 2019 (COVID-19) pandemic and accompanying restrictions on activity, combined with an increased number of fatalities in 2020—though the agency continues to analyze the causes of this result. These rates are also used as the basis for estimating changes in safety resulting from reductions in the mass of new vehicles, additional rebound-effect driving, and changes in the numbers of cars and light trucks from different model years making up each calendar year's fleet. The underlying causes and methods for estimating each of those three sources of changes in safety are discussed in detail in various sub-sections of Chapter 7 of the accompanying TSD.

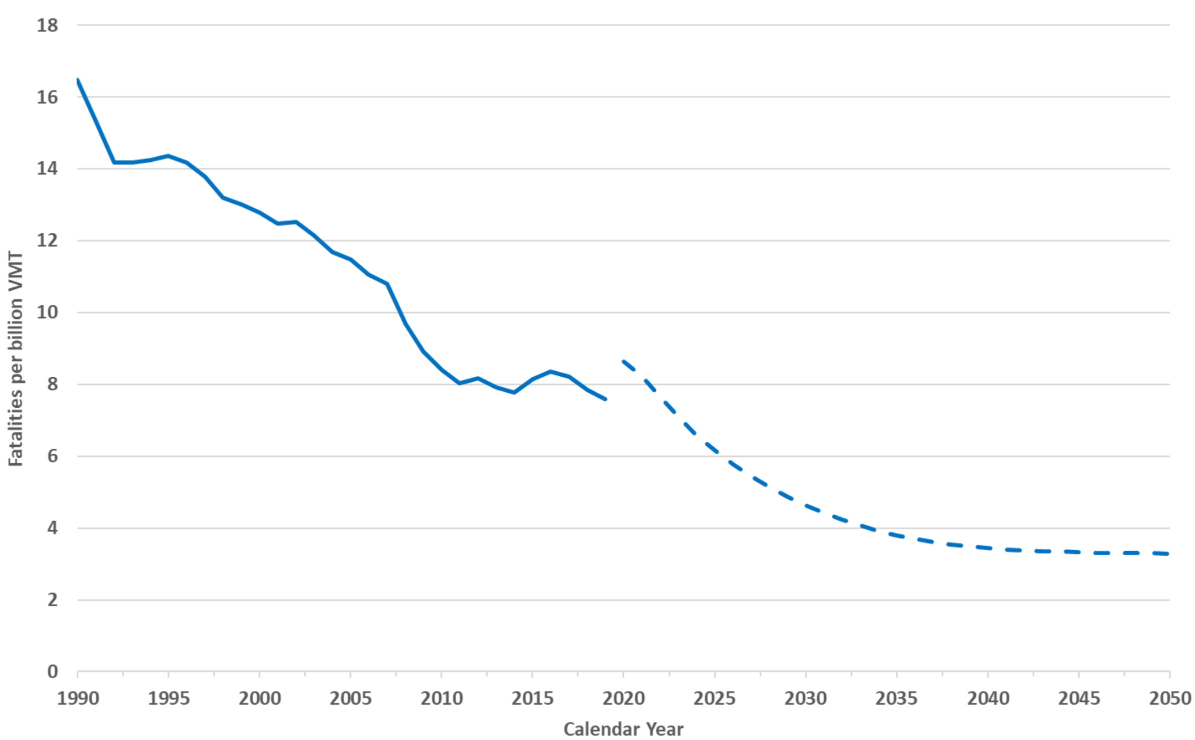

Figure 5-1 – Recent and Projected Future Fatality Rates for Cars and Light Trucks

5.1.1 Future Safety Trends Predicted by Advanced Safety Technologies

The model described above uses trends observed over several decades to make a coarse projection of future safety rates. To augment these projections with knowledge about forthcoming safety improvements, the agency applied detailed empirical estimates of the market uptake and improving effectiveness of crash avoidance technologies to estimate their effect on the fleet-wide fatality rate, including explicitly incorporating both the direct effect of those technologies on the crash involvement rates of new vehicles equipped with them, as well as the "spillover" effect of those technologies on improving the safety of occupants of vehicles that are not equipped with these technologies.

The development of advanced crash avoidance technologies in recent years indicates some level of safety improvement is almost certain to occur going forward. TSD Chapter 7.2 provides an extensive catalog of these technologies and describes how the agency develops empirical estimates of their effectiveness in reducing fatalities, injuries, and property damage in crashes; the following paragraphs summarize those technologies and their anticipated effects. Moreover, autonomous vehicles offer the possibility of significantly reducing the effect of human perception, judgment or error in crash causation, a contributing factor in roughly 94 percent of all crashes. However, there is insufficient information and certainty regarding the eventual impact of autonomous vehicles eventual impact to include them in this analysis.[93]

Beginning with the 2020 CAFE final rule, we augmented the sales-scrappage safety analysis with recent research into the effectiveness of specific advanced crash avoidance safety technologies (also known as ADAS or advanced driver assistance systems) that are expected to drive future safety improvement to estimate the impacts of crash avoidance technologies. The analysis analyzes six crash avoidance technologies that are currently being produced and commercially deployed in the new vehicle fleet. These include forward collision warning (FCW), Automatic Emergency Braking (AEB),[94] lane departure warning (LDW), lane keep assist (LKA), blind spot detection (BSD), and lane change alert (LCA). These are the principal technologies that are being developed and adopted in new vehicle fleets and will likely drive vehicle-based safety improvements for the coming decade. These technologies are being installed in more and more new vehicles; in fact, manufacturers recently reported that they voluntarily installed AEB systems in more than 70 percent of their new vehicles sold in the year ending August 31, 2019.[95] We note that the terminology and the detailed characteristics of these systems may differ across manufacturers, but the basic system functions are generally similar.

[93] TSD Chapter 7.1.13 describes technologies that are being developed and/or deployed that may substantially affect the fatality rate in future years.
[94] AEB is a combination of CIB, DBS, and sometimes PAEB.
[95] NHTSA Announces Update to Historic AEB Commitment by 20 Automakers, NHTSA press release December 17, 2019. https://www.nhtsa.gov/press-releases/nhtsa-announces-update-historic-aeb-commitment-20-automakers. (Accessed: February 14, 2022).

These 6 technologies address three basic crash scenarios through warnings to the driver or alternately, through dynamic vehicle control:

1. Forward collisions, typically involving a crash into the rear of a stopped vehicle;

2. Lane departure crashes, typically involving inadvertent drifting across or into another traffic lane; and

3. Blind spot crashes, typically involving intentional lane changes into unseen vehicles driving in or approaching the driver's blind spot.

Unlike traditional safety features where the bulk of the safety improvements were attributable to improved protection when a crash occurs (crash worthiness), the impact of advanced crash avoidance technologies (ADAS or advanced driver assistance systems) will have on fatality and injury rates is a direct function of their effectiveness in preventing or reducing the severity of the crashes they are designed to mitigate. This effectiveness is typically measured using real world data comparing vehicles with these technologies to similar vehicles without them. While these technologies are actively being deployed in new vehicles, their penetration in the larger on-road vehicle fleet has been at a low but increasing level. This limits the precision of statistical regression analyses, at least until the technologies become more common in the on-road fleet.

Our approach to measuring these impacts is to derive effectiveness rates for these advanced crash-avoidance technologies from safety technology literature. We then apply these effectiveness rates to specific crash target populations for which the crash avoidance technology is designed to mitigate and adjusted to reflect the current pace of adoption of the technology, including the public commitment by manufactures to install these technologies. The products of these factors, combined across all 6 advanced technologies, produce a fatality rate reduction percentage that is applied to the fatality rate trend model discussed above, which projects both vehicle and non-vehicle safety trends. The combined model produces a projection of impacts of changes in vehicle safety technology as well as behavioral and infrastructural trends. A much more detailed discussion of the methods and inputs used to make these projections of safety impacts from advanced technologies is included in Chapter 7 of the accompanying TSD.

5.2 Mass Reduction Impacts

As a safety agency, we have long considered the potential for adverse safety consequences when establishing CAFE standards. Vehicle mass reduction can be one of the more cost-effective means of improving fuel economy, particularly for makes and models not already built with much high-strength steel or aluminum closures or low-mass components. Manufacturers have stated that they will continue to reduce vehicle mass to meet more stringent standards, and therefore, this expectation is incorporated into the modeling analysis supporting the standards. Newer vehicles incorporate design and hardware improvements that may mitigate some of the direct safety effects to occupants associated with light-weighting. Likewise, safety rules that have reduced fatality and injury risk (e.g., first-event rollover risk reduction through electronic stability control [ESC]) have placed downward pressure on safety effects associated with mass reduction. This relationship is likely a key driver of decreasing magnitudes of estimated effects of mass reduction on societal fatality risk over time. To the extent that safety rules have had an impact on crashes evaluated in the analysis summarized below (i.e., fewer fatalities in the sample for first-event rollovers due to mandatory ESC), this impact is accounted for directly in our analysis through a lower weight being placed on such crashes in the estimation of the effects of mass reduction on societal fatality risk.

Historically, as shown in our FARS data analysis,[96] mass reduction concentrated among the heaviest vehicles (chiefly, the largest light trucks and vans (LTVs), crossover utility vehicles [CUVs], and minivans) has been estimated to reduce overall fatalities, while mass reduction concentrated among the lightest vehicles (chiefly, smaller passenger cars) has been estimated to increase overall fatalities. Our past analyses have consistently indicated that increasing the disparity of the masses of vehicles is harmful to safety, and that decreasing the disparity of the masses of vehicles improves safety. In collisions among vehicles, mass reduction in heavier vehicles alone is more beneficial to the occupants of lighter vehicles than it is harmful to the occupants of the heavier vehicles. Mass reduction in lighter vehicles alone is more harmful to the occupants of lighter vehicles than it is beneficial to the occupants of the heavier vehicles. Reducing mass simultaneously across multiple vehicles can have a range of net effects; for example, proportional mass reduction across the vehicle fleet based on this historical analysis would be expected to have a roughly neutral effect on societal fatality rates for two-vehicle crashes. This highlights the role of mass disparity in societal fatality risk: as the overall vehicle fleet moves closer together is in terms of mass (or, as measured in our analysis, curb weight), the impacts of changes in vehicle mass on fatality risk decrease for crashes involving two or more vehicles. However, many fatalities and injuries occur in single vehicle crashes and collisions between light-duty vehicles and cyclists or pedestrians and these must also be taken into account in representing the effects of mass reduction on societal fatality rates.

This is most apparent when considering mass reduction in the heaviest and lightest vehicles. Based on these prior analyses, mass reduction in heavier vehicles has been more beneficial to the occupants of lighter vehicles than it has been harmful to the occupants of the heavier vehicles. Mass reduction in lighter vehicles has been more harmful to the occupants of lighter vehicles than it has been beneficial to the occupants of the heavier vehicles. In response to questions of whether designs and materials of more recent model year vehicles may have weakened the historical statistical relationships between mass, size, and safety, we have

[96] *See* Kahane, C. J. (1997). Relationships Between Vehicle Size and Fatality Risk in Model Year 1985- 93 Passenger Cars and Light Trucks, NHTSA Technical Report. DOT HS 808 570. Washington, DC: National Highway Traffic Safety Administration, http://wwwnrd.nhtsa.dot.gov/Pubs/808570.PDF; Kahane, C. J. (2003). Vehicle Weight, Fatality Risk and Crash Compatibility of Model Year 1991-99 Passenger Cars and Light Trucks, NHTSA Technical Report. DOT HS 809 662. Washington, DC: National Highway Traffic Safety Administration, http://wwwnrd.nhtsa.dot.gov/Pubs/809662.PDF; Kahane, C. J. (2010). "Relationships Between Fatality Risk, Mass, and Footprint in Model Year 1991-1999 and Other Passenger Cars and LTVs," Final Regulatory Impact Analysis: Corporate Average Fuel Economy for MY 2012-MY 2016 Passenger Cars and Light Trucks. Washington, DC: National Highway Traffic Safety Administration, pp. 464-542, http://www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/Rulemaking/Rules/Associated%20Files/CAF E_2012-2016_FRIA_04012010.pdf Kahane, C.J. (2012). Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000-2007 Passenger Cars and LTVs: Final Report, NHTSA Technical Report. Washington, DC: National Highway Traffic Safety Administration, Report No. DOT-HS-811-665; Puckett, S.M. and Kindelberger, J.C. (2016, June). Relationships between Fatality Risk, Mass, and Footprint in Model Year 2003-2010 Passenger Cars and LTVs – Preliminary Report. (Docket No. NHTSA2016-0068). Washington, DC: National Highway Traffic Safety Administration.

periodically updated its database for statistical analysis consisting of crash data. The database incorporates the full range of real-world crash types. We also sponsored a study conducted by George Washington University to develop a fleet simulation model and study the impact and relationship of light-weighted vehicle design with crash injuries and fatalities. That study is discussed in Chapter 7.2.5 of the TSD.

As described below, NHTSA's current analysis did not find a statistically significant relationship between mass and safety. This may reflect the effects of a decreased sample size (the current study was based on 32 percent fewer fatal cases than the Kahane 2012 study) as well as possible mitigating effects from newer safety technologies or vehicle designs. While not finding statistical significance, NHTSA's current study did find results that are directionally consistent with previous NHTSA studies and the George Washington University fleet simulation. The common pattern across all studies is that changes in mass disparity are associated with changes in motor vehicle safety: increased disparity increases fatality risk, while decreased disparity decreases risk. The agency will continue to conduct research on the impacts of mass disparity on vehicle safety in an effort to identify the impacts of evolving vehicle fleets.

The CAFE standards detailed here are "footprint-based," with footprint being defined as a measure of a vehicle's size, roughly equal to the wheelbase times the average of the front and rear track widths. Manufacturers are less likely than they were in the past to reduce vehicle footprint to reduce mass for increased fuel economy. Indeed, as reflected in shifts from smaller passenger cars to larger trucks, SUVs, and CUVs (see FRIA Chapter 3.2 and TSD Chapter 1.2.8), the average footprint of light-duty vehicles has increased slightly and gradually since the adoption of footprint-based standards. Footprint-based standards create a disincentive for manufacturers to produce smaller-footprint vehicles. This is because, as footprint decreases, the corresponding fuel economy target becomes more stringent. The agency believes that the shape of the footprint curves themselves is such that the curves should neither encourage manufacturers to increase the footprint of their fleets, nor to decrease it. Several technologies, such as substitution of light, high-strength materials for conventional materials during vehicle redesigns, have the potential to reduce weight and conserve fuel while maintaining a vehicle's footprint.

For the rulemaking analysis, as in the most recent Final Rule, the CAFE Model tracks the amount of mass reduction applied to each vehicle model, and then applies estimated changes in societal fatality risk per 100 pounds of mass reduction determined through the statistical analysis of FARS crash data. 100-pound mass reductions have been considered in our analyses as a matter of convention; the implications of the analysis would not change meaningfully either for focal vehicle classes or for the fleet at large (i.e., in terms of mass disparity) if different magnitudes of mass reduction were considered. This process allows the CAFE Model to tally changes in fatalities attributed to mass reduction across all the analyzed future model years. In turn, the CAFE Model is able to provide an overall impact of the final standards and alternatives on fatalities attributed to changes in mass disparity resulting from mass reduction. The projections of societal effects of mass reduction from the CAFE Model are subject to uncertainty in the paths that manufacturers will follow in applying mass reduction to the fleet. That is, there is uncertainty as to which vehicle models will undergo mass reduction. Rather, the model is calibrated to incorporate the best available information on the application, and safety effects, of mass reduction.

The basic analytical method used to analyze the impacts of weight reduction on safety for this final rule is the same as in the 2016 Puckett and Kindelberger report.[97] We released the 2016 Puckett and Kindelberger report as a preliminary report on the relationship between fatality risk, mass, and footprint in June 2016 in advance of the Draft TAR. The 2016 Puckett and Kindelberger report covered the same scope as previous NHTSA reports, offering a detailed description of the crash and exposure databases, modeling approach, and analytical results on relationships among vehicle size, mass, and fatalities that informed the Draft TAR. The modeling approach described in the 2016 Puckett and Kindelberger report was developed with the collaborative input of NHTSA, EPA, and U.S. Department of Energy (DOE), and subject to extensive public review, scrutiny in two NHTSA-sponsored workshops, and a thorough peer review that compared it with the methodologies used in other studies.

In computing the impact of changes in mass on safety, we are faced with competing challenges. Research has consistently shown that mass reduction affects "lighter" and "heavier" vehicles differently across crash types. The 2016 Puckett and Kindelberger report found mass reduction concentrated among the heaviest vehicles is likely to have a beneficial effect on overall societal fatalities, while mass reduction concentrated among the lightest vehicles is likely to have a detrimental effect on fatalities. To accurately capture the differing effect on lighter and heavier vehicles, we must split vehicles into lighter and heavier vehicle classifications in the analysis. However, this poses a challenge of creating statistically-meaningful results. There is limited relevant crash data to use for the analysis. Each partition of the data reduces the number of observations per vehicle classification and crash type, and thus reduces the statistical robustness of the results. Our methodology was designed to balance these competing forces as an optimal trade-off to accurately capture the impact of mass-reduction across vehicle curb weights and crash types while preserving the potential to identify robust estimates.

For this final rule, as in the 2020 CAFE rule, we employed the modeling technique developed in the 2016 Puckett and Kindelberger report to analyze the updated crash and exposure data by examining the cross sections of the societal fatality rate per billion vehicle miles of travel (VMT) by mass and footprint, while controlling for driver age, gender, and other factors, in separate logistic regressions for five vehicle groups and nine crash types. We utilized the relationships between weight and safety from this analysis, expressed as percentage increases in fatalities per 100-pound weight reduction, to examine the weight impacts applied in this CAFE analysis. The effects of mass reduction on safety were estimated relative to (incremental to) the regulatory baseline in the CAFE analysis, across all vehicles for MY 2020 and beyond.

As in the 2012 Kahane report, 2016 Puckett and Kindelberger report, the Draft TAR, and the 2020 CAFE rule, the vehicles are grouped into three classes: passenger cars (including both two-door and four-door cars); CUVs and minivans; and truck-based LTVs. The curb weight of passenger cars is formulated, as in the 2012 Kahane report, 2016 Puckett and Kindelberger report, Draft TAR, and 2020 CAFE rule, as a two-piece linear variable to estimate one effect of mass reduction in the lighter cars and another effect in the heavier cars.

[97] Puckett, S.M. and Kindelberger, J.C. (2016, June). Relationships between Fatality Risk, Mass, and Footprint in Model Year 2003-2010 Passenger Cars and LTVs – Preliminary Report. (Docket No. NHTSA2016-0068). Washington, DC: National Highway Traffic Safety Administration.

Comments on the NPRM for the 2020 CAFE rule included suggestions that the sample of LTVs in the analysis should not include the medium- or heavy-duty (i.e., truck-based vehicles with GVWR above 8,500 pounds) equivalents of light-duty vehicles in the sample (e.g., Ford F-250 versus F-150, RAM Trucks [RAM] 2500 versus RAM 1500, Chevrolet Suburban 2500 versus Chevrolet Suburban 1500), or Class 2b and 3 vehicles. For the proposal, we explored revising the analysis consistent with such comments. The process involved two key analytical steps: (1) removing all case vehicles from the analysis whose GVWR exceeded 8,500 pounds; and (2) re-classifying all crash partners with GVWR above 8,500 pounds as heavy vehicles. The direct effects of these changes are: (1) the range of curb weights in the LTV sample is reduced, lowering the median curb weight from 5,014 pounds to 4,808 pounds; (2) the sample size of LTVs is reduced (the number of case LTVs under this alternative specification is approximately 18 percent lower than in the central analysis); and (3) the relative impact of crashes with LTVs on overall impacts on societal fatality rates decreases, while the corresponding impact of crashes with heavy vehicles increases.

The results from the exploratory analysis of this alternative approach are provided in Table 5-2. We did not identify any public comments on this alternative approach, and thus will defer the decision whether to incorporate the results into the CAFE Model to future rulemakings. The primary functional change offered by the alternative approach is that the sample of vehicles classified as LTVs would be restricted to vehicles that would be subject to CAFE regulations; it is important to note that the LTVs in question are subject to other fuel economy regulations, hence their relevance within a study informing the CAFE Model is not immediately nullified by being outside the scope of CAFE regulations. At the statistical level, the concerns raised in our response to comment on the 2018 CAFE NPRM remain. In particular, including Class 2b and 3 vehicles in the analysis to determine the relationship of vehicle mass on safety has the added benefit of improving correlation constraints. Notably, curb weight increases faster than footprint for large light trucks and Class 2b and 3 pickup trucks and SUVs, in part because the widths of vehicles are constrained more tightly (i.e., due to lane widths) than their curb weights. Including data from Class 2b and 3 pick-up truck and SUV fatal crashes provides data over a wider range of vehicle weights, which improves the ability to estimate the mass-crash fatality relationship. That is, by extending the footprint-curb weight-fatality data to include Class 2b and 3 trucks that are functionally and structurally similar to corresponding ½-ton models that are subject to CAFE regulation, the sample size and ranges of curb weights and footprint are improved. However, this result may arise due to the presence of non-linearities over the relatively large range of vehicle curb weights when Class 2b and 3 vehicles are included in the sample. Sample size is a challenge for estimating relationships between curb weight and fatality risk for individual crash types in the main analysis; dividing the sample further or removing observations makes it increasingly difficult to identify meaningful estimates and the relationships that are present in the data, as shown in the sensitivity analysis below. For the final rule, we have determined that the benefit of the additional data points outweighs the concern that some of the vehicles used to determine the mass-safety coefficients are not regulated by CAFE vehicles.

We also explored three other alternative model specifications that are presented in Table 5-2. The first alternative centers on aligning CUVs and minivans with the rest of the sample, by splitting these vehicles into two weight classes. The key factor restricting this change historically has been a low sample size for these vehicles; the exploratory analysis examined whether the current database (which, due to the range of CYs covered, contains a smaller share of CUVs and minivans than the current fleet) contains a sufficient sample size to evaluate two weight classes for CUVs and minivans. A complicating factor in this analysis is that minivans tend to have higher curb weights than other CUVs, adding statistical burden in identifying meaningful effects of mass on societal fatality rates after accounting for body type in the weight class with the fewest minivans (i.e., lighter CUVs and minivans).

The second alternative centers on aligning passenger cars with the rest of the sample by including cars that are equipped with AWD. In previous analyses, passenger cars with AWD were excluded from the analysis because they represented a sufficiently low share of the vehicle fleet that statistical relationships between AWD status and societal fatality risk were highly prone to being conflated with other factors associated with AWD status (e.g., location, luxury vehicle status). However, the share of AWD passenger cars in the fleet has grown. Approximately one-quarter of the passenger cars in the database have AWD, compared to an approximately five-percent share in the MY 2000-2007 database. Furthermore, all other vehicle types in the analysis include AWD as an explanatory variable. Thus, we find the inclusion of a considerable portion of the real-world fleet (i.e., passenger cars with AWD) to be a meaningful consideration.

The third alternative is a minor procedural question: whether to expand the calendar years and model years used to identify the distribution of fatalities across crash types. The timing of the safety databases places the years of the analysis used to establish the distribution of fatalities by crash type firmly within the central years of the economic downturn of the late 2000s and early 2010s. During these years, travel demand was below long-term trends, resulting in fewer crashes. In turn, applying the same window of calendar years and model years to the identification of the distribution of fatalities across crash types results in notably fewer crashes to incorporate into the analysis. We conducted exploratory analysis on the question of whether to add calendar years and model years to the range of crashes used to identify the distribution of fatalities across crash types; this analysis was conducted in concert with the two alternatives discussed directly above. Results incorporating these three alternatives are presented in Table 5-2.

The boundary between "lighter" and "heavier" cars is 3,201 pounds (which is the median mass of MY 2004-2011 cars in fatal crashes in CY 2006-2012, up from 3,106 pounds for MY 2000-2007 cars in CY 2002-2008 in the 2012 NHTSA safety database, and up from 3,197 pounds for MY 2003-2010 cars in CY 2005-2011 in the 2016 NHTSA safety database). Likewise, for truck-based LTVs, curb weight is a two-piece linear variable with the boundary at 5,014 pounds (again, the MY 2004-2011 median, higher than the median of 4,594 pounds for MY 2000-2007 LTVs in CY 2002-2008 and the median of 4,947 pounds for MY 2003-2010 LTVs in CY 2005-2011). CUVs and minivans are grouped together in a single group covering all curb weights of those vehicles; as a result, curb weight is formulated as a simple linear variable for CUVs and minivans. Historically, CUVs and minivans have accounted for a relatively small share of new-vehicle sales over the range of the data, resulting in less crash data available than for cars or truck-based LTVs. CUVs have increased their share of the fleet both across the years covered in the database and since, in turn increasing the importance of relationships between mass and societal fatality risk for CUVs. As the share of CUVs increases, any estimated beneficial mass reduction in CUVs will have a larger beneficial effect on overall societal fatality risk. As discussed in the sensitivity analysis below, we evaluated whether the current database contains sufficient observations of CUVs and minivans to separate these vehicles into two weight classes. The evidence does not support such a change under the current database; however, adding new calendar years and model years to the next database may yield sufficient observations to make this change. In sum, vehicles are distributed into five groups by class and curb weights: passenger cars < 3,201 pounds; passenger cars 3,201 pounds or greater; truck-based LTVs < 5,014 pounds; truck-based LTVs 5,014 pounds or greater; and all CUVs and minivans.

There are nine types of crashes specified in the analysis for each vehicle group: three types of single-vehicle crashes, five types of two-vehicle crashes; and one classification of all other crashes. Single-vehicle crashes include first-event rollovers, collisions with fixed objects, and collisions with pedestrians, bicycles, and motorcycles. Two-vehicle crashes include collisions with: heavy-duty vehicles; cars, CUVs, or minivans < 3,187 pounds (the median curb weight of other, non-case, cars, CUVs and minivans in fatal crashes in the database); cars, CUVs, or minivans ≥ 3,187 pounds; truck-based LTVs < 4,360 pounds (the median curb weight of other truck-based LTVs in fatal crashes in the database); and truck-based LTVs ≥ 4,360 pounds. Grouping partner-vehicle CUVs and minivans with cars rather than LTVs is more appropriate because their front-end profile and rigidity more closely resemble a car than a typical truck-based LTV. An additional crash type includes all other fatal crash types (e.g., collisions involving more than two vehicles, animals, or trains). Splitting the vehicles from this crash type involved in crashes involving two light-duty vehicles into a lighter and a heavier group permits more accurate analyses of the mass effect in collisions of two vehicles.

For a given vehicle class and weight range (if applicable), regression coefficients for mass (while holding footprint constant) in the nine types of crashes are averaged, weighted by the number of baseline fatalities that would have occurred for the subgroup MY 2008-2011 vehicles in CY 2008-2012 if these vehicles had all been equipped with ESC. The adjustment for ESC, a feature of the analysis added in 2012, accounts for the fact that all mass reduction in future vehicles will apply to vehicles that are equipped with ESC, as required by our regulations. Table 5-1 presents the estimated percent increase in U.S. societal fatality risk per ten billion VMT for each 100-pound reduction in vehicle mass, while holding footprint constant, for each of the five vehicle classes.

Table 5-1 – Fatality Increase (%) per 100-Pound Mass Reduction While Holding Footprint Constant – MY 2004-2011, CY 2006-2012

Vehicle Class	Point Estimate	95% Confidence Bounds
Cars < 3,201 pounds	1.20	-.35 to +2.75
Cars > 3,201 pounds	0.42	-.67 to +1.50
CUVs and minivans	-0.25	-1.55 to +1.04
Truck-based LTVs < 5,014 pounds	0.31	- .51 to +1.13
Truck-based LTVs > 5,014 pounds	-0.61	-1.46 to +.25

Techniques developed in the 2011 (preliminary) and 2012 (final) Kahane reports have been retained to test statistical significance and to estimate 95 percent confidence bounds (sampling error) for mass effects and to estimate the combined annual effect of removing 100 pounds of mass from every vehicle (or of removing different amounts of mass from the various classes of vehicles), while holding footprint constant. Confidence bounds estimate only the sampling error internal to the data used in the specific analysis that generated the point estimate. Point estimates are also sensitive to the modification of components of the analysis, as shown in Table 5-2. However, this degree of uncertainty is methodological in nature rather than statistical.

None of the estimated effects has 95-percent confidence bounds that exclude zero, and thus are not statistically significant at the 95-percent confidence level. We have evaluated these results and provided them for the purposes of transparency. Sensitivity analyses have confirmed that the exclusion of these statistically-insignificant results would not affect our policy determination, because the net effects of mass reduction on safety costs are small relative to predominant estimated benefit and cost impacts. Among the estimated effects, the most important effects of mass reduction are, as expected, concentrated among the lightest and heaviest vehicles. Societal fatality risk is estimated to: (1) increase by 1.2 percent if mass is reduced by 100 pounds in the lighter cars; and (2) decrease by 0.61 percent if mass is reduced by 100 pounds in the heavier truck-based LTVs. We conducted exploratory analyses on four candidate revisions to the model. The first candidate revision, per feedback on the 2018 CAFE NPRM, is the reclassification of Class 2b and Class 3 truck-base vehicles. In the exploratory analysis, we removed Class 2b and Class 3 truck-based vehicles as case vehicles, and re-assigned crash partner Class 2b and Class 3 vehicles from LTVs to heavy-duty vehicles. The second candidate revision is the inclusion of passenger cars equipped with AWD. The third candidate revision is splitting CUVs and minivans into two vehicle classes by curb weight, consistent with the treatment of passenger cars and truck-based LTVs. The fourth candidate revision is the expansion of the range of calendar years and model years used to establish the distribution of fatalities by crash type.

Results based on the candidate revisions are consolidated in Table 5-2.

Table 5-2 – Fatality Increase (%) per 100-Pound Mass Reduction While Holding Footprint Constant with Alternative Model Specifications – MY 2004-2011, CY 2006-2012

Vehicle Class	Point Estimates, Fatalities Weighted Across MY 2008-2011 in CY 2008-2012 (Original Weights)	Point Estimates, Fatalities Weighted Across MY 2007-2011 in CY 2007-2012	Point Estimates, Fatalities Weighted Across MY 2006-2011 in CY 2006-2012	Point Estimates, Fatalities Weighted Across MY 2004-2011 in CY 2006-2012 (Full Sample)
Cars < 3,201 Pounds (including AWD)	1.12%	1.12%	1.11%	1.12%
Cars 3,201+ Pounds (including AWD)	0.89%	0.87%	0.84%	0.86%
LTVs < 4,808 Pounds (No Class 2b/3)	0.26%	0.26%	0.26%	0.29%
LTVs 4,808+ Pounds (No Class 2b/3)	-0.16%	-0.17%	-0.16%	-0.17%
CUVs and Minivans < 3,955 Pounds	0.20%	0.19%	0.18%	0.18%
CUVs and Minivans 3,955+ Pounds	-0.52%	-0.52%	-0.53%	-0.51%

Under the alternative specification excluding Class 2b and Class 3 truck-based vehicles as case vehicles, the median curb weight for LTVs is 4,808 pounds, or 206 pounds lighter than in the central analysis. When splitting CUVs and minivans into two weight classes, the median curb weight for the vehicles is 3,955 pounds. Under this alternative specification, where Class 2b and Class 3 truck-based crash partners are shifted from truck-based LTVs to heavy-duty vehicles, the median curb weight for LTV crash partners is 4,216 pounds, or 144 pounds lighter than in the central analysis.

Re-classifying Class 2b and Class 3 truck-based vehicles has a strong effect on the point estimate for heavier LTVs. Critically, removing the heaviest trucks as case vehicles yields a much smaller point estimate (reduction in societal fatality rates of between 0.16 and 0.17 percent per 100-pound mass reduction, versus 0.61 percent in the central analysis). This result is consistent with a relationship where a key share of the sensitivity of fatality risk is attributed to the mass of the heaviest vehicles in the fleet (i.e., supporting the role of mass dispersion in societal fatality rates). Importantly, the point estimate for lighter LTVs is not meaningfully different from the corresponding estimate in the central analysis (increase in societal fatality rates of between 0.26 and 0.29 percent per 100-pound mass reduction, versus 0.3 percent in the central analysis). Considered in concert, these results indicate that the most effective reductions in societal fatality rates via mass reduction in truck-based vehicles would arise not from light-weighting the heaviest vehicles subject to CAFE regulation, but rather from light-weighting similar, medium- and heavy-duty vehicles.

Including passenger cars with AWD in the analysis has little effect on the point estimate for lighter passenger cars (increase in societal fatality rates of approximately 1.1 percent per 100-pound mass reduction, versus 1.2 percent in the central analysis). However, this revision has a strong effect on the point estimate for heavier passenger cars (increase in societal fatality rates of between 0.84 and 0.89 percent per 100-pound mass reduction, versus 0.42 percent in the central analysis). This result supports a hypothesis that, after taking AWD status into account, mass reduction in heavier passenger cars is a more important driver of societal fatality rates than previously estimated. Although this result could be spurious, estimated confidence bounds (presented below) indicate that accounting for AWD status reduces uncertainty in the point estimate. The agency did not identify any public comments on the inclusion of passenger cars with AWD when estimating the effects of mass reduction on societal fatality rates, and thus will defer the decision whether to incorporate the results into the CAFE Model to future rulemakings. Splitting CUVs and minivans into two vehicle classes yields point estimates that are consistent with the point estimate for the consolidated CUV-minivan vehicle class (an average decrease in societal fatality rates of approximately 0.16 to 0.18 percent per 100-pound mass reduction across the two vehicle classes, versus a decrease of 0.25 percent in the central analysis). However, sample sizes half as large in the two vehicle classes relative to the consolidated vehicle class lead to very large estimated confidence bounds, as shown below. Due to this uncertainty, we do not feel that the current databases contain a large enough sample of CUVs and minivans to split these vehicles into two classes in the analysis; however, this issue will be re-examined when the next iteration of the databases is complete.

Extending the range of calendar years and model years used to establish the distribution of fatalities across crash types has a negligible effect on the point estimates. Based on the narrow ranges of results in Table 5-2, we find evidence supporting a flexible approach in the choice of calendar years and model years used in this manner. All else being equal, extending the range helps to mitigate the potential for individual crash types with large estimated effects to drive spurious effects on overall estimates through unrepresentatively high estimated shares of overall fatalities. As a hedge in this direction, we applied the estimates from the alternative specification with two additional calendar years and model years (i.e., the second column from the right in Table 5-2) when evaluating 95-percent confidence bounds for the alternative models considered here. The agency did not identify any public comments on this approach to representing the distribution of fatalities across crash types, and thus will defer the decision whether to incorporate the results into the CAFE Model to future rulemakings.

We believe the most recent analysis represents the best estimate of the impacts of mass reduction that results in increased mass disparities on crash fatalities, although it is important to note that these best estimates are not significantly different from zero. We have conducted sensitivity analyses to illustrate the uncertainty of the estimates, and we have determined that inclusion of these estimates does not alter the agency's determination of what is maximum feasible because the effects are so small. We continue to believe that is reasonable for the analysis to continue to include the best available estimates despite their lack of statistical significance at the 0.05 level. Similar to past analyses, the most recent analysis uses the best available data and estimates. We feel it is inappropriate to ignore likely impacts of the standards simply because the best available estimates have confidence levels below 95 percent; uniform estimates of zero are statistically weaker than the estimates identified in the analysis, and thus are not the best available. Because the point estimates are derived from the best-fitting estimates for each crash type (all of which are non-zero), the confidence bounds around an overall estimate of zero would necessarily be larger than the corresponding confidence bounds around the point estimates presented here. Ultimately, the point estimates for the lightest and heaviest vehicles in the sample are the estimates that have shown consistent directionality (and, to a lesser extent, magnitude) across studies, and these estimates are the most important in representing the effects of changes in mass disparity. Thus, the point estimates for lighter passenger cars and heavier LTVs offer the highest informative value among the estimates in the analysis; the smaller estimates corresponding to vehicles near the median of the fleet curb weight distribution are likely to be less informative.

The sensitivity analysis in Chapter 7 of the FRIA provides an evaluation of extreme cases in which all the estimated net fatality rate impacts of mass reduction are either at their fifth- or 95th-percentile values. The range of net impacts in the sensitivity analysis not only covers the relatively more likely case that uncertain, yet generally offsetting, effects are distinct from the central estimates considered here (e.g., in a plausible case where mass reduction in the heaviest LTVs is less beneficial than indicated by the central estimates, it would also be relatively likely that mass reduction in the lightest passenger cars would be less harmful, yielding a similar net impact), but also covers the relatively unlikely case that all of the estimates are uncertain in the same direction.

A more detailed description of the mass/safety analysis can be found in Chapter 7 of the accompanying TSD.

5.3 Sales/Scrappage Impacts

The sales response discussed above impacts the number of vehicles produced in a given model year and, consequently, in service in subsequent years. Setting aside other responses, then, the sales response changes the absolute numbers of estimated fatalities by simply changing the size of the fleet. Related, the DFS model discussed above also impacts the relative shares of passenger cars and light trucks produced in each model year (because as the fuel economy levels of both passenger cars and light trucks improve, the improvements add more value to the latter, the effect being amplified as fuel prices increase over time), and this impacts the absolute numbers of fatalities because our estimates of impacts of changes in mass reduction on fatality risk are different for passenger cars and light trucks. The scrappage response discussed above also impacts safety because it changes the rate at which we estimate the fleet will "turn over" to newer vehicles, which tend to be safer than older vehicles.[98]

Any effects on fleet turnover (either from changes in the pace of vehicle retirement or sales of new vehicles will affect the distribution of both ages and model years present in the on-road fleet. Because each vintage carries an inherent rate of fatal crashes, and newer vintages are generally safer than older ones, changing that distribution will change the total number of on-road fatalities under each regulatory alternative. Similarly, the DFS model captures the changes in the fleet's composition of cars and trucks. As cars and trucks have different fatality rates, differences in fleet composition across the alternatives will affect fatalities.

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[98] *See* Passenger Vehicle Occupant Injury Severity by Vehicle Age and Model Year in Fatal Crashes, Traffic Safety Facts Research Note, DOT-HS-812-528, National Highway Traffic Safety Administration, April, 2018, and The Relationship Between Passenger Vehicle Occupant Injury Outcomes and Vehicle Age or Model Year in Police-Reported Crashes, Traffic Safety Facts Research Note, DOT-HS-812-937, National Highway Traffic Safety Administration, March, 2020.

5.4 Rebound Effect Impacts

The "rebound effect" is a measure of the additional driving that occurs when the cost of driving declines. More stringent standards reduce vehicle operating costs, and in response, some consumers may choose to drive more. Driving more increases exposure to risks associated with on-road transportation, and this added exposure translates into higher fatalities. We have calculated this impact by estimating the change in VMT that results from alternative standards. Estimates of the rebound effect in the literature differ significantly. For this analysis, we use a rebound effect of 10 percent. A full discussion of the basis for selecting this rate is provided in Chapter 4.3.3 of the accompanying TSD.

Rebound miles are not imposed on consumers by regulation, but instead are a voluntary response to the reduction in vehicles' operating costs that results from improved fuel economy. Because of its voluntary nature, we believe some or all of the safety risks associated with additional driving must be offset by the benefits drivers gain from added driving. The level of risk recognized and accounted for by drivers when the elect to make additional trips is extremely uncertain, but for purposes of this analysis the agency assumes that drivers account for or "internalize" 90 percent of the risk associated with additional driving. Thus, the agency calculates that 90 percent of the costs of crashes attributable to additional vehicle use are offset by corresponding benefits to drivers and their passengers, so that only the remaining 10 percent of costs represent an external cost they impose on other travelers or on the remainder of society. Additional discussion of internalized risk is contained in TSD Chapter 7.4.

5.5 Value of Safety Impacts

Fatalities, nonfatal injuries, and property damage crashes are valued as a societal cost within the CAFE Model's cost and benefit accounting. Their value is based on the comprehensive value of a fatality, which includes lost quality of life and is quantified in the VSL as well as economic consequences such as medical and emergency care, insurance administrative costs, legal costs, and other economic impacts not captured in the VSL alone. These values were derived from data in Blincoe et al. (2015), adjusted to 2018 economics, and updated to reflect the official DOT guidance on the VSL.[99] Nonfatal injury costs, which differ by severity, were weighted according to the relative incidence of injuries across the Abbreviated Injury Scale (AIS). To determine this incidence, the agency applied a KABCO (scale used to represent injury severity in crash reporting)/maximum abbreviated injury scale (MAIS) translator to GES KABCO based injury counts from 2010 through 2015. This produced the MAIS based injury profile. This profile was used to weight nonfatal injury unit costs derived from Blincoe et al, adjusted to 2018 economics and updated to reflect the official DOT guidance on the VSL. Property-damaged vehicle costs were also taken from Blincoe et al and adjusted to 2018 economics. VSL does not impact property damage. This gives societal values of $10.8 million for each fatality, $132,000 for each nonfatal injury, and $7,100 for each property damaged vehicle.

[99] https://www.transportation.gov/office-policy/transportation-policy/revised-departmental-guidance-on-valuation-of-a-statistical-life-in-economic-analysis. (Accessed: February 14, 2022).

5.6 Summary of Safety Impacts

Table 5-3 through Table 5-8 summarize the safety impacts of each alternative broken down by safety factor. These impacts are summarized over the lifetimes of MY 1981 through 2029 vehicles, as well as for CYs 2020-2035, for all light passenger vehicles (including passenger cars and light trucks). Economic impacts are shown separately under both 3 and 7 percent discount rates. Discounting is applied to model year lifetime cost impacts. Fatality counts are undiscounted.

As noted previously, safety impacts are driven by changes in vehicle mass which make vehicles lighter to improve fuel economy, by added exposure from rebound miles driven in response to reduced driving costs that result from improved fuel efficiency, and by changes in fleet composition resulting from the impact of higher prices on new and used vehicle sales, as well as the relative desirability of passenger cars compared to light trucks.

Generally, the stricter alternative requirements have increasingly higher safety impacts. Changes to improve increasing levels of fuel efficiency trigger more use of mass reduction and the resulting reductions in driving costs produce more rebound driving. Higher prices resulting from higher CAFE requirement slow fleet turnover. These composition changes reflect fewer new vehicles being purchased, older vehicles being retained longer and used more frequently, and a shift towards more light trucks over time as larger vehicles become more cost-efficient to operate.

The safety impacts in Table 5-3 through Table 5-5 represent accumulated impacts over the full lifetime of MY 1981 through 2029 fleets during the years analyzed in this final rule. MYs 1981 through 2029 were examined because they represent the model years that might be impacted by shifts in fleet composition due to the impact of higher new vehicle prices on sales of new vehicles and retention of older vehicles. Earlier years will be impacted by slower scrappage rates and we expect the impacts of these standards will be fully realized in vehicle designs by MY 2029.

Table 5-6 through Table 5-8 illustrate the safety impacts by calendar year under each alternative out through 2035, separately for fatalities, nonfatal injuries, and property damage vehicles. For context, during this 2020-2035 CY period, baseline fatalities are expected to total roughly 330,000 deaths. Sales/Scrappage impacts initially dominate safety influences, but by the early 2030s the on-road fleet is mostly composed of vehicles that have the same advanced safety technologies as newer vehicles, so the influence of this factor is less prevalent.

Note that due to rounding of presented output components within each table, totals may not exactly match the sum of the rounded impacts.

Table 5-3 – Change in Safety Parameters from Alternative 0 (Baseline) for MY 1981-2029 for Total Fleet, 3 Percent Discount Rate, by Alternative

Alternative	1	2	2.5	3
Fatalities				
Fatalities From Mass Changes	72	95	95	134
Fatalities from Rebound Effect	360	561	620	758

Fatalities from Sales/Scrappage	245	548	620	812
Total Changes in Fatalities	677	1,204	1,335	1,704
Fatality Costs ($b)				
Fatality Costs From Mass Changes	0.5	0.7	0.7	0.9
Fatality Costs From Rebound Effect	2.4	3.8	4.2	5.1
Fatality Costs from Sales/Scrappage	2.1	4.7	5.4	7.1
Total - Fatality Costs ($b)	4.9	9.1	10.2	13.1
Non-Fatal Injury Crash Costs ($b)				
Non-Fatal Crash Costs From Mass Changes	0.6	0.7	0.7	1.1
Non-Fatal Crash Costs From Rebound Effect	2.6	4.2	4.6	5.6
Non-Fatal Crash Costs from Sales/Scrappage	0.6	1.4	1.6	2.0
Total - Non-Fatal Crash Costs ($b)	3.8	6.3	6.9	8.7
Property Damage Costs ($b)				
Property Damage Costs From Mass Changes	0.1	0.2	0.2	0.2
Property Damage Costs From Rebound Effect	0.5	0.9	1.0	1.2
Property Damage Costs From Sales/Scrappage	0.1	0.2	0.3	0.3
Total - Property Damage Costs ($b)	0.8	1.2	1.4	1.7
Societal Crash Costs ($b)				
Crash Costs from Mass Changes	1.2	1.5	1.5	2.2
Crash Costs from Rebound Effect	5.5	8.8	9.7	11.9
Crash Costs from Sales/Scrappage	2.8	6.3	7.2	9.5
Total - Societal Crash Costs ($b)	9.5	16.7	18.5	23.5

Table 5-4 – Change in Safety Parameters from Alternative 0 (Baseline) for MY 1981-2029 for Total Fleet, 7 Percent Discount Rate, by Alternative

Alternative	1	2	2.5	3
Fatalities				
Fatalities From Mass Changes	72	95	95	134
Fatalities from Rebound Effect	360	561	620	758
Fatalities from Sales/Scrappage	245	548	620	812
Total Changes in Fatalities	677	1,204	1,335	1,704
Fatality Costs ($b)				
Fatality Costs From Mass Changes	0.3	0.4	0.4	0.5
Fatality Costs From Rebound Effect	1.4	2.2	2.4	2.9
Fatality Costs from Sales/Scrappage	1.5	3.5	4.0	5.4
Total - Fatality Costs ($b)	3.2	6.1	6.8	8.8
Non-Fatal Injury Crash Costs ($b)				
Non-Fatal Crash Costs From Mass Changes	0.4	0.5	0.5	0.7
Non-Fatal Crash Costs From Rebound Effect	1.6	2.6	2.9	3.5
Non-Fatal Crash Costs from Sales/Scrappage	0.5	1.1	1.3	1.7
Total - Non-Fatal Crash Costs ($b)	2.5	4.2	4.6	5.9

Property Damage Costs ($b)				
Property Damage Costs From Mass Changes	0.1	0.1	0.1	0.1
Property Damage Costs From Rebound Effect	0.3	0.5	0.6	0.7
Property Damage Costs From Sales/Scrappage	0.1	0.2	0.2	0.3
Total - Property Damage Costs ($b)	0.5	0.8	0.9	1.2
Societal Crash Costs ($b)				
Crash Costs from Mass Changes	0.7	1.0	1.0	1.4
Crash Costs from Rebound Effect	3.3	5.3	5.9	7.2
Crash Costs from Sales/Scrappage	2.1	4.8	5.5	7.3
Total - Societal Crash Costs ($b)	6.1	11.1	12.4	15.9

Table 5-5 – Change in Non-Fatal Safety Parameters from Alternative 0 (Baseline) for MY 1981-2029 for Total Fleet, by Alternative

Alternative	1	2	2.5	3
Non-Fatal Injuries				
Non-Fatal Injuries From Mass Changes	6,310	8,238	8,234	11,733
Non-Fatal Injuries from Rebound Effect	29,554	46,915	51,936	63,338
Non-Fatal Injuries from Sales/Scrappage	5,455	11,684	12,986	16,206
Total Changes in Non-Fatal Injuries	41,318	66,837	73,156	91,278
Property Damaged Vehicles				
Property Damaged Vehicles From Mass Changes	24,159	31,543	31,530	44,932
Property Damaged Vehicles from Rebound Effect	112,966	179,371	198,576	242,157
Property Damaged Vehicles from Sales/Scrappage	17,287	36,723	40,597	49,865
Total Changes in Property Damaged Vehicles	154,412	247,637	270,704	336,953

Table 5-6 – Change in Fatalities from Alternative 0 (Baseline) for CY 2020-2035 for Total Fleet, by Alternative

Calendar Year	Incremental Fatalities - Alt. 1				Incremental Fatalities - Alt. 2				Incremental Fatalities - Alt. 2.5				Incremental Fatalities - Alt. 3			
	Mass	Rebound	Sales / Scrap	Total	Mass	Rebound	Sales / Scrap	Total	Mass	Rebound	Sales / Scrap	Total	Mass	Rebound	Sales / Scrap	Total
2020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2021	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2023	0	0	1	1	0	0	3	4	0	0	3	4	0	1	4	5
2024	0	2	7	9	1	2	17	20	1	2	19	22	1	3	24	28
2025	1	3	20	24	1	5	33	39	1	5	36	43	2	7	52	60
2026	1	6	25	32	2	9	50	60	2	10	55	66	3	12	77	92
2027	2	8	27	37	3	13	63	79	3	14	73	90	4	18	97	119
2028	3	11	26	39	3	18	61	83	3	20	71	95	5	25	95	124
2029	3	15	25	43	4	23	60	87	4	26	70	100	6	32	92	130
2030	4	19	23	45	5	30	55	90	5	33	65	103	7	40	86	133
2031	5	22	20	46	6	36	50	92	6	39	59	104	9	48	78	134
2032	5	26	17	48	7	42	44	93	7	46	52	105	10	56	68	134
2033	6	29	14	49	8	48	38	94	8	53	45	105	11	63	59	134
2034	7	33	11	51	9	54	31	94	9	59	37	105	12	71	49	132
2035	7	36	9	52	9	59	25	94	9	65	30	105	13	78	39	130

Table 5-7 – Change in Non-Fatal Injuries from Alternative 0 (Baseline) for CY 2020-2035 for Total Fleet, by Alternative

Calendar Year	Incremental Non-Fatal Injuries - Alt. 1				Incremental Non-Fatal Injuries - Alt. 2				Incremental Non-Fatal Injuries - Alt. 2.5				Incremental Non-Fatal Injuries - Alt. 3			
	Mass	Rebound	Sales / Scrap	Total	Mass	Rebound	Sales / Scrap	Total	Mass	Rebound	Sales / Scrap	Total	Mass	Rebound	Sales / Scrap	Total
2020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2021	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2023	0	47	42	89	23	60	131	214	23	74	141	238	24	102	169	295
2024	66	238	281	584	106	304	642	1,053	106	352	697	1,154	143	483	900	1,526
2025	111	494	691	1,296	175	693	1,156	2,024	172	776	1,271	2,220	243	1,007	1,820	3,070
2026	181	810	818	1,809	264	1,236	1,669	3,169	263	1,378	1,838	3,479	374	1,720	2,586	4,680
2027	264	1,151	839	2,254	363	1,815	1,997	4,175	362	2,014	2,308	4,684	520	2,475	3,057	6,052
2028	350	1,537	725	2,612	465	2,462	1,778	4,704	464	2,728	2,067	5,260	667	3,324	2,728	6,720
2029	436	1,908	637	2,981	567	3,073	1,569	5,210	567	3,406	1,836	5,810	812	4,139	2,414	7,365
2030	509	2,356	511	3,376	655	3,818	1,296	5,769	654	4,224	1,526	6,405	942	5,109	1,994	8,044
2031	582	2,710	380	3,671	748	4,418	1,018	6,185	745	4,872	1,209	6,825	1,070	5,866	1,564	8,499
2032	648	3,089	254	3,991	836	5,057	749	6,642	829	5,569	898	7,296	1,190	6,677	1,149	9,016
2033	712	3,413	153	4,277	918	5,619	508	7,044	908	6,180	617	7,704	1,303	7,387	769	9,459
2034	736	3,713	69	4,519	960	6,146	294	7,399	946	6,754	367	8,067	1,374	8,055	423	9,851
2035	756	3,961	2	4,719	995	6,597	111	7,702	978	7,248	151	8,376	1,435	8,623	129	10,186

Table 5-8 – Change in Property – Damaged Vehicles from Alternative 0 (Baseline) for CY 2020-2035 for Total Fleet, by Alternative

Calendar Year	Incremental Property Damage - Alt. 1				Incremental Property Damage - Alt. 2				Incremental Property Damage - Alt. 2.5				Incremental Property Damage - Alt. 3			
	Mass	Rebound	Sales / Scrap	Total	Mass	Rebound	Sales / Scrap	Total	Mass	Rebound	Sales / Scrap	Total	Mass	Rebound	Sales / Scrap	Total
2020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2021	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2023	2	190	135	327	93	242	425	761	93	299	455	848	98	413	547	1,058
2024	265	962	890	2,116	429	1,229	2,019	3,677	429	1,419	2,192	4,039	578	1,949	2,836	5,363
2025	447	1,984	2,192	4,623	701	2,786	3,665	7,151	692	3,120	4,028	7,839	978	4,047	5,766	10,791
2026	725	3,242	2,608	6,574	1,056	4,954	5,321	11,331	1,050	5,520	5,862	12,431	1,495	6,887	8,241	16,623
2027	1,052	4,588	2,675	8,315	1,445	7,241	6,387	15,073	1,440	8,035	7,387	16,862	2,072	9,869	9,767	21,708
2028	1,388	6,102	2,301	9,791	1,842	9,778	5,665	17,285	1,840	10,836	6,591	19,267	2,645	13,197	8,679	24,521
2029	1,724	7,542	2,011	11,277	2,239	12,155	4,973	19,367	2,240	13,471	5,824	21,535	3,206	16,363	7,633	27,201
2030	2,005	9,274	1,598	12,877	2,575	15,040	4,072	21,687	2,571	16,636	4,801	24,009	3,701	20,110	6,245	30,056
2031	2,280	10,628	1,166	14,074	2,930	17,335	3,162	23,426	2,915	19,111	3,759	25,785	4,187	22,998	4,830	32,015
2032	2,529	12,071	760	15,360	3,260	19,767	2,288	25,314	3,233	21,763	2,748	27,744	4,640	26,081	3,481	34,202
2033	2,767	13,290	433	16,490	3,567	21,887	1,506	26,960	3,527	24,068	1,838	29,433	5,062	28,758	2,249	36,068
2034	2,849	14,411	165	17,426	3,713	23,862	822	28,397	3,660	26,221	1,037	30,919	5,315	31,254	1,139	37,708
2035	2,912	15,328	-49	18,191	3,834	25,539	239	29,612	3,769	28,053	351	32,173	5,533	33,360	204	39,097

5.7 Sensitivity Analysis – Safety Impacts

Estimates of future impacts on safety from CAFE requirements reflect our best judgment regarding the future values of the factors that influence these analyses. However, we acknowledge that there is a level of uncertainty regarding many of these factors. Uncertainties exist in: (1) the joint effects of the mass effects model across vehicle classes; (2) estimates of the adoption of mass reduction technologies across vehicle models and model years; (3) estimates of changes in market shares; (4) driver behavior, particularly with respect to changes in scrappage rates and rebound VMT, but also as it affects future fatality and injury rates; and (5) the effectiveness and timing of advanced technology adoption. While we are confident that our estimates are the best available representations of each of these factors for which uncertainty is present, and that the resulting forecasts of safety impacts inform the comparison of policy alternatives in a meaningful way, we also recognize that there is uncertainty inherent in any attempt to project outcomes that extend into future decades. To support the robustness of comparisons across alternatives, we consider a range of plausible values across the three safety impacts presented in this chapter within sensitivity analyses. The values applied within the sensitivity analyses enable the model to represent alternative outcomes reflecting the areas of uncertainty described above.

Table 5-9 through Table 5-14 present sensitivity analyses isolating the uncertainty parameters of each of the three safety impacts. The content of each table is comparable to Table 5-3, which examines economic impacts using a 3 percent discount rate. Each set of two consecutive tables examine first the low and then the high end of the safety parameters examined in this analysis. For mass/safety, these parameters are noted in Table 5-1 of this chapter. For rebound impacts, the low parameter assumes a 5 percent rebound rate and the high parameter assumes a 15 percent rebound rate. For Sales/Scrappage, the low and high parameters are noted in Table 7-15 of the accompanying Technical Support Document. In each of these following tables, all inputs are kept constant except the noted factor safety parameter. Generally mass parameters that cause more mass disparity increase fatalities while those that decrease disparity tend to decrease fatalities. A lower rebound effect decreases risk exposure which results in fewer fatalities, while a higher rebound effect increases risk exposure and fatalities. Higher technology effectiveness rates tend to increase the impact of delaying new vehicle purchases while lower effectiveness rates tend to decrease these impacts. However, note that there are interactive impacts among these factors which are applied simultaneously, and these interactive impacts are lumped with sales/scrappage impacts, which is calculated as the difference between the total interactive impact and the mass and rebound impacts. This complicates the analysis of sales/scrappage impacts somewhat and makes their sensitivity results less predictable.

Table 5-15 presents the impacts on safety of an alternate fuel savings payback assumption. In the central analysis, we estimate that consumers value 30 months of fuel savings when making purchasing decisions about new vehicles. Table 5-15 examines the impact of a 60-month payback assumption. A higher payback assumption shifts consumer preferences towards added fuel efficiency, which means they are more likely to value the extra cost of added fuel efficiency. This produces fewer instances of lost new vehicle sales, which reduces the safety impact of the added vehicle cost that is associated with increased fuel efficiency. As with the other sensitivity tables, Table 5-15 is formatted similar to Table 5-3 in the central analysis.

Note that due to rounding of presented output components within each table, totals may not exactly match the sum of the rounded impacts.

Table 5-9 – Low Mass Safety Parameters

Alternative	1	2	2.5	3
Fatalities				
Fatalities From Mass Changes	-364	-412	-419	-589
Fatalities from Rebound Effect	342	537	595	722
Fatalities from Sales/Scrappage	235	534	604	796
Total Changes in Fatalities	213	659	780	929
Fatality Costs ($b)				
Fatality Costs From Mass Changes	-2.4	-2.7	-2.8	-3.9
Fatality Costs From Rebound Effect	2.3	3.6	4.0	4.8
Fatality Costs from Sales/Scrappage	2.0	4.6	5.3	7.0
Total - Fatality Costs ($b)	1.8	5.5	6.5	7.9
Non-Fatal Injury Crash Costs ($b)				
Non-Fatal Crash Costs From Mass Changes	-2.7	-3.0	-3.1	-4.3
Non-Fatal Crash Costs From Rebound Effect	2.5	4.0	4.4	5.3
Non-Fatal Crash Costs from Sales/Scrappage	0.5	1.3	1.4	1.9
Total - Non-Fatal Crash Costs ($b)	0.3	2.2	2.8	2.9
Property Damage Costs ($b)				
Property Damage Costs From Mass Changes	-0.6	-0.6	-0.6	-0.9
Property Damage Costs From Rebound Effect	0.5	0.8	0.9	1.1
Property Damage Costs From Sales/Scrappage	0.1	0.2	0.2	0.3
Total - Property Damage Costs ($b)	0.0	0.4	0.5	0.5
Societal Crash Costs ($b)				
Crash Costs from Mass Changes	-5.7	-6.4	-6.5	-9.2
Crash Costs from Rebound Effect	5.2	8.4	9.3	11.3
Crash Costs from Sales/Scrappage	2.6	6.1	7.0	9.2
Total - Societal Crash Costs ($b)	2.2	8.1	9.8	11.3

Table 5-10 – High Mass Safety Parameters

Alternative	1	2	2.5	3
Fatalities				
Fatalities From Mass Changes	506	598	605	853
Fatalities from Rebound Effect	378	586	646	794
Fatalities from Sales/Scrappage	254	562	635	827
Total Changes in Fatalities	1,139	1,747	1,886	2,475
Fatality Costs ($b)				
Fatality Costs From Mass Changes	3.4	4.0	4.1	5.8

Fatality Costs From Rebound Effect	2.5	3.9	4.3	5.3
Fatality Costs from Sales/Scrappage	2.1	4.8	5.5	7.2
Total - Fatality Costs ($b)	8.0	12.8	13.9	18.3
Non-Fatal Injury Crash Costs ($b)				
Non-Fatal Crash Costs From Mass Changes	3.8	4.5	4.6	6.4
Non-Fatal Crash Costs From Rebound Effect	2.7	4.3	4.8	5.9
Non-Fatal Crash Costs from Sales/Scrappage	0.7	1.5	1.7	2.1
Total - Non-Fatal Crash Costs ($b)	7.2	10.3	11.0	14.4
Property Damage Costs ($b)				
Property Damage Costs From Mass Changes	0.8	0.9	0.9	1.3
Property Damage Costs From Rebound Effect	0.6	0.9	1.0	1.2
Property Damage Costs From Sales/Scrappage	0.1	0.3	0.3	0.4
Total - Property Damage Costs ($b)	1.5	2.1	2.2	2.9
Societal Crash Costs ($b)				
Crash Costs from Mass Changes	8.0	9.5	9.6	13.5
Crash Costs from Rebound Effect	5.8	9.2	10.1	12.4
Crash Costs from Sales/Scrappage	2.9	6.6	7.4	9.7
Total - Societal Crash Costs ($b)	16.7	25.2	27.1	35.6

Table 5-11 – Low Rebound Assumption

Alternative	1	2	2.5	3
Fatalities				
Fatalities From Mass Changes	72	95	95	134
Fatalities from Rebound Effect	184	293	323	395
Fatalities from Sales/Scrappage	245	548	620	812
Total Changes in Fatalities	502	936	1,037	1,341
Fatality Costs ($b)				
Fatality Costs From Mass Changes	0.3	0.4	0.4	0.5
Fatality Costs From Rebound Effect	0.7	1.1	1.2	1.5
Fatality Costs from Sales/Scrappage	1.5	3.5	4.0	5.4
Total - Fatality Costs ($b)	2.5	5.0	5.7	7.4
Non-Fatal Injury Crash Costs ($b)				
Non-Fatal Crash Costs From Mass Changes	0.4	0.5	0.5	0.7
Non-Fatal Crash Costs From Rebound Effect	0.8	1.3	1.5	1.8
Non-Fatal Crash Costs from Sales/Scrappage	0.5	1.1	1.3	1.7
Total - Non-Fatal Crash Costs ($b)	1.7	2.9	3.2	4.1
Property Damage Costs ($b)				
Property Damage Costs From Mass Changes	0.1	0.1	0.1	0.1

Property Damage Costs From Rebound Effect	0.2	0.3	0.3	0.4
Property Damage Costs From Sales/Scrappage	0.1	0.2	0.2	0.3
Total - Property Damage Costs ($b)	0.3	0.6	0.6	0.8
Societal Crash Costs ($b)				
Crash Costs from Mass Changes	0.7	1.0	1.0	1.4
Crash Costs from Rebound Effect	1.7	2.7	3.0	3.7
Crash Costs from Sales/Scrappage	2.1	4.8	5.5	7.3
Total - Societal Crash Costs ($b)	4.5	8.5	9.5	12.4

Table 5-12 – High Rebound Assumption

Alternative	1	2	2.5	3
Fatalities				
Fatalities From Mass Changes	72	95	95	134
Fatalities from Rebound Effect	536	830	918	1,121
Fatalities from Sales/Scrappage	245	548	620	812
Total Changes in Fatalities	853	1,473	1,632	2,067
Fatality Costs ($b)				
Fatality Costs From Mass Changes	0.3	0.4	0.4	0.5
Fatality Costs From Rebound Effect	2.0	3.2	3.5	4.3
Fatality Costs from Sales/Scrappage	1.5	3.5	4.0	5.4
Total - Fatality Costs ($b)	3.8	7.1	8.0	10.2
Non-Fatal Injury Crash Costs ($b)				
Non-Fatal Crash Costs From Mass Changes	0.4	0.5	0.5	0.7
Non-Fatal Crash Costs From Rebound Effect	2.4	3.9	4.3	5.2
Non-Fatal Crash Costs from Sales/Scrappage	0.5	1.1	1.3	1.7
Total - Non-Fatal Crash Costs ($b)	3.3	5.5	6.0	7.6
Property Damage Costs ($b)				
Property Damage Costs From Mass Changes	0.1	0.1	0.1	0.1
Property Damage Costs From Rebound Effect	0.5	0.8	0.9	1.1
Property Damage Costs From Sales/Scrappage	0.1	0.2	0.2	0.3
Total - Property Damage Costs ($b)	0.7	1.1	1.2	1.5
Societal Crash Costs ($b)				
Crash Costs from Mass Changes	0.7	1.0	1.0	1.4
Crash Costs from Rebound Effect	5.0	7.9	8.7	10.7
Crash Costs from Sales/Scrappage	2.1	4.8	5.5	7.3
Total - Societal Crash Costs ($b)	7.8	13.6	15.2	19.3

Table 5-13 – Low Safety Technology Effectiveness (Sales/Scrappage)

Alternative	1	2	2.5	3
Fatalities				
Fatalities From Mass Changes	72	94	94	134
Fatalities from Rebound Effect	358	559	618	755
Fatalities from Sales/Scrappage	245	550	621	814
Total Changes in Fatalities	676	1,203	1,333	1,703
Fatality Costs ($b)				
Fatality Costs From Mass Changes	0.5	0.6	0.6	0.9
Fatality Costs From Rebound Effect	2.4	3.7	4.1	5.1
Fatality Costs from Sales/Scrappage	2.1	4.7	5.4	7.1
Total - Fatality Costs ($b)	4.9	9.1	10.2	13.1
Non-Fatal Injury Crash Costs ($b)				
Non-Fatal Crash Costs From Mass Changes	0.6	0.7	0.7	1.0
Non-Fatal Crash Costs From Rebound Effect	2.5	4.0	4.5	5.5
Non-Fatal Crash Costs from Sales/Scrappage	0.6	1.4	1.6	2.1
Total - Non-Fatal Crash Costs ($b)	3.7	6.2	6.8	8.6
Property Damage Costs ($b)				
Property Damage Costs From Mass Changes	0.1	0.1	0.1	0.2
Property Damage Costs From Rebound Effect	0.5	0.8	0.9	1.1
Property Damage Costs From Sales/Scrappage	0.1	0.2	0.3	0.4
Total - Property Damage Costs ($b)	0.7	1.2	1.4	1.7
Societal Crash Costs ($b)				
Crash Costs from Mass Changes	1.2	1.5	1.5	2.2
Crash Costs from Rebound Effect	5.4	8.6	9.5	11.6
Crash Costs from Sales/Scrappage	2.8	6.4	7.3	9.6
Total - Societal Crash Costs ($b)	9.4	16.5	18.3	23.4

Table 5-14 – High Safety Technology Effectiveness (Sales/Scrappage)

Alternative	1	2	2.5	3
Fatalities				
Fatalities From Mass Changes	73	95	95	135
Fatalities from Rebound Effect	361	563	621	760
Fatalities from Sales/Scrappage	245	548	619	811
Total Changes in Fatalities	678	1,205	1,335	1,705
Fatality Costs ($b)				
Fatality Costs From Mass Changes	0.5	0.7	0.7	0.9
Fatality Costs From Rebound Effect	2.4	3.8	4.2	5.1
Fatality Costs from Sales/Scrappage	2.1	4.7	5.4	7.1
Total - Fatality Costs ($b)	4.9	9.1	10.2	13.1

Non-Fatal Injury Crash Costs ($b)				
Non-Fatal Crash Costs From Mass Changes	0.6	0.8	0.8	1.1
Non-Fatal Crash Costs From Rebound Effect	2.7	4.3	4.7	5.8
Non-Fatal Crash Costs from Sales/Scrappage	0.6	1.3	1.5	1.9
Total - Non-Fatal Crash Costs ($b)	3.8	6.4	7.0	8.8
Property Damage Costs ($b)				
Property Damage Costs From Mass Changes	0.1	0.2	0.2	0.2
Property Damage Costs From Rebound Effect	0.6	0.9	1.0	1.2
Property Damage Costs From Sales/Scrappage	0.1	0.2	0.3	0.3
Total - Property Damage Costs ($b)	0.8	1.3	1.4	1.7
Societal Crash Costs ($b)				
Crash Costs from Mass Changes	1.2	1.6	1.6	2.2
Crash Costs from Rebound Effect	5.6	8.9	9.9	12.0
Crash Costs from Sales/Scrappage	2.7	6.3	7.1	9.4
Total - Societal Crash Costs ($b)	9.6	16.8	18.6	23.6

Table 5-15 – Five Year (60 month) Fuel Savings Payback Assumption

Alternative	1	2	2.5	3
Fatalities				
Fatalities From Mass Changes	3	21	34	84
Fatalities from Rebound Effect	257	479	530	695
Fatalities from Sales/Scrappage	171	415	549	738
Total Changes in Fatalities	430	916	1,113	1,516
Fatality Costs ($b)				
Fatality Costs From Mass Changes	0.0	0.1	0.2	0.6
Fatality Costs From Rebound Effect	1.7	3.2	3.5	4.6
Fatality Costs from Sales/Scrappage	1.5	3.5	4.7	6.4
Total - Fatality Costs ($b)	3.2	6.8	8.5	11.6
Non-Fatal Injury Crash Costs ($b)				
Non-Fatal Crash Costs From Mass Changes	0.0	0.2	0.3	0.7
Non-Fatal Crash Costs From Rebound Effect	1.8	3.5	3.9	5.1
Non-Fatal Crash Costs from Sales/Scrappage	0.4	1.0	1.3	1.7
Total - Non-Fatal Crash Costs ($b)	2.2	4.7	5.5	7.5
Property Damage Costs ($b)				
Property Damage Costs From Mass Changes	0.0	0.0	0.1	0.1
Property Damage Costs From Rebound Effect	0.4	0.7	0.8	1.1
Property Damage Costs From Sales/Scrappage	0.1	0.2	0.2	0.3

Total - Property Damage Costs ($b)	0.4	0.9	1.1	1.5
Societal Crash Costs ($b)				
Crash Costs from Mass Changes	0.0	0.3	0.6	1.4
Crash Costs from Rebound Effect	3.9	7.4	8.2	10.8
Crash Costs from Sales/Scrappage	1.9	4.7	6.3	8.4
Total - Societal Crash Costs ($b)	5.9	12.5	15.1	20.6

6. Effects of Regulatory Alternatives

6.1 Overview

CAFE standards produce wide-ranging effects in the vehicles market, in society, and in the environment, and NHTSA considers such impacts when making decisions about new CAFE standards. Like past rulemakings, the current rule is supported by the analysis of many potential impacts of changing CAFE standards. The rule promulgates standards for MYs 2024 through 2026; explicitly estimates manufacturers' responses to those standards through MY 2029; and considers impacts throughout those vehicles' lives. The analysis should be interpreted not as a forecast, but rather as an assessment—reflecting in some cases best judgments regarding different and often uncertain factors—of impacts that could occur. As discussed in Chapter 7, the analysis explores the sensitivity of this assessment to a variety of potential changes in key analytical inputs (*e.g.*, fuel prices).

This section describes the impacts of each of the four alternatives in relation to the No-Action Alternative scenario (described in detail in Chapter 2 of this FRIA and in Chapter 1.4 of the TSD). The discussion of impacts is separated into those affecting (i) vehicle manufacturers, (ii) new car and truck buyers, (iii) society as a whole, and (iv) the physical environment. Effects for vehicle manufacturers include compliance outcomes (e.g., achieved average fuel economy levels), technology application choices, costs associated with technology adoption and compliance, and sales and employment impacts. Assessment of new car and truck buyer impacts include vehicle price changes, fuel savings, and other mobility-related benefits (i.e., benefits that consumers receive as a result of additional travel made possible by increased fuel efficiency). The analysis of social impacts includes effects that accrue to vehicle purchasers and non-purchasers alike. Examples of social impacts are the monetized value of changes in GHG emissions, congestion, and road noise, as well as energy security consequences, and safety-related outcomes. The rule also directly affects the physical environment by altering overall vehicle use (e.g., VMT), fuel consumption, GHG emission quantities, and criteria pollutant and toxic air pollutant emission quantities.

As discussed in the TSD, the underlying CAFE Model accounts explicitly for each of MYs 2020-2050, simulating fleet turnover and mileage accumulation until all of these vehicles are projected to have been scrapped (i.e., through CY 2089, when the last of the MY 2050 vehicles are projected to be in service). The current rulemaking addresses CAFE standards during each of MYs 2024-2026, and many impacts are most meaningfully understood by considering the vehicles produced in those *model years*, and the adjacent years in which manufacturers take early or late actions to comply with the CAFE standards (through MY 2029). On the other hand, an understanding of the rule's physical impacts over time can also be important in some contexts.

For example, when the United States reports progress toward goals adopted under the United Nations Framework Convention on Climate Change (UNFCCC), it reports annual inventories of GHG emissions, which would correspond to a "calendar year" approach rather than a "model year" approach. Accordingly, today's analysis presents most physical impacts on a *calendar year* basis—that is, showing projected total or incremental quantities through CY 2050, accounting for all vehicles projected in service in each calendar year (including vehicles produced during model years 2030-2050).

Underlying CAFE Model output files are available (along with input files, model, source code, and documentation) on NHTSA's website.[100] A comprehensive appendix of detailed manufacturer and model-year tables is also available in Appendix I.

Additional and more detailed analysis of environmental impacts is provided for CAFE regulatory alternatives in the accompanying Final SEIS. NHTSA has prepared a Final SEIS estimating environmental impacts of the regulatory alternatives in this rule. Results presented herein for the CAFE standards differ slightly from those presented in the Final SEIS. While EPCA/EISA requires that the Secretary (by delegation, NHTSA) determine the maximum feasible levels of CAFE standards in a manner that, as presented here, sets aside the potential use of CAFE credits or application of alternative fuels toward compliance with new standards,[101] the National Environmental Policy Act (NEPA) does not impose such constraints on analysis presented in corresponding EISs, and the Final SEIS presents results of an "unconstrained" analysis that considers manufacturers' potential application of alternative fuels and use of CAFE credits. Detailed manufacturer and model-year tables of results for the Final SEIS are available in Appendix II.

Throughout this section, figures and tables report outcomes for a three percent and seven percent discount rate, as directed by OMB Circular A-4. And while those discount rates have been applied to all social and private benefits and costs in the analysis, the SC-GHG, and corresponding social costs of high global warming potential (GWP) gases (methane and nitrous oxide, in particular), are discounted at rates recommended by the IWG. NHTSA stresses that it does not have a primary estimate for the discount rate for the SC-GHG and instead presents non-GHG related impacts of the final rule discounted at 3 and 7 percent alongside estimates of the SC-GHG valued at each of the discount rates recommended by the IWG. This approach was selected because, as NHTSA noted in the NPRM, the IWG does not specify a single recommended discount rate for use as an agency's primary estimate, and NHTSA agrees that all three values provide useful information to decision-makers.

The agency's analysis showing our primary non-GHG impacts at 3 and 7 percent alongside climate-related benefits discounted at each rate recommended by the IWG may be found in FRIA Chapter 6.5.6. For the sake of simplicity, most tables throughout today's analysis pair both the 3 percent and the 7 percent discount rates with a 3 percent value for the social costs of greenhouse gases.[102] The discount rates referenced in this section refer to the social discount rate applied to

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[100] https://www.nhtsa.gov/corporate-average-fuel-economy/cafe-compliance-and-effects-modeling-system. (Accessed: February 14, 2022).
[101] 49 U.S.C. 32902(h).
[102] These rates are consistent with recommendations from the IWG on the Social Cost of Greenhouse Gases, as discussed in Chapter 4.7 of this FRIA.

non-GHG cost streams. Unless otherwise noted, the compliance simulation portion of the analysis is limited to all model years up to 2029. This is an effort to capture any residual product line adjustments manufacturers make on existing redesign schedules. That is, stringency levels mandated in 2026 may have effects on model offerings out to 2029 as related product refresh and redesign activities conclude.

This section proceeds by summarizing costs and benefits of the regulatory alternatives relative to the No-Action Alternative. It then examines modeled compliance outcomes before exploring each of the above-mentioned impacts categories in detail.

6.2 Summary of Benefits and Costs

To assess the effect of the considered regulatory alternatives, NHTSA aggregates outputs of the CAFE Model and compares the resulting cost and benefit values for each simulated alternative to those of the No-Action Alternative (Alternative 0). Figure 6-1 reports the outcome of this calculation for MYs 1981[103] through 2029 at both a 3 and 7 percent social discount rate.[104] Costs and benefits increase across alternatives, corresponding with increased stringency. Relative to the baseline, program net benefits are positive across all alternatives.

[103] The reporting includes vehicles as far back as MY 1981 because it seeks to account for all vehicles in the on-road fleet, because new CAFE standards can affect how all of these vehicles are driven – as one example, higher costs for new vehicles may shift sales and VMT to older vehicles, with consequent effects on fuel consumed and pollution rates. After 40 years, fewer than 2 percent of initial sales of a given model year tend to remain on the road, so NHTSA assumes that vehicles of a given model year vintage may still be on the road for up to 40 years, and any remaining vehicles at that point are assumed to be scrapped.

[104] Results are presented for SC-GHG discount rates of 3 percent. Benefit summaries for alternate SC-GHG discount rates are included in Chapter 6.5.6, Table 6-10.

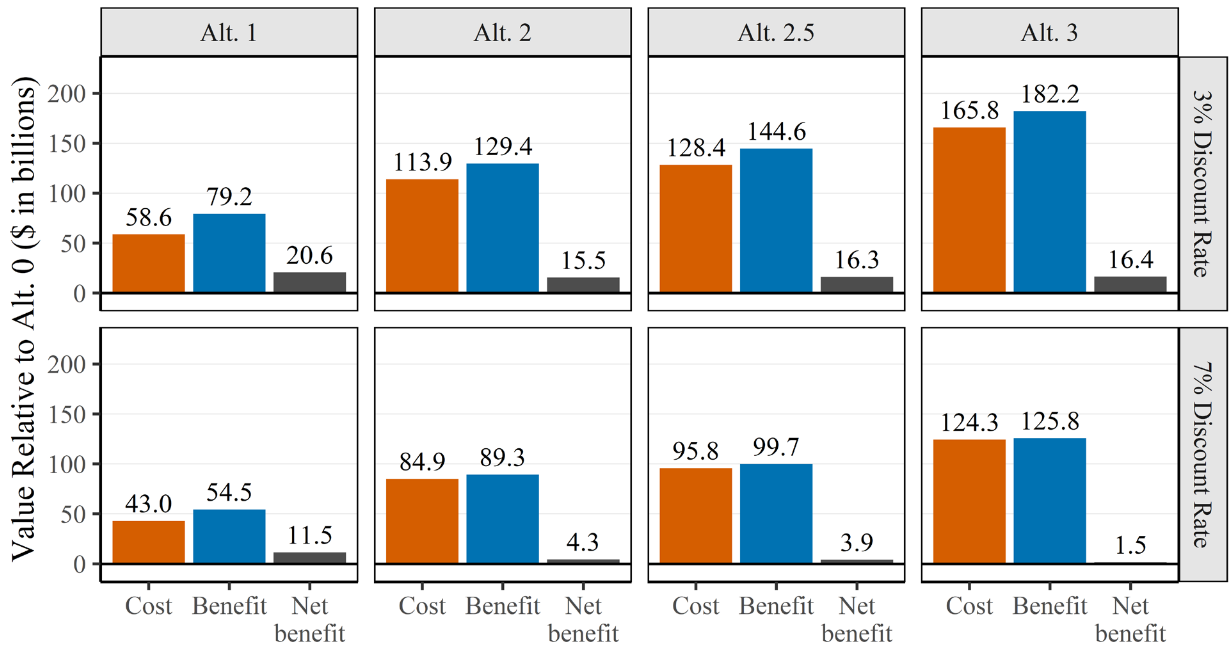


Figure 6-1 – Costs and Benefits for Overall Vehicle Fleet, MY 1981-2029

Chapter 6.5 outlines the main categories of costs and benefits aggregated to produce Figure 6-1. The largest component of these estimated costs is the technology cost that manufacturers pay to improve fleet fuel economy and meet the CAFE targets under each alternative. Reductions in fuel costs for consumers who purchase more fuel-efficient vehicles is the largest benefit component.

6.3 Effects on Vehicle Manufacturers

The CAFE Model produces the industry-level, achieved fuel efficiency values plotted in Figure 6-2 (all fleets) and Figure 6-3 (by regulatory class). These figures report achieved fuel efficiency relative to fuel economy standards. The figures also include indication of the achieved levels without AC and OC credits. Standards are generally met across alternatives. Notably, Figure 6-2 shows a trend of over-compliance in the early model years (e.g., MY 2022 through MY 2024). This is driven in part by manufacturer redesign schedules and cost-based decisions regarding technology application. That is, in an effort to meet known later program stringency requirements, manufacturers modify vehicle lines at the time of scheduled redesigns, as opposed to making incremental technology upgrades in the specific years in which fuel economy requirements change, which might be more expensive than making changes at a redesign. This pattern is most apparent in the higher stringency alternatives (e.g., Alternative 2 and beyond). Examining achieved and target efficiency levels by regulatory class, Figure 6-3 shows fleet-level compliance is consistently met in the domestic car fleet, while imported car and light truck fleet achieved fuel efficiency remains very close to each alternative's corresponding standards.

These figures also show significant overcompliance under Alternative 0 and, after MY 2026, shows modest overcompliance under Alternative 1. While some of this overcompliance results from the projected "inheritance" of technologies (e.g., changes to engines shared across multiple vehicle model/configurations) applied in earlier MYs, fuel prices also play a role. Today's analysis continues the approach followed for the PRIA—that is, NHTSA assumes that beyond fuel economy improvements necessitated by CAFE standards, EPA-GHG standards, and ZEV mandates, manufacturers could also apply fuel economy improvements that, given projected fuel prices, would pay for themselves within the first 30 months of vehicle operation. The resultant relative role of fuel prices is greatest when standards are the least stringent (and, of course, when fuel prices are the highest).

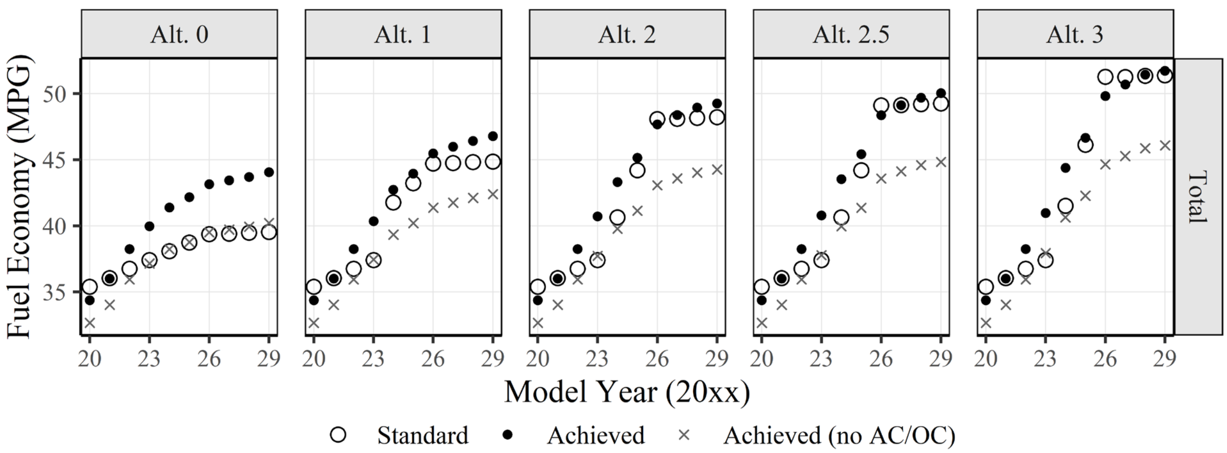


Figure 6-2 – Fleet Modeled Fuel Economy

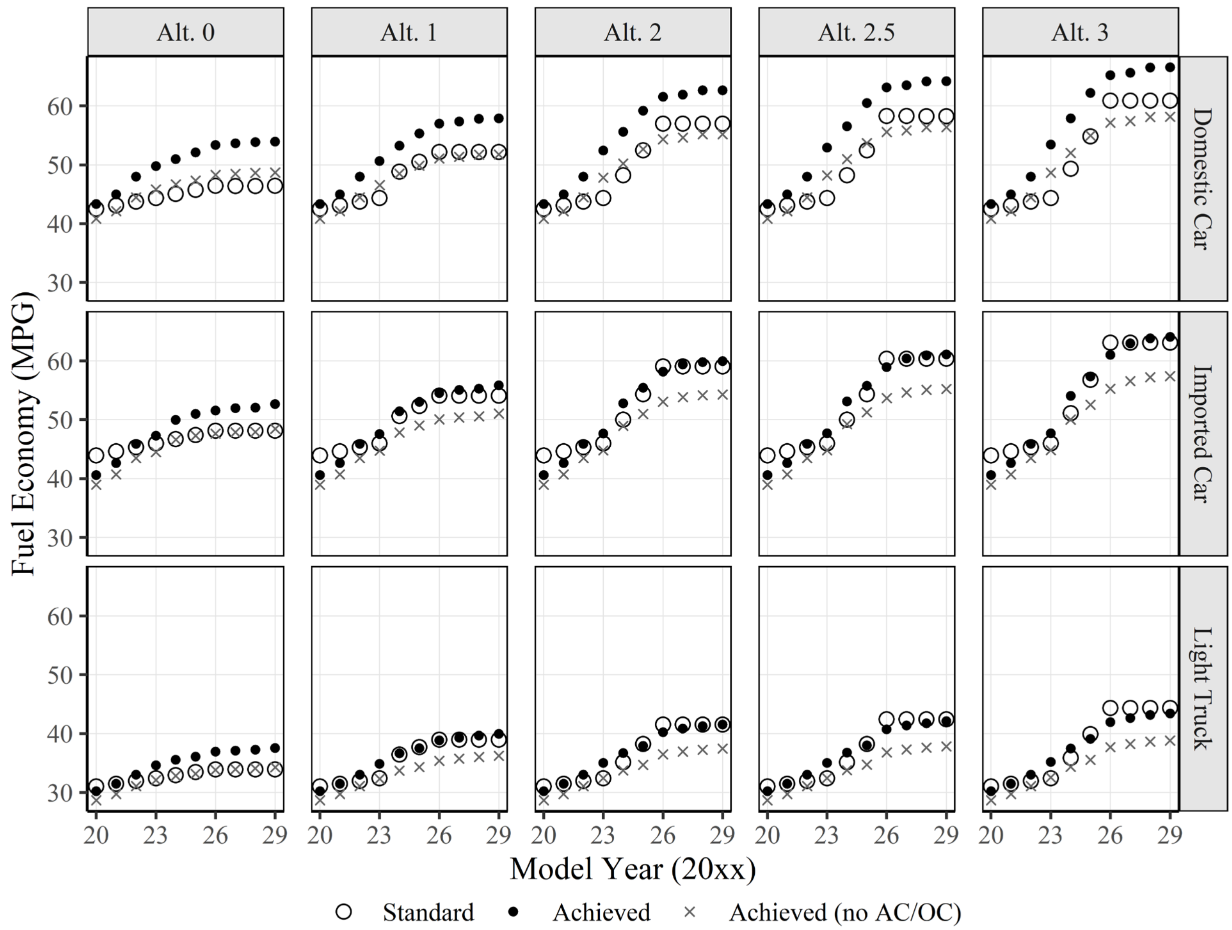


Figure 6-3 – Fleet Modeled Fuel Economy by Regulatory Class

These are industry-wide fleet-level results, and we note that results vary considerably among specific manufacturers. Figure 6-4 presents manufacturer-level differences between achieved and required fuel economy levels on a fleet-wide basis. Lighter colored shading represents manufacturer-years with small, estimated deviations between standards and achieved efficiency levels. Regions shaded blue indicate manufacturer fleets that are more efficient than required and those shaded red fall short of their compliance thresholds.[105] By statute, manufacturers need not precisely fulfill their compliance obligations through technology application in each given model year, though the difference must be made up through the use of over-compliance credits from another fleet or model year, or civil penalty payments, as discussed in Section VII of the final rule preamble. The vertical line in the figure indicates the start of MY 2024, the first period of the revised standards.

[105] Figure 6-4 and Figure 6-5 include Tesla and Ford's import car fleet, though both far exceeded standards—Ford due to a limited number of vehicles in the segment and Tesla due to their BEV-only fleet. To preserve the color gradient in both figures, compliance that exceeds standards by more than 20 percent (or falls short by more than 20 percent) falls into the highest (lowest) color category.

The figure illustrates that many manufacturers begin the modeling period out of compliance, as indicated by the consistent red cell shading across manufacturers in MY 2020. Manufacturers such as Daimler and FCA maintain fleet MPG lower than their respective standards through MY 2029 and across all modeled alternatives. Ford, Subaru, Tesla, and Toyota consistently exceed CAFE standards across scenarios and model years. As the regulatory alternatives increase in stringency from Alternative 1 to Alternative 3, manufacturers that fail to meet MPG standards in Alternative 1 find themselves further from their compliance obligations in Alternatives 2, 2.5, and 3. Most manufacturers that reach their required levels in Alternative 1 do so under Alternatives 2, 2.5, and 3, with many overshooting their compliance obligations shortly after MY 2024 (as indicated by darker blue shading) before leveling off at—or slightly above—standards in MYs 2026 and beyond. This is consistent with the industry-wide trend shown in Figure 6-2.

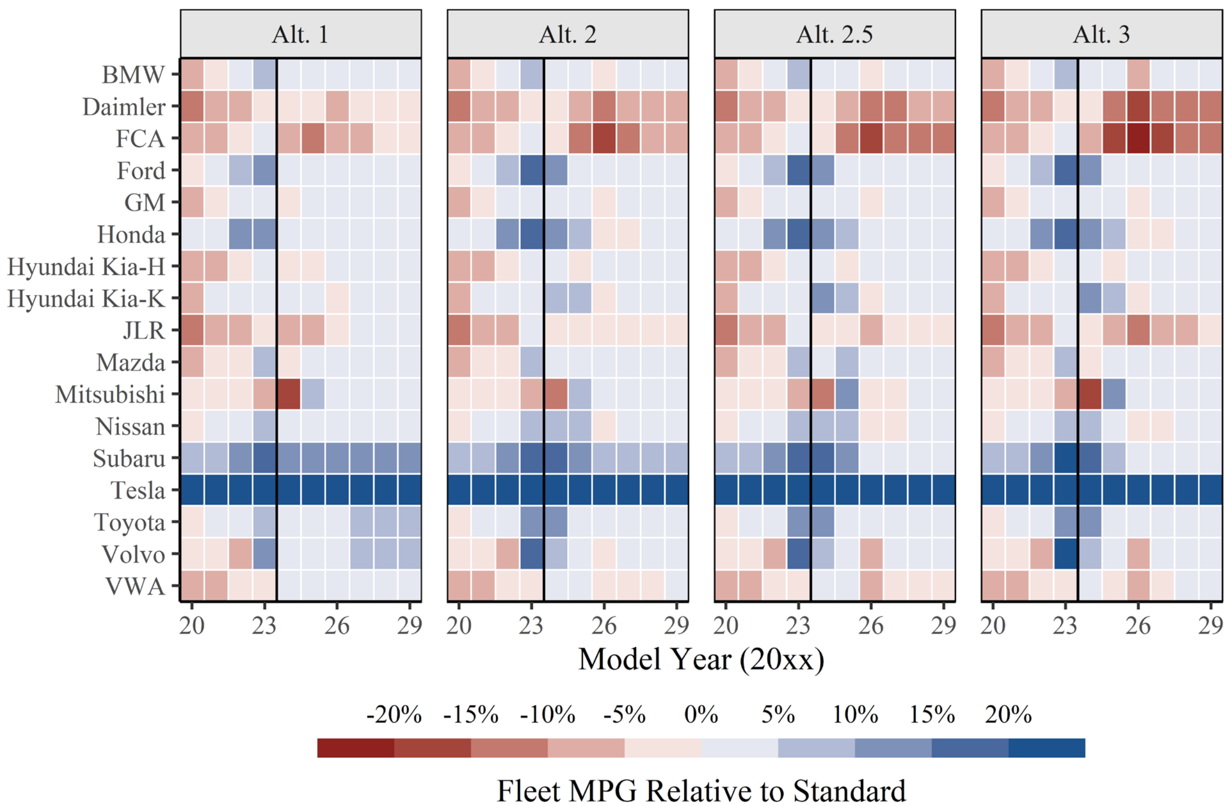


Figure 6-4 – Modeled Fleet-wide Achieved CAFE by Manufacturer

Within manufacturer fleets, there is heterogeneity in modeled response by regulatory class. Figure 6-5 separates achieved fuel economy levels by manufacturer and fleet. Each individual panel represents a manufacturer's achieved fuel economy levels relative to the standard within a regulatory class. White cells indicate a manufacturer has little or no presence in a given regulatory class. Examining results across columns in the figure illustrates that some manufacturers achieve vastly different levels of compliance across regulatory classes. Volvo, for instance, offers fuel economy above levels of the standard in its light truck fleet but falls below its standard for its imported and domestic car fleets at least through MY 2027. Toyota, Honda, and Nissan indicate generally consistent performance across regulatory classes and stringency alternatives, though Honda and Nissan see efficiency levels drop slightly below standards in the higher stringency alternatives in MY 2026. Manufacturers generally meet efficiency standards by MY 2029. The exceptions to this are Daimler, FCA, JLR, Mitsubishi, and VWA in the light truck fleet and Daimler, JLR, Subaru, and Volvo in the car fleet.

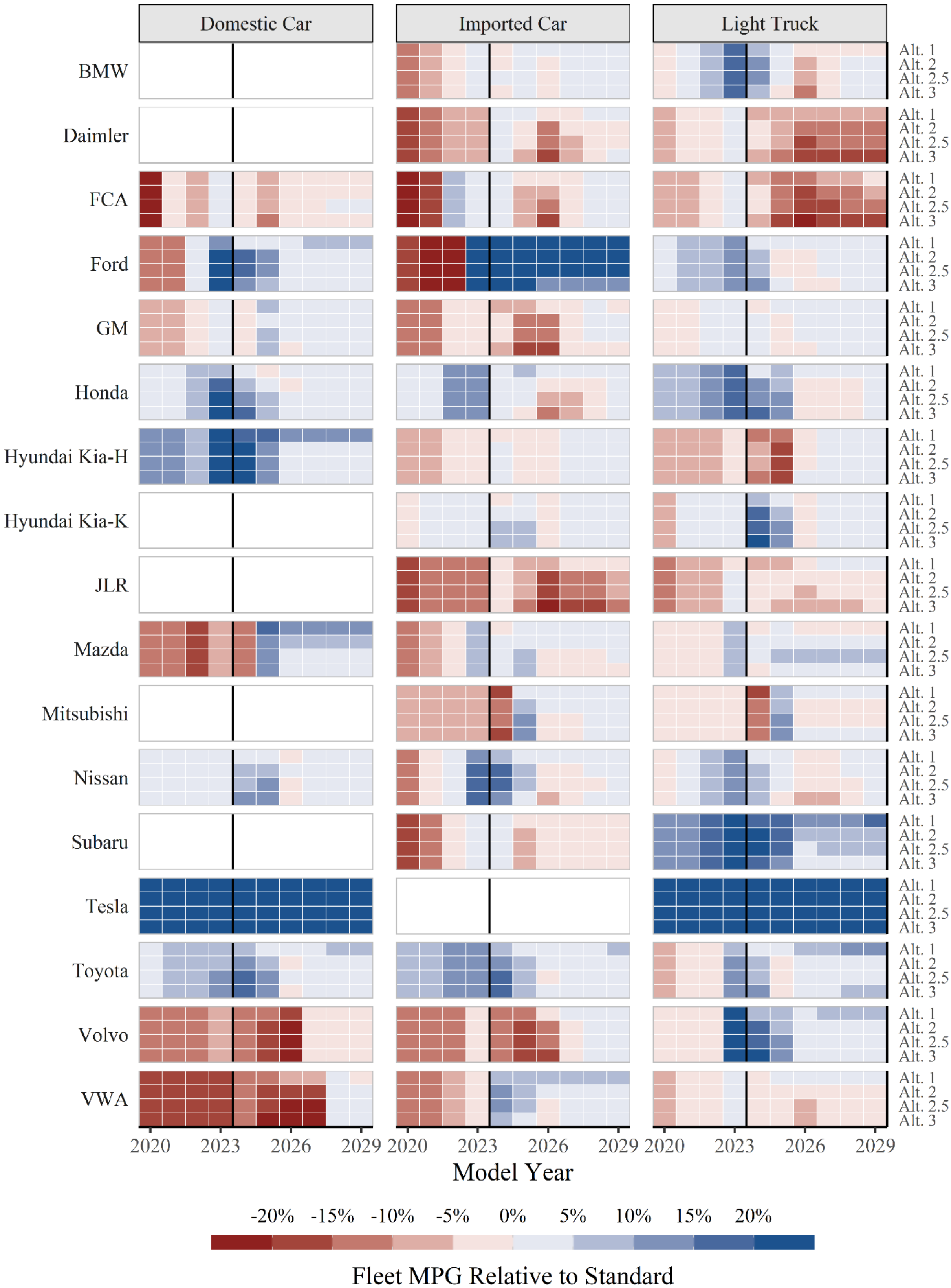


Figure 6-5 – Modeled Achieved CAFE Levels by Manufacturer and Regulatory Class

6.3.1 Technology Application

To meet the required CAFE levels under each regulatory alternative, the CAFE Model simulates compliance in part by applying various technologies to vehicle models in a given manufacturer's regulated fleet. As shown in Figure 6-6, the majority of this technology application occurs for MYs 2021 through 2026 in the regulatory alternatives. Technology application in MYs 2021 and 2022 is nearly identical to the No-Action Alternative in all alternative scenarios. The action alternatives estimate more technology application in most years between MY 2022 and MY 2029. At these points, some technologies are inexpensive enough that application is economical even in the absence of binding CAFE standards.

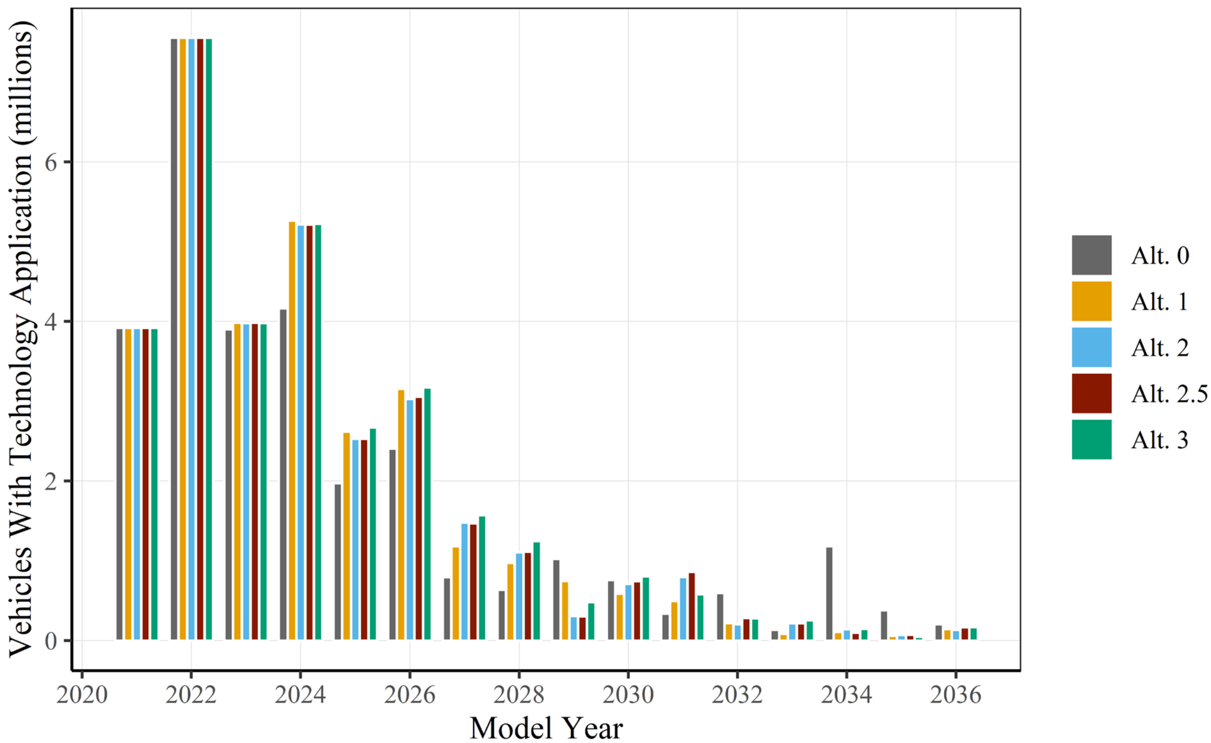


Figure 6-6 – Timing of Technology Application in Response to Regulatory Alternatives

Figure 6-7 through Figure 6-11 present the resulting industry-wide technology penetration rates. Each horizontal line segment in the figure represents the change in technology penetration between 2020 (represented by a short vertical line segment) and 2029 (represented by a circle). Arrows indicate the direction of the change and line colors represent the regulatory alternative. Between 2020 and 2029, CAFE Model estimates reveal a number of trends, including:

Engine technology (Figure 6-7):

- Basic engine technology (including VVT, VVL, SGDI, and stoichiometric gasoline direct injection [SDGI]) decreases significantly between the base 2020 fleet and MY 2029 across all alternatives. Penetration rates of these technologies decline by alternative stringency (greater declines in more stringent alternatives).

- Engine advancements including Turbo, HCR, and other advanced gas technologies (VCR, VTG, and variable turbo geometry (Electric) [VTGE]) all increase between MY 2020 and MY 2029 in each of the simulated alternatives, though higher stringency alternatives see lower penetration rates by MY 2029.

- Diesel engines see limited adoption in all scenarios in MY 2029.

- Though not presented in the figure below, advanced cylinder deactivation technology (ADEAC, turbocharging and downsizing with ADEAC [TURBOAD], DSLIAD) does not change significantly across Alternatives 1, 2, and 2.5. For Alternative 3, penetration rates increase from approximately 3 percent to 6 percent.

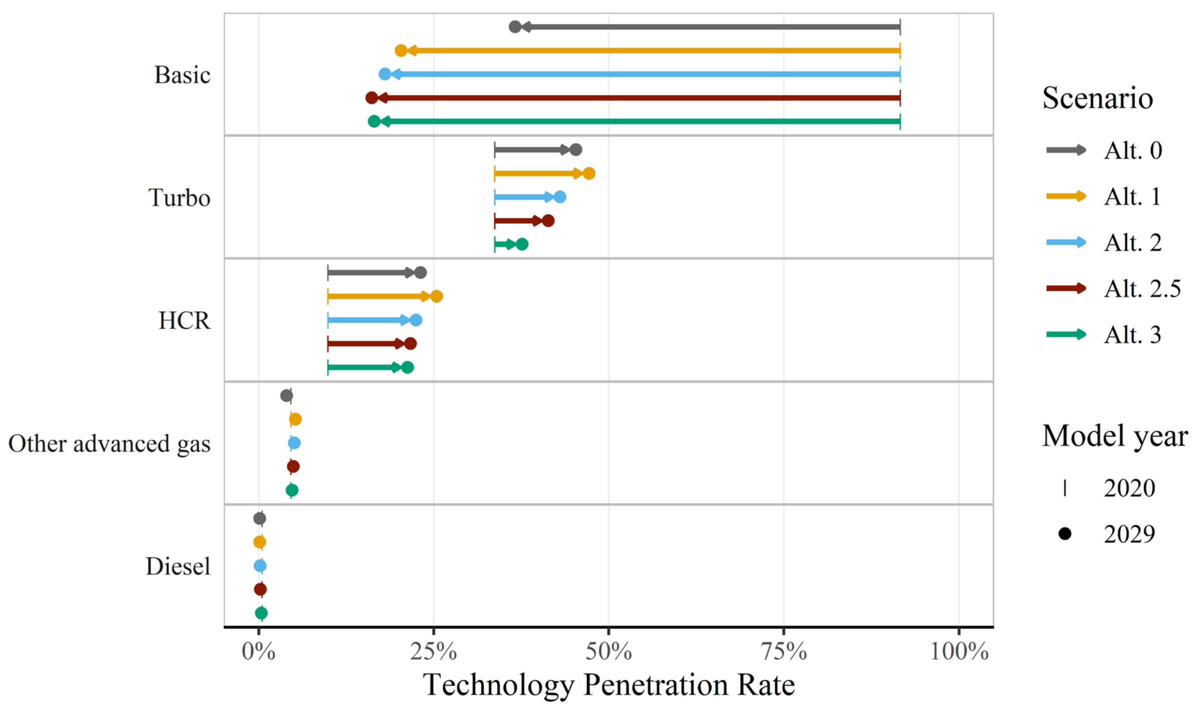


Figure 6-7 – Prevalence of Engine Technology in the Fleet Under Different Regulatory Alternatives

Transmission technology (Figure 6-8):

- Seven-, 8-, and 9-speed automatic transmissions decline in penetration rate as 10-speed transmissions increase from 10 percent to over 40 percent.

- The most significant difference in transmission choices across alternatives is the prevalence of 8-speed transmissions. All four action alternatives see AT8 penetration rates drop into the single digits by 2029, while the baseline remains at approximately 15 percent.

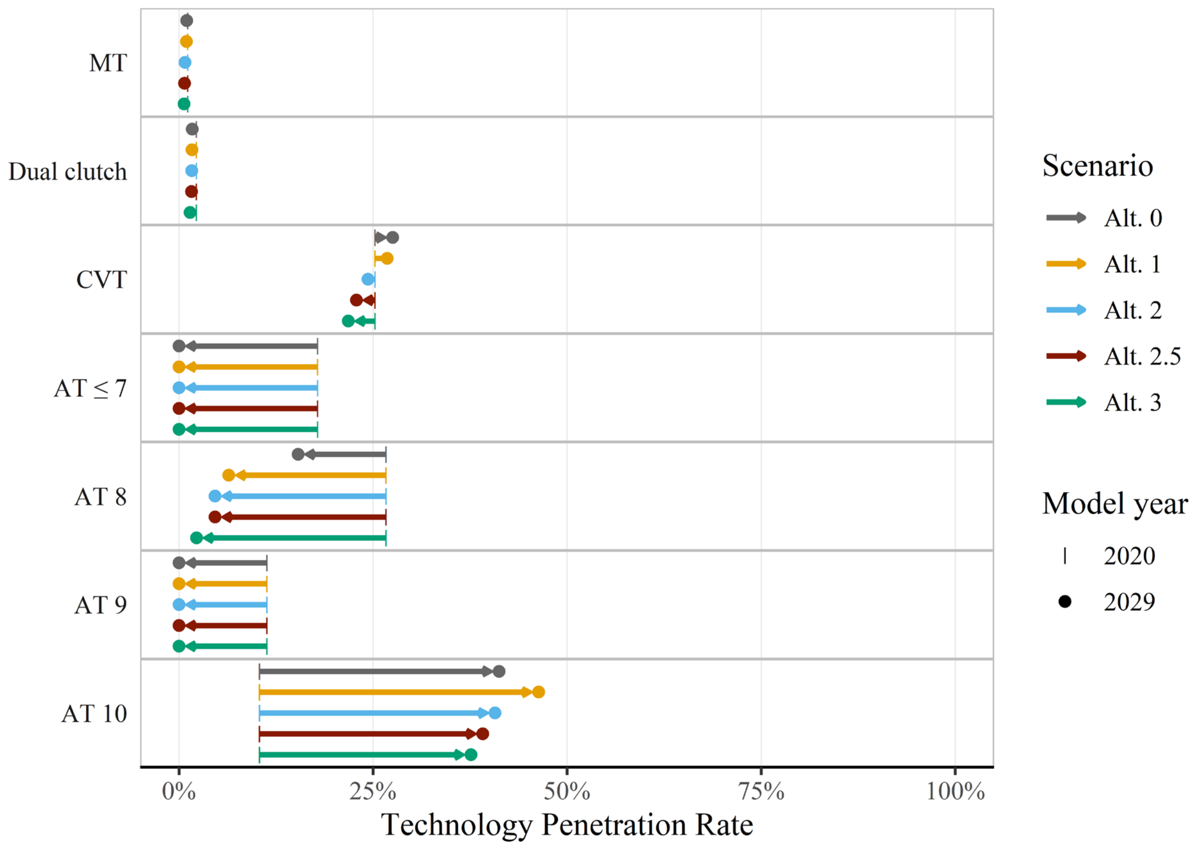


Figure 6-8 – Prevalence of Transmission Technology in the Fleet Under Different Regulatory Alternatives

Powertrain technology (Figure 6-10):

- Conventional powertrains decrease across all scenarios, and to greater degrees than in the No-Action Alternative as alternative stringency increases; in parallel, application of alternative powertrain technology similarly increases.
- In all scenarios, the use of stop-start technology declines and is replaced with either BISG or various hybrid or BEV technologies.
- SHEVs increase substantially as alternative stringency increases, with penetration rates of approximately 21 percent in MY 2029 in Alternative 2.5 and 25 percent in Alternative 3.
- More stringent alternatives, especially Alternatives 2, 2.5, and 3, see higher application rates of hybrid and electrified powertrains. The industry-wide penetration rates of SHEV, PHEV, and BEV technology by model year are displayed in Figure 6-9.

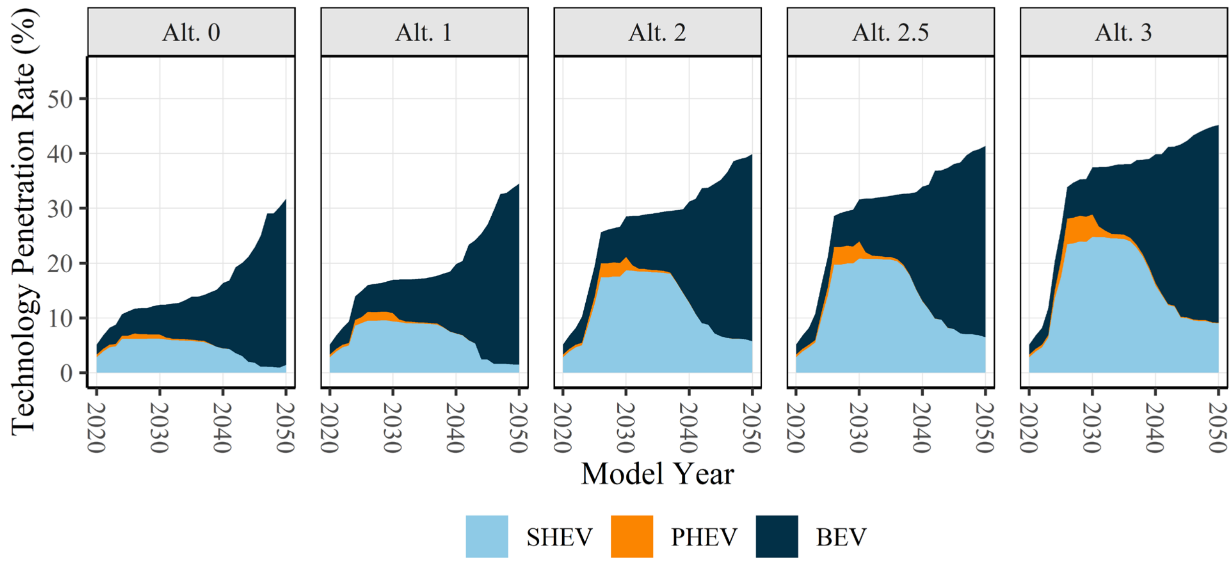


Figure 6-9 – Hybrid and Electrified Technology Penetration Rates by Model Year

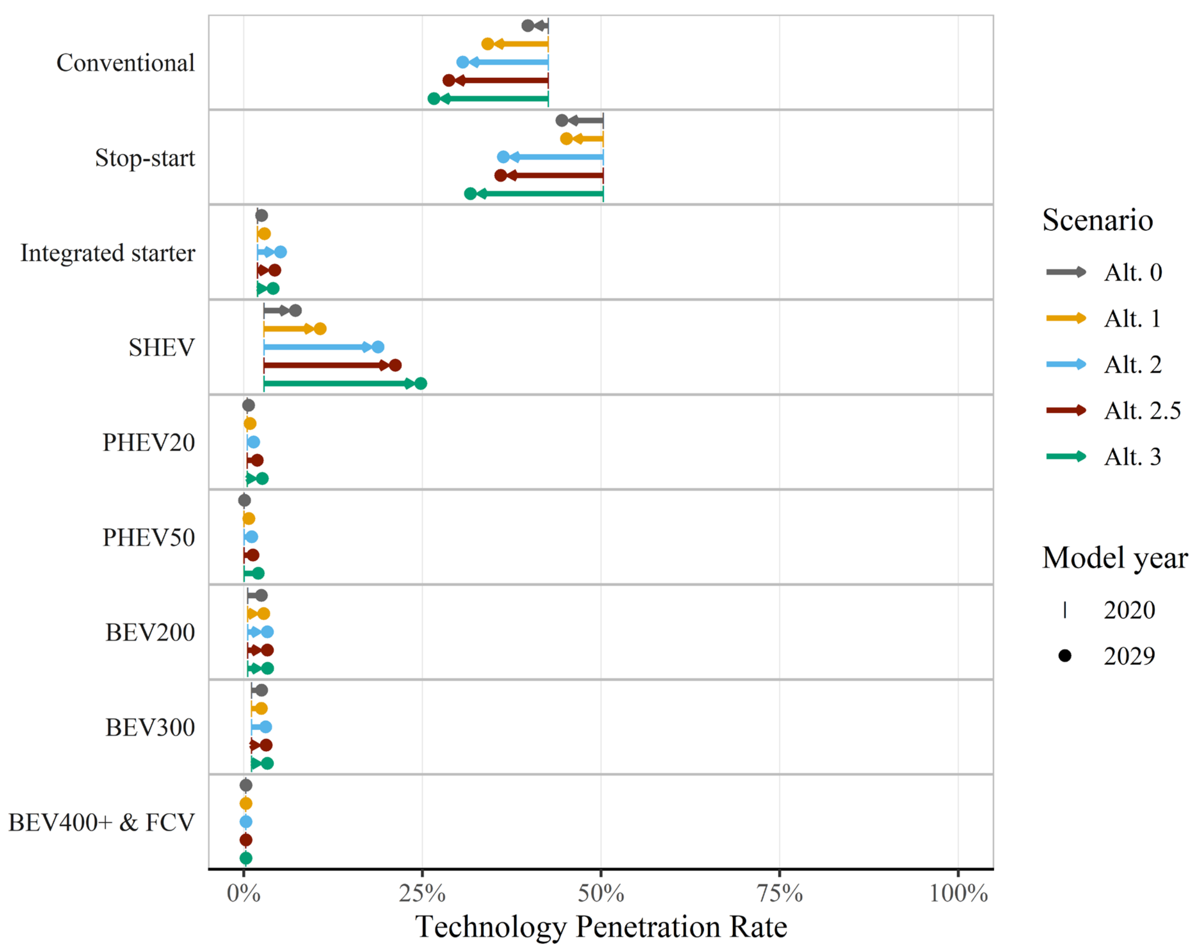


Figure 6-10 – Prevalence of Powertrain Technology in the Fleet Under Different Regulatory Alternatives

Tire rolling resistance, aerodynamics, and mass reduction technologies (Figure 6-11):

- Rolling resistance results are very similar across scenarios and do not show significant differences from the baseline. With few exceptions, the CAFE Model applies ROLL20 to all models by 2029.

- Higher stringency alternatives rely on more aggressive aerodynamic improvements than the No-Action Alternative does. Alternatives 2 and 3 employ 20 percent AERO reductions at much higher rates (e.g., Alternative 2.5 has a technology penetration rate approximately 10 percentage points higher than that of Alternative 1. The rate for Alternative 3 is nearly 15 percentage points higher than Alternative 1).

- Vehicle mass reduction technologies are more varied across alternatives than other technology choices. Where the baseline scenario employs a combination of 5- and 10-percent mass reduction, all of the alternatives replace MR2 (7.5 percent mass reduction) with MR3 (10 percent mass reduction) and above with the reliance on MR3 increasing with increased stringency.

- Mass reduction greater than 20 percent is applied sparingly in all scenarios, due in part to modeled cost parameters and limits imposed on application due to feasibility concerns. A few manufacturers select mass reduction at this level. This is discussed in more detail in the next section.

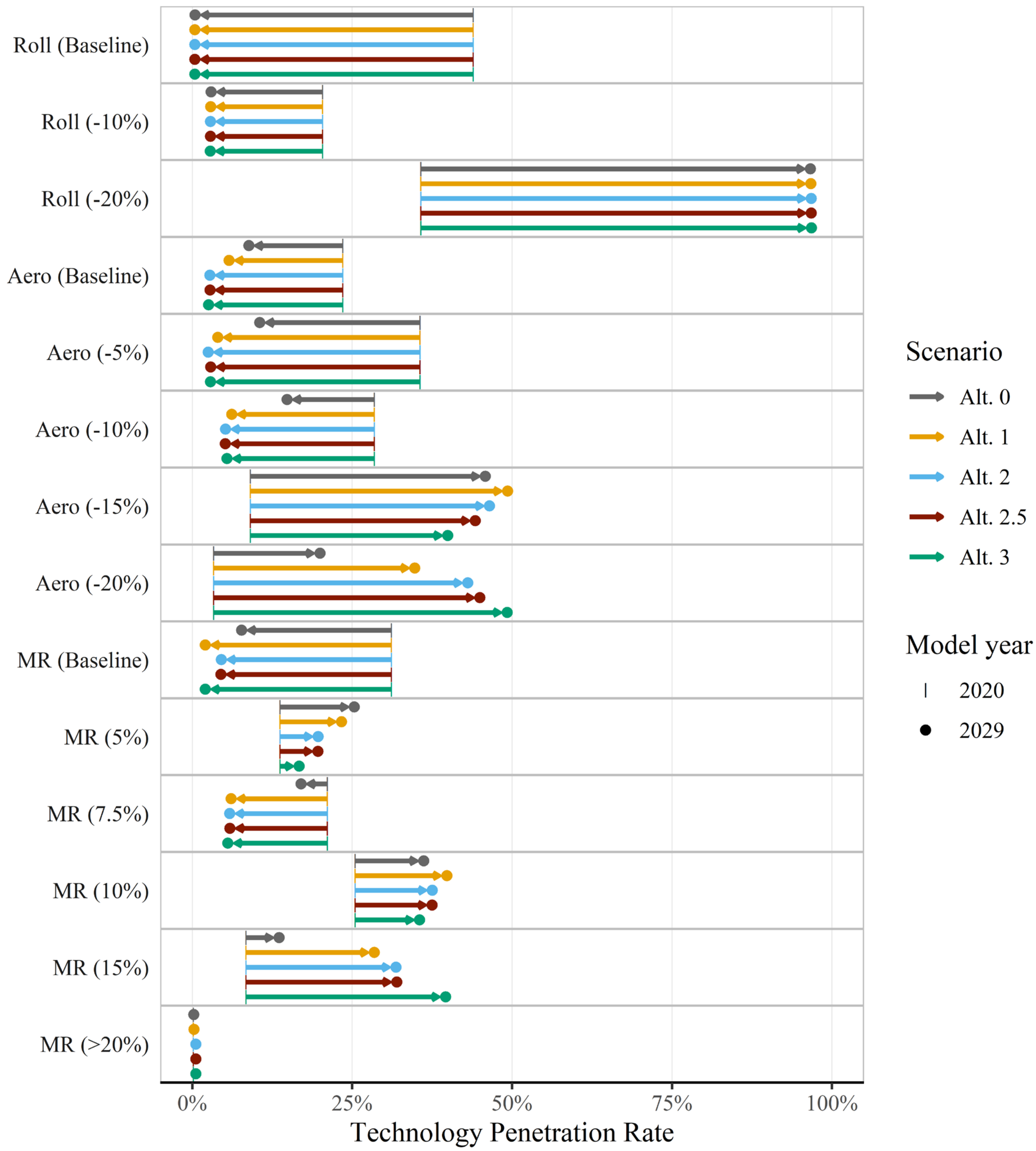


Figure 6-11 – Prevalence of Tire Rolling Resistance, Aerodynamics, and Mass Reduction Technologies in the Fleet Under Different Regulatory Alternatives

6.3.2 Compliance Costs

Manufacturers comply with CAFE regulations by applying fuel-economy-improving technologies, or use over-compliance credits (whether earned or purchased), or pay civil penalties for non-compliance. The CAFE Model computes both aggregate and per-vehicle values of these costs. Model outputs report regulatory costs—the combination of technology costs and total civil penalties across all regulatory classes—as well as technology costs alone. Technology costs are a major component of regulatory costs. Figure 6-12 reports industry-wide, model year trends in per-vehicle technology costs.

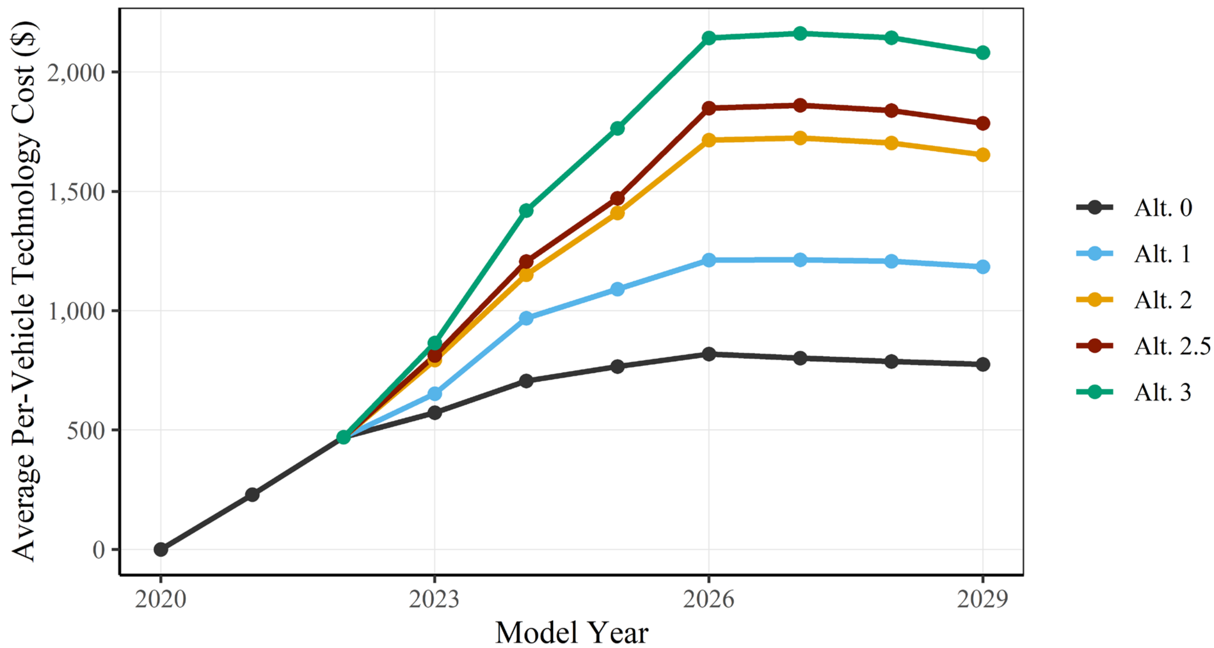


Figure 6-12 – Average Per-vehicle Technology Cost

Per-vehicle technology costs vary widely by manufacturer and across alternatives due in part to estimated technology application choices. Additionally, NHTSA does not model compliance via fully-electric powertrains for the standard-setting runs shown here, consistent with statutory restrictions. In the case that BEVs are less costly than alternative technology options, modeled technology costs shown here are likely to overstate actual costs. This affects both technology cost levels and the resulting margin between benefits and costs; this margin may be lower than in the absence of NHTSA's statutory restriction (and in the real world).

Figure 6-13 presents baseline per-vehicle technology costs for a MY 2029 vehicle. Gray bars in the figure are costs in the No-Action Alternative. Total No-Action Alternative costs are listed in the data labels in the "Alt. 0" panel. The portions of the bar in color represent the changes in manufacturer technology costs for each action alternative. For example, average per-vehicle technology costs for VWA in the No-Action Alternative are $1,770. Under Alternative 1, these costs increase by $210 per vehicle to $1,980.[106] Under Alternative 2, technology costs increase by $220 to $1,990. Manufacturers including Honda, BMW, Nissan, and Ford substantially increase per-vehicle technology costs between Alternative 1 and Alternative 2. Relative to the

[106] The negative incremental value for Honda under Alternative 1 is a rare instance where a stringency increase produces a technology cost reduction. Note that this means costs are reduced on average, across the full fleet of Honda vehicles. This particular change is the result of decreased application of HEV technology in Alternative 1 compared to the No-Action Alternative. For detail, see Figure 6-17 later in this section.

No-Action Alternative, Alternative 1 represents an average industry-wide increase in per-vehicle technology costs of $410—an increase of 53 percent. Technology costs increase by $880 per vehicle in Alternative 2 (113 percent over the No-Action Alternative), $1,010 in Alternative 2.5 (129 percent), and $1,310 per vehicle in Alternative 3 (a 168 percent increase).

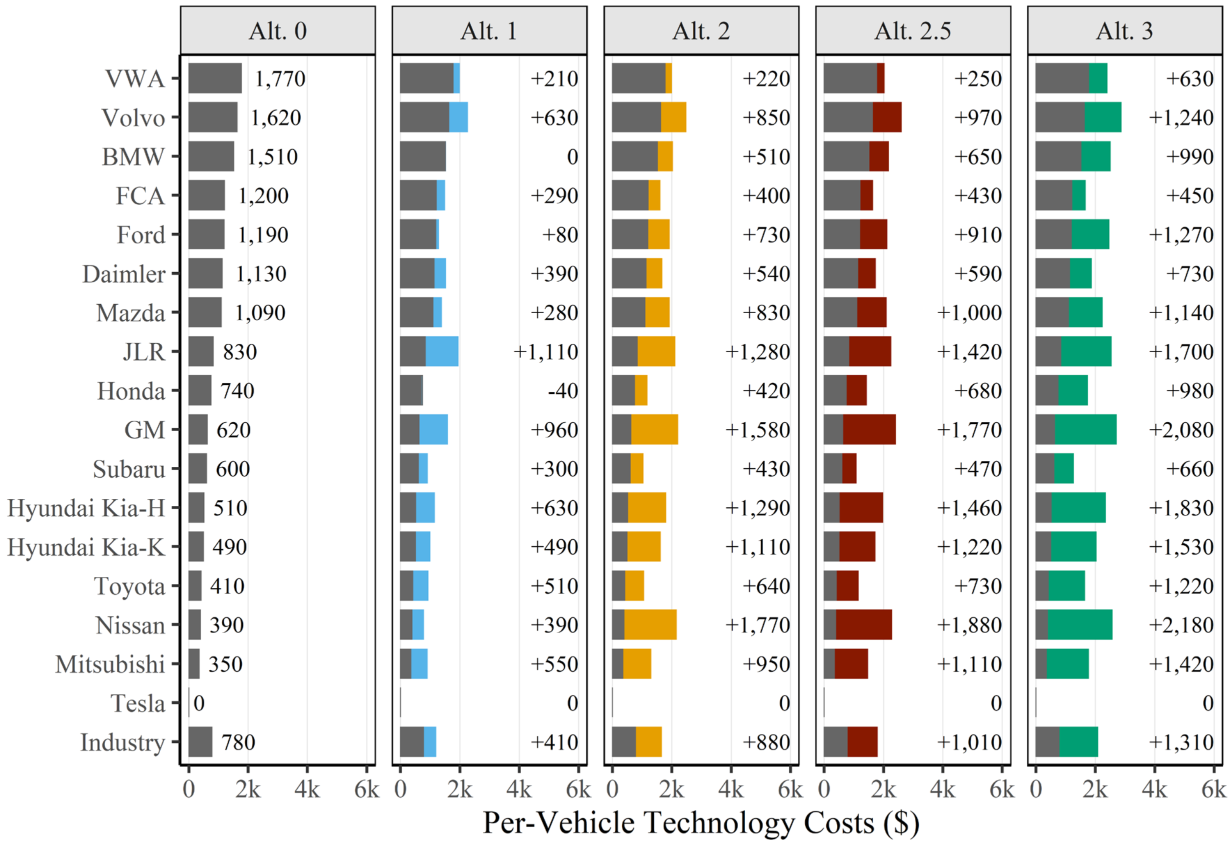


Figure 6-13 – Per-vehicle Technology Cost, MY 2029 Vehicle

Figure 6-14 reports total technology costs for MYs 2020 through 2029 in the No-Action Alternative alongside labeled aggregate technology cost increases for each action alternative. In most cases, differences in manufacturer rankings between Figure 6-13 and Figure 6-14 are the result of production-scale variation (e.g., and importantly, General Motors [GM]'s large production volumes means it has the third largest total technology cost even though GM's average per-vehicle costs place it in the middle of the manufacturer ranking in Figure 6-13). However, in a few instances differences in technology application play a significant role in determining aggregate manufacturer costs. This causes a portion of the estimated increases in cost between Alternative 1 and the higher stringency alternatives and can be seen by examining cost changes attributed to particular technologies.

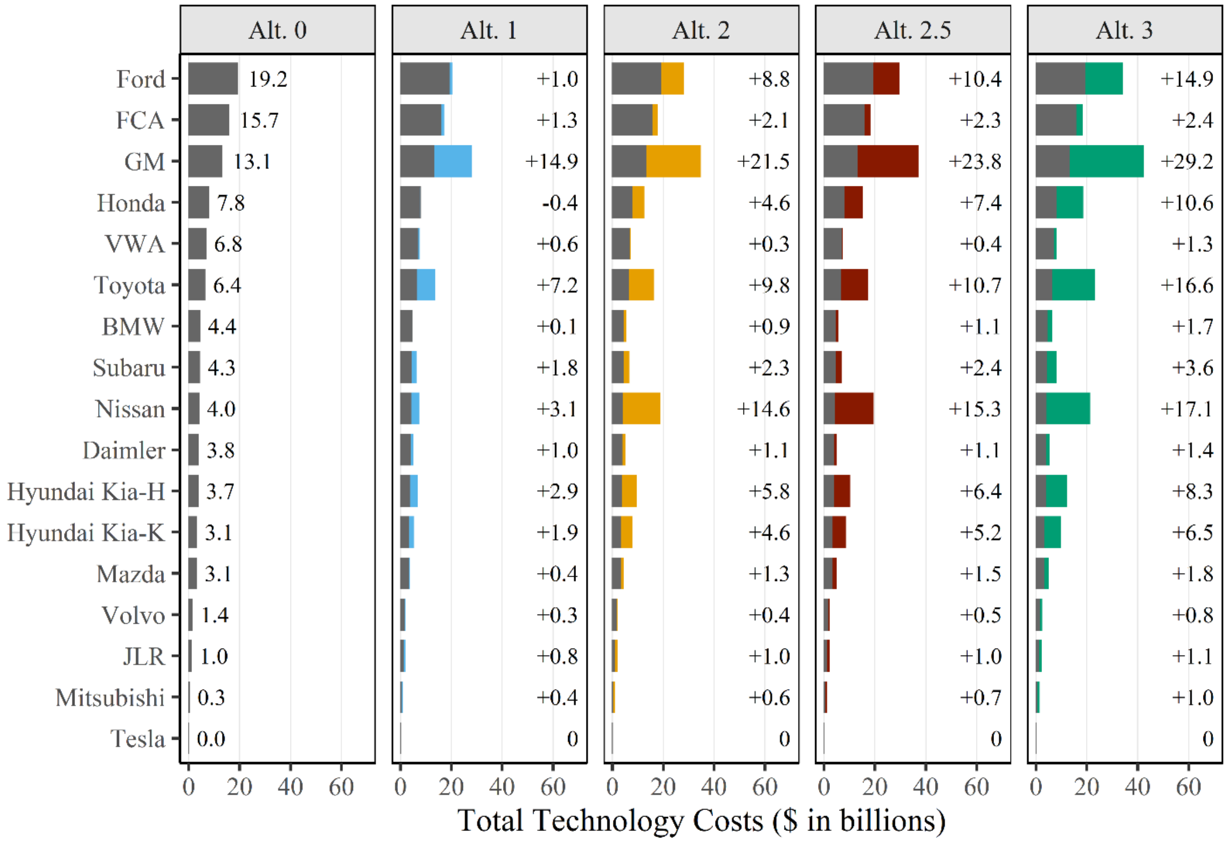


Figure 6-14 – Technology Costs by Manufacturer, MYs 2020-2029

At an industry level, approximately half of all technology cost expenditure by MY 2029 in the No-Action Alternative comes from various levels of powertrain electrification or mass reduction. Figure 6-15 presents these technology categories as a percent of total technology application cost within each modeled scenario. Across alternatives, aggregate costs attributable to the application of electrification technologies increase significantly. Alternatives 2, 2.5, and 3 see more application of high-level mass reduction (e.g., MR6). On a per-vehicle basis, costs of applied BEV technology increase by approximately 40 percent—from $220 to $300—between Alternatives 1 and 2.5 (Figure 6-16), while per-vehicle hybrid electric vehicle (HEV) values increase by a factor of 1.5.[107] Readers should note that across alternatives, input cost values do not change (e.g., HEV application costs the same regardless of CAFE stringency), so these per-vehicle cost increases are due to greater reliance on the technology for compliance.

[107] For the analysis presented in the FRIA, NHTSA exercised the model in a manner that excludes the potential that manufacturers might respond to new CAFE standards by introducing new BEV model/configurations during MYs 2024-2026, the MYs for which NHTSA is promulgating new CAFE standards, but that still allows for the potential that manufacturers might introduce new BEV model/configurations prior to MY 2024 or after MY 2026, or at any time in response to state ZEV mandates. The sensitivity analysis presented below in Chapter 7 includes a case in which this modeling restriction is extended throughout MYs 2023-2029. The analysis presented in the Final SEIS exercises the model in a manner that allows for the potential introduction of new BEV model/configurations in any model year, including in response to new CAFE standards.

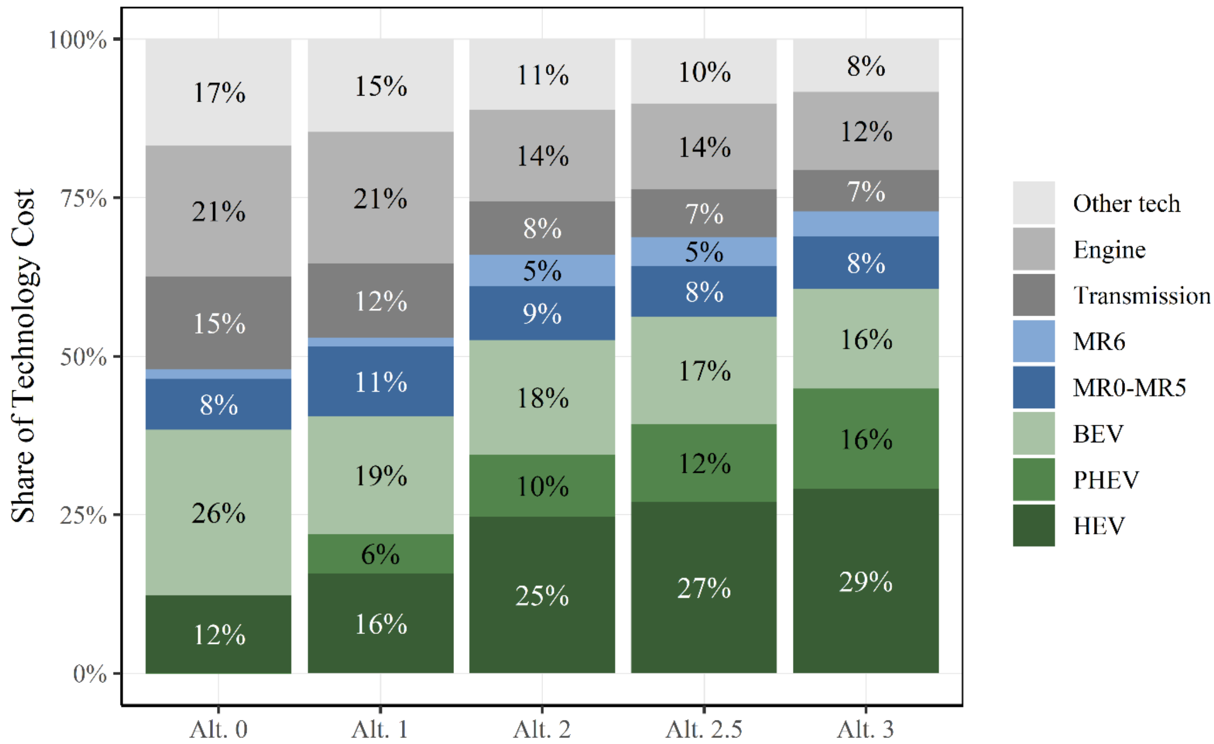


Figure 6-15 – Applied Technology Cost for Selected Technologies (MY 2029)

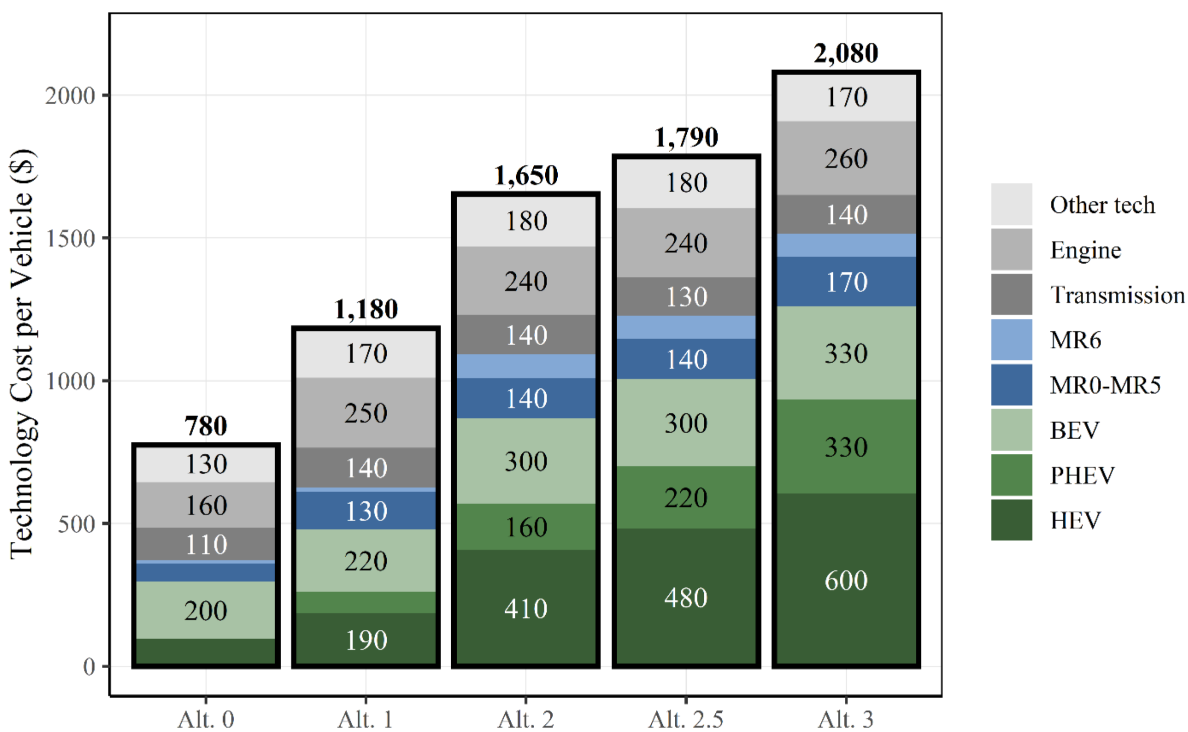


Figure 6-16 – Per-vehicle Technology Cost by Technology Category (MY 2029)

Manufacturers that rely on these advanced technology options to meet program compliance goals have a higher per-vehicle technology cost burden during the rulemaking timeframe. Figure 6-17 illustrates the relationship between these technology choices and per-vehicle technology costs by manufacturer. It highlights the technology application behavior that drives differences in per-vehicle cost across manufacturer and alternative presented in Figure 6-13.[108] In most instances, these estimated cost increases are associated with plug-in vehicle technology costs. For example, BMW and GM see a cost increase between Alternative 1 and Alternative 2 due to broader use of PHEV technology. Ford, Hyundai, and Kia see similar increases from HEV application. Mazda, Nissan, and Volvo all apply MR6 to meet compliance limits, with a notably large jump in MR6 for Nissan in in alternatives beyond Alternative 1. The levels of mass reduction that these manufacturers are applying in MY 2029 is likely a consequence of the modeling restrictions intended to reflect statutory restrictions on consideration of BEVs in standard setting. Because the model limits application of BEV technology and these manufacturers are constrained in their credit use and civil penalty payment in the "standard setting" runs, manufacturers instead apply MR6. In practice, achieving weight reductions consistent with MR6 nearly always requires a vehicle's primary structure be wholly made from carbon fiber reinforced plastics (CFRP). The current state of the art in this regard is a CFRP monocoque structure where all exterior and interior surfaces are structural. Such primary structures have been successful at mass reduction in the upper echelons of Formula and LeMans racing cars, but have found only sparse application thus far in passenger vehicles. Besides the BMW i3, in the 2020 fleet (which was discontinued in summer 2021 and not replaced with a vehicle with as much carbon fiber technology as the i3), CFRP primary structure exists only in the highest strata of quasi-racing car passenger vehicles. Monocoque structures made from CFRP cost in the tens of thousands of dollars alone. It is currently difficult to foresee how their application in cars or trucks with retail prices at roughly the same amount would lead to a positive business case. Moreover, the supply base in this area is quite limited and for a car manufacturer to build in-house capability would require billions of dollars and decades of sustained commitment. If fuel savings is the aim, such effort and expense on the part of OEMs could perhaps be better spent on developing electric powertrains. And while the final rule analysis is statutorily restricted in ways that prohibit the consideration of electric powertrains as a compliance strategy during action years (MYs 2024-2026), the analysis that supports the Final SEIS is not. In those simulations, the same manufacturers that apply MR6 in the figure (with the exception of Mazda, who still applies MR6 but in smaller volumes) opt instead to produce additional EVs.

Repairability of carbon fiber body panels is another issue. In the case of a collision, the material's lack of ductility may lead to more extensive damage. Metals deform plastically in a collision and in some cases can be bent back to their original shape. A component made from carbon fiber composite material will more likely fracture, necessitating replacement. In the rare instances where repair is an option for a carbon fiber component, specialized tools, personnel,

[108] The model employs the same effective cost metric across all regulatory alternatives. That is, the logic that determines manufacturer technology choices does not vary by alternative, rather increasing fuel-economy stringency requires manufacturers to apply more fuel-efficient (and hence more costly) technologies.

and facilities are required. Adding all this up, collisions repair costs could be higher for vehicles with primary structure made from carbon fiber.

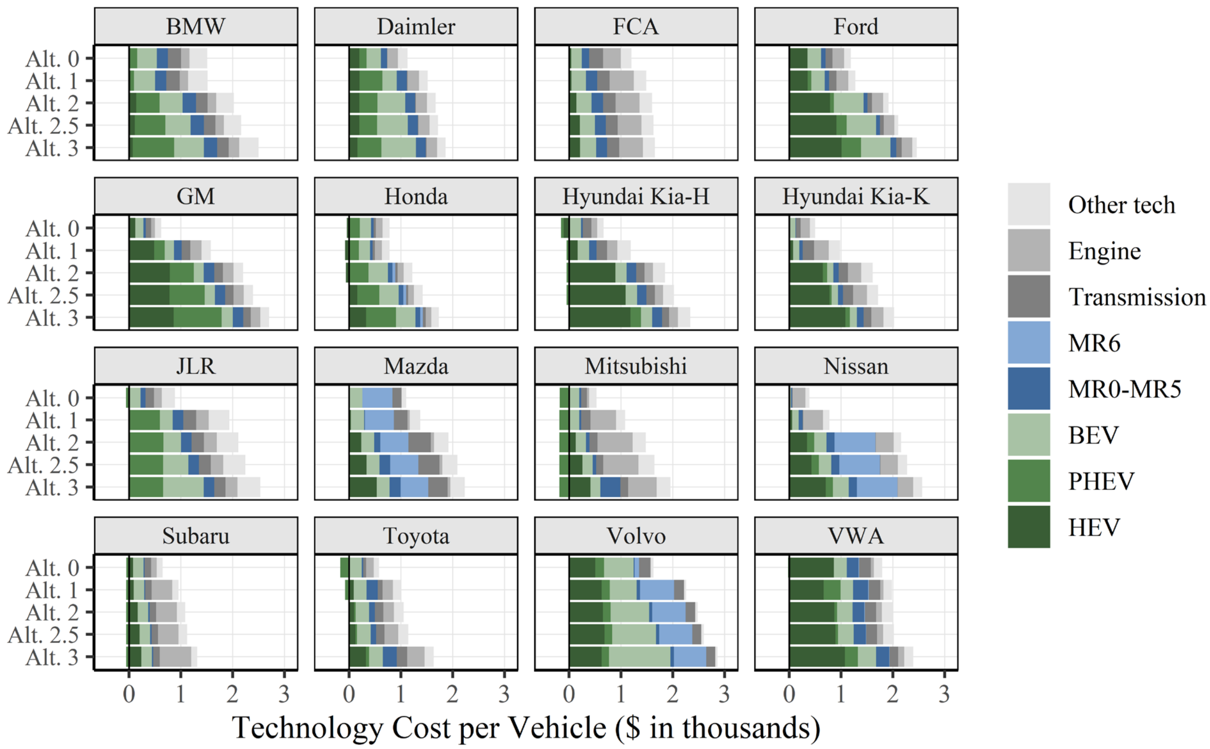


Figure 6-17 – Per-vehicle Technology Cost by Manufacturer (MY 2029)[109]

6.3.3 Sales and Employment Impacts

As manufacturers modify their vehicle offerings and utilize fuel-efficient technologies in response to CAFE standards, vehicle costs increase. The analysis assumes that these cost increases are passed on to consumers and higher retail prices decrease vehicle sales. Because each of the action alternatives leads to technology costs above those of the No-Action baseline, sales decline more in each alternative than in the No-Action Alternative.[110] Figure 6-18 illustrates the magnitude of this effect in the context of total sales. Readers should note that the

[109] In some cases, costs to apply a technology may be negative. In these instances, the aggregate cost of a new technology is less than the current cost of the existing technology. For example, moving to BEV200 from a PHEV may reduce cost if removing the cost of the engine is greater than the cost of increasing the battery capacity.
[110] Sales differences among alternatives are dictated by the assumed price elasticity of demand and the change in vehicle price net of future fuel savings. For this analysis, the assumed price elasticity is -0.4 and the model assumes new vehicle buyers value the first 2.5 years of future fuel savings. For a detailed discussion of these assumptions, see TSD Chapter 4.2.

steep increase in total sales, across all the alternatives, between MY 2020 and MY 2023 represents a recovery from the sales shock caused by the pandemic.

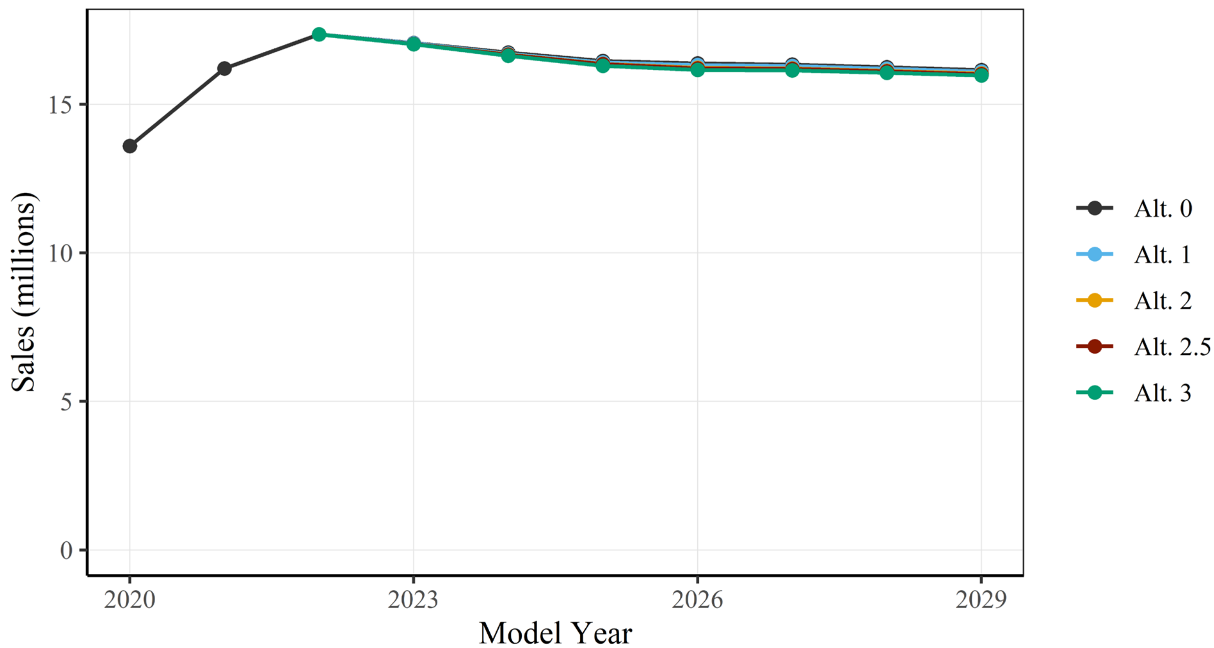


Figure 6-18 – Industry-wide Sales

Figure 6-19 shows the simulated sales differences for the current analysis at the industry level across alternatives relative to the baseline between 2020 and 2050. The largest differences in technology costs occur during the years covered by this action, peaking in 2026 and then beginning a gradual (or in some instances, rapid) decline as cost learning erodes technology cost differences between the alternatives – causing absolute technology costs, and thus sales, to converge in later years. Removing the value of fuel savings from the price change limits the sales decrease in the alternatives by reducing the absolute difference in price if only the regulatory costs were considered. The most stringent alternative (Alternative 3) has annual sales differences that peak just over one percent of total sales between 2020 and 2050. Alternative 2.5 differs by approximately 1 percent in 2026.

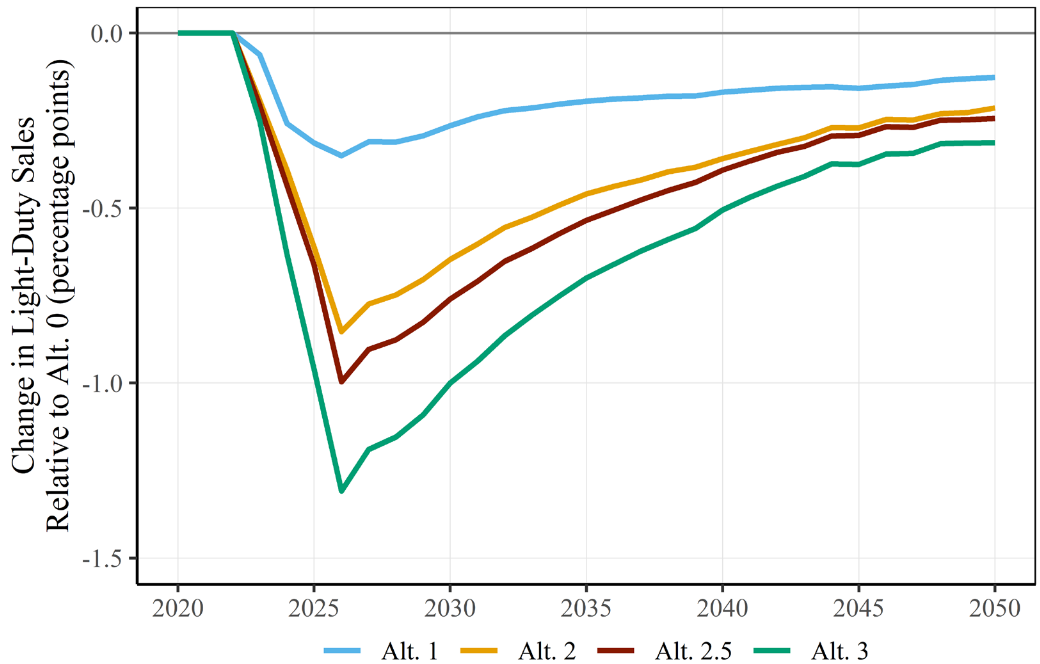


Figure 6-19 – Percentage Change in Sales, by Alternative

When fewer vehicles are sold, manufacturers require fewer labor hours to satisfy demand. Hence, the decline in sales shown in Figure 6-18 reduces industry-wide labor hours. However, development and deployment of new fuel-efficient technologies increases demand for labor. Overall estimated CAFE program impacts on employment utilization depend on the relative magnitude of these two forces. Table 6-1 reports total employment utilization in full-time equivalent job units (i.e., the number of individuals working a full-time position that are required to meet new vehicle demand). Chapter 6.2.5 of the TSD offers further detail on this measure and how it is calculated. In the No-Action Alternative, sales declines drive reductions in labor utilization beyond MY 2023. In each of the action alternatives, labor utilization declines by less than in the No-Action Alternative. This trend in labor effects indicates that technology effects ultimately outweigh sales effects and result in higher labor utilization than in the baseline case.

Table 6-1 – Industry-wide Labor Utilization Effects (in Full-time Equivalent Jobs)

Model Year	Alt. 0	Difference from Alt. 0			
		Alt. 1	Alt. 2	Alt. 2.5	Alt. 3
2020	942,950	0	0	0	0
2021	1,127,977	0	0	0	0
2022	1,213,281	0	0	0	0
2023	1,197,493	118	1,266	1,753	2,570
2024	1,177,404	3,856	5,775	7,183	11,195
2025	1,159,628	5,469	9,345	10,788	16,253
2026	1,155,150	6,722	13,807	16,204	21,312
2027	1,151,451	8,058	15,677	18,255	23,670
2028	1,144,014	8,521	16,017	18,517	24,108
2029	1,135,707	8,649	15,796	18,242	23,746

6.4 Effects on New Car and Truck Buyers

6.4.1 Vehicle Purchasing Price

The CAFE Model uses vehicle-level MSRP values provided in the input fleet as the starting point for modeling vehicle purchase prices. These initial MSRPs are revised over successive model years to produce final MSRP values that incorporate the regulatory cost of compliance. Figure 6-20 displays trends in these MSRPs for MYs 2020 through 2029 and reports values separately for light trucks and passenger cars. For both regulatory classes, Alternative 3 produces the largest deviation from the No-Action Alternative, an increase of approximately 4.6 percent on average for MY 2026 through MY 2029 passenger cars and 3.5 percent for light trucks. For Alternative 2.5, these values are 3.7 and 2.6 percent, respectively. Because these prices are influenced in large part by technology costs, the overall price trends are similar to those found in Figure 6-12, which presents average technology cost per vehicle, especially between MY 2023 and 2026. After MY 2026, sales-weighted MSRP values decline slightly. Once most manufacturers apply technologies to respond to the new CAFE standards, vehicles retain these technologies. The associated costs of these technologies gradually decline due to the model's assumed technology learning rates and, to a lesser extent, to declining real civil penalty costs.[111] As higher stringency alternatives apply more advanced technologies and more civil penalty costs, this gradual decline beyond MY 2026 is more pronounced than in lower stringency alternatives and the No-Action Alternative.

[111] Civil penalties are projected to be based on a nominal underlying rate (i.e., nominal dollars per 0.1 mpg per vehicle) that will increase over time reflecting projected future inflation. *See* the discussion in Section VII of the final rule preamble for additional detail.

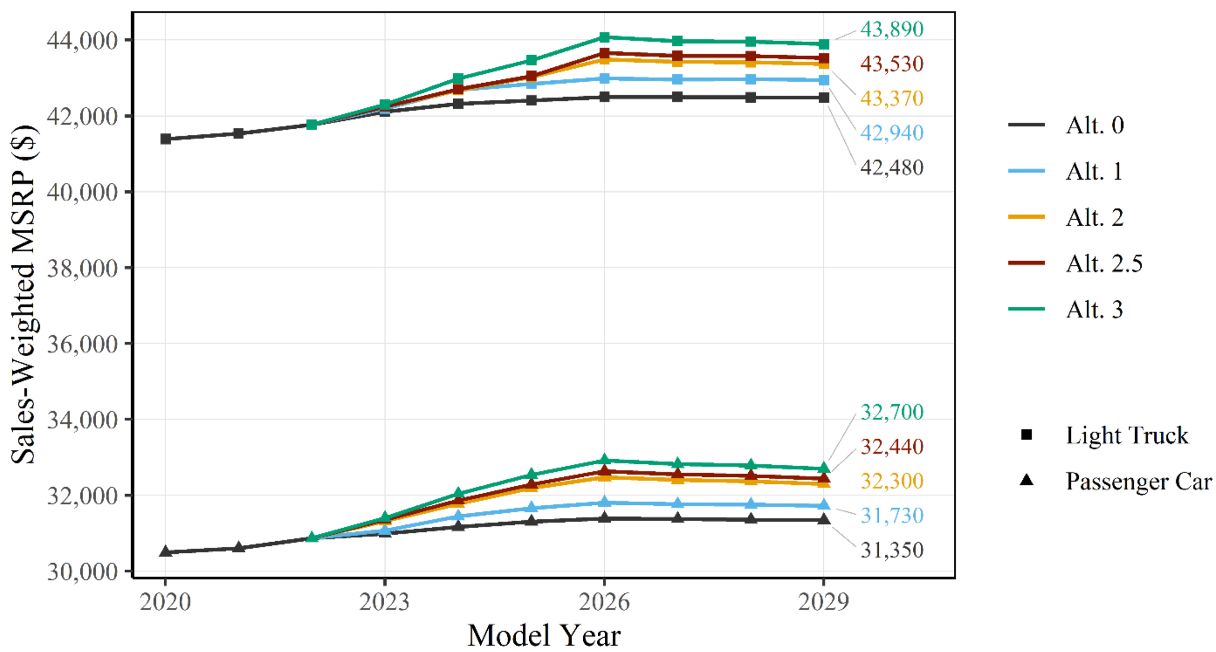


Figure 6-20 – Sales-weighted MSRP by Regulatory Class

6.4.2 Additional Consumer Purchasing Costs and Benefits

In addition to vehicle price effects, the CAFE Model computes various categories of consumer costs and benefits.[112] Table 6-2 summarizes these cost and benefit categories for MY 2029 and MY 2039 vehicles. The table includes per-vehicle aggregate values for the No-Action Alternative and differences from the No-Action Alternative for each of the regulatory alternatives.[113] Insurance cost and vehicle taxes and fees are all derived as a portion of modeled MSRP levels and hence vary directly with MSRP across alternatives. Regulatory costs are composed primarily of compliance costs due to technology application and therefore increase as alternative stringency increases. As shown in Table 6-2, this regulatory cost component increases by nearly 40 percent over the No-Action Alternative for Alternative 1 and nearly doubles for Alternative 2.5 in MY 2029.

Estimated private benefits include decreased fuel expenditures, time saved due to less frequent fueling, additional value derived from reallocated vehicle miles, and realized benefits from rebound travel miles. As presented in Table 6-2, fuel savings benefits are the largest component of estimated consumer benefits. Estimates for the No-Action Alternative indicate average retail fuel outlay costs of approximately $15,600 per vehicle. Fuel-economy improvements implemented under Alternative 1 produce estimated retail fuel savings of $709 per vehicle. Alternative 2.5 doubles these savings on a per vehicle basis to $1,377 per vehicle.

[112] This section considers only private consumer costs and benefits. Chapter 6.5 presents model results for costs and benefits attributable to society as a whole.
[113] Results for additional regulatory fleet aggregations and discount rates is included in Appendix I and II.

Table 6-2 – Per-vehicle Consumer Costs and Benefits (MY 2029 and MY 2039, 2018$, 3 Percent Discount Rate)

	MY 2029					MY 2039				
	Alt. 0	Relative to Alt. 0				Alt. 0	Relative to Alt. 0			
		Alt. 1	Alt. 2	Alt. 2.5	Alt. 3		Alt. 1	Alt. 2	Alt. 2.5	Alt. 3
Consumer costs										
Insurance cost	3,480	49	102	118	152	3,440	39	80	92	118
Taxes and fees	2,014	29	59	68	88	1,992	23	46	53	68
Regulatory cost	1,100	432	938	1,087	1,407	935	314	689	790	1,015
Foregone consumer sales surplus	0	0	2	3	6	0	0	1	1	2
Maintenance and repair cost	0	0	0	0	0	0	0	0	0	0
Implicit opportunity cost	0	0	0	0	0	0	0	0	0	0
Total consumer costs	6,594	511	1,102	1,276	1,654	6,367	376	816	936	1,202
Consumer benefits										
Retail fuel outlay	15,629	-709	-1,222	-1,377	-1,692	15,741	-626	-1,457	-1,761	-2,216
Refueling time cost	818	-8	6	0	-12	929	-17	42	84	106
Drive value	456	74	111	121	145	588	73	100	99	111
Reallocated value	0	14	37	42	55	0	6	24	26	35
Total consumer benefits	16,903	805	1,363	1,539	1,904	17,258	723	1,539	1,802	2,257
Net benefits	10,309	295	261	262	251	10,891	347	723	866	1,055

Note: Totals may not sum due to rounding
Note: Retail fuel outlay and refueling time cost are reported as negative numbers as they are lower than the baseline values, however these are treated as positive values when aggregating relative total consumer benefits (i.e., consumers paying less for fuel and spending less time refueling accrue positive private benefits).

Overall, private consumer benefits as estimated outweigh private consumer costs in the No-Action Alternative.[114] Relative to this baseline, net benefits to the consumer are positive across regulatory alternatives. Comparing MY 2029 and MY 2039 in Table 6-2 illustrates the differences in cost and benefit components across model years. Figure 6-21 reports net benefits results from MY 2020 through MY 2050. Across model years, private net benefits vary significantly. In early model years for Alternatives 2, 2.5, and 3, net consumer benefits are negative as technology application costs of compliance outweigh consumer benefits. As these technology costs decline after the initial compliance period, residual consumer benefits from reduced fuel expenditure, refueling time, and additional drive time continue to accrue. This produces positive net private benefits in later model years. Net benefits become positive in MY 2023 for Alternative 1 and in MY 2026 for Alternative 2 and MY 2027 for Alternatives 2.5 and 3, respectively. Chapter 7 of this document explores the sensitivity of these results to alternate modeling assumptions.

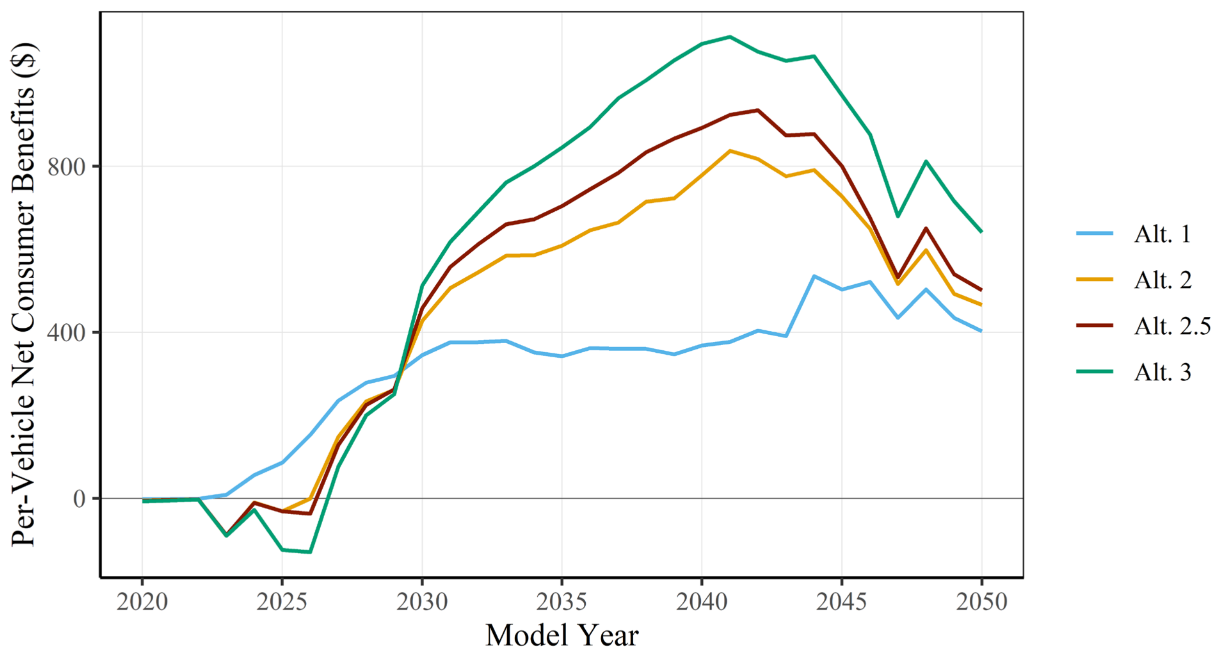


Figure 6-21 – Private Consumer Net Benefits, 3 Percent Social Discount Rate

Figure 6-22 plots trends in each of the consumer cost components that are directly tied to vehicle MSRP. As expected, patterns of these costs track each other and MSRP trends (i.e., initial increases followed by gradual declines). Figure 6-23 breaks out the other cost and benefit components of the private net benefit calculation. Fluctuations in foregone consumer sales surplus, refueling time cost, and reallocated value are relatively small compared to the retail fuel outlay and drive value magnitudes. As expected, retail fuel outlay and drive value move in

[114] Note that in Table 6-2, retail fuel outlay and refueling time cost are reported as negative numbers as they are lower than the baseline values, however these are treated as positive values when aggregating relative total consumer benefits (i.e., consumers paying less for fuel and spending less time refueling accrue positive private benefits).

opposite directions over time, retail fuel outlay decreasing with more efficient fleets and drive value increasing with a larger number of rebound miles traveled. Note, as above, private consumer benefits due to avoided retail fuel savings are substantial, especially in the cases of Alternative 2, 2.5, and 3.

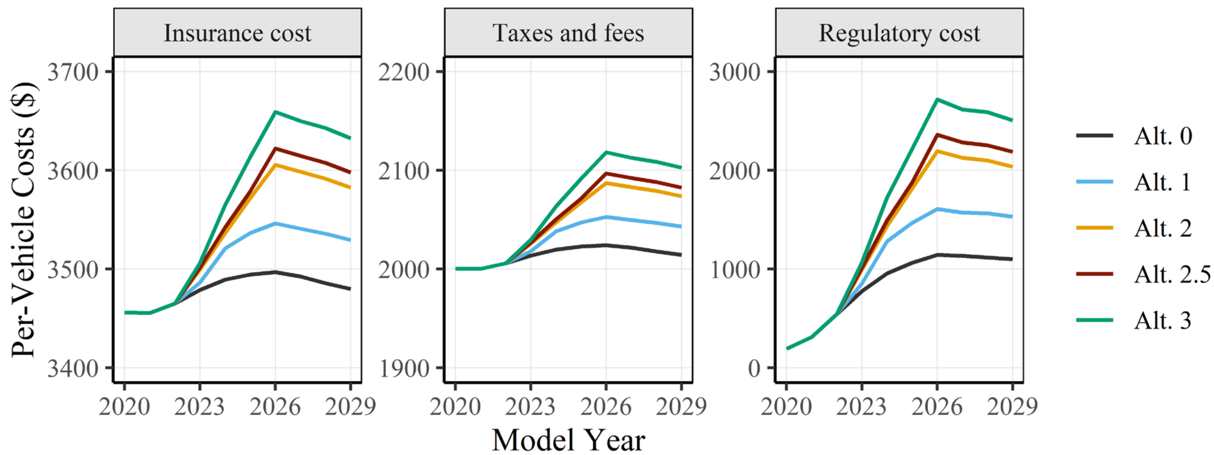


Figure 6-22 – MSRP-based Consumer Costs, 3 Percent Social Discount Rate

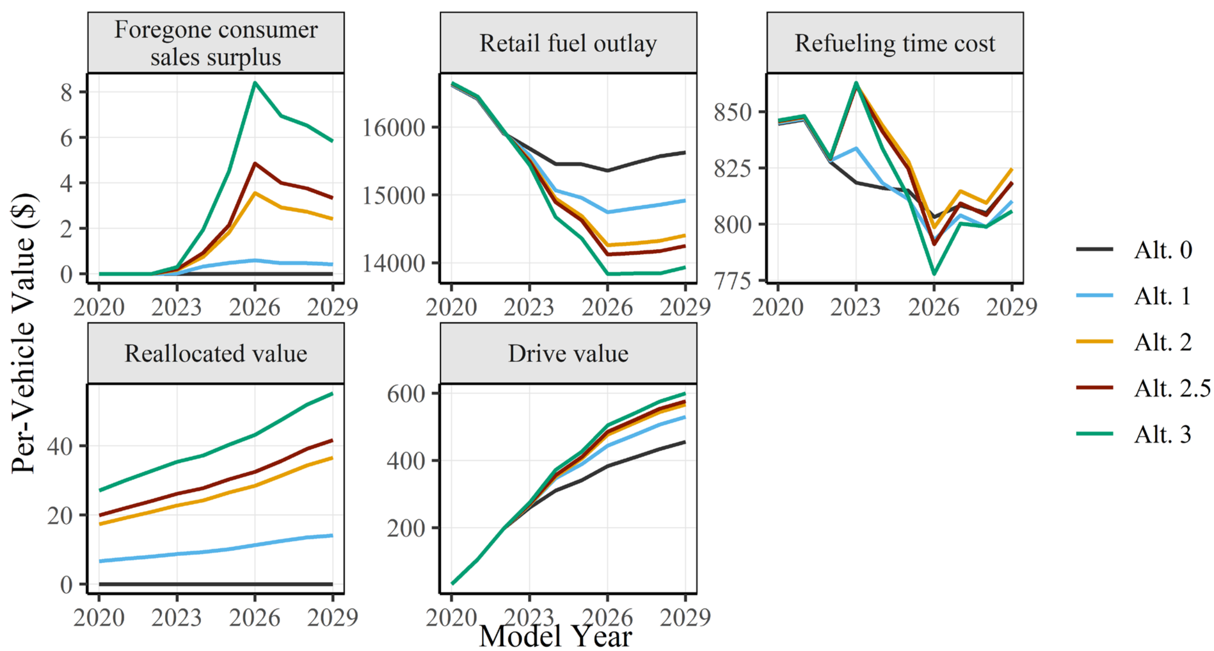


Figure 6-23 – Consumer Costs and Benefits, 3 Percent Social Discount Rate

6.4.3 Total Cost of Ownership Payback Period

An alternative metric for evaluating relative costs and benefits of fuel efficiency regulations is to compute the time required for fuel economy improvements to produce positive returns from resulting fuel savings. To estimate the payback period for total cost of ownership (TCO) changes, the model aggregates regulatory costs—including the cost of applied technology and civil penalties—and maintenance and repair costs for new technologies. It then compares these to a running total of fuel savings and ownership cost changes (e.g., vehicle taxes and fees, finance and insurance costs) relative to the initial state of a given vehicle.[115] The vehicle age at which estimated benefits outweigh estimated costs is the payback period. Figure 6-24 illustrates the distribution of payback periods across all modeled vehicle sales.

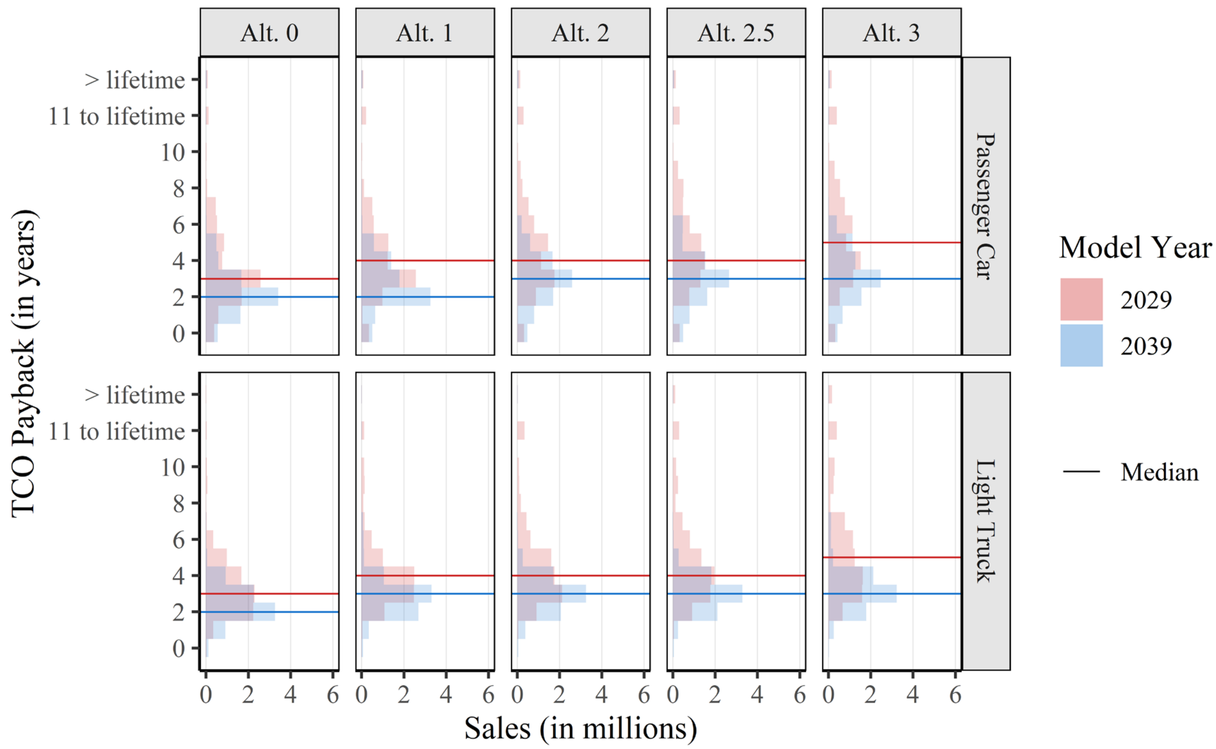


Figure 6-24 – Distribution of Vehicle TCO Payback

Figure 6-24 summarizes payback periods for undiscounted costs from the CAFE Model's vehicles report.[116] Passenger car payback periods are slightly longer than light truck payback periods on average in MY 2029 and slightly shorter by MY 2039. Overall, payback times are longer in MY 2029, likely due to larger regulatory costs closer to the modeled CAFE regulation period.

[115] The "initial state" of each vehicle is based on the vehicle's technology status in MY 2020.

[116] In instances where costs outweigh benefits over the full vehicle lifetime, the payback period for individual models is reported as 99 years in the CAFE Model outputs. Because these values do not represent the full payback period, they were excluded from mean and median calculations in Table 6-3. As presented in Figure 6-24, vehicles with payback periods longer than their assumed lifetime represent a small fraction of overall sales, though this fraction does increase across alternatives. Including these values in the calculation of the mean increase's payback periods. For example, for MY 2029 passenger cars, the baseline average TCO payback period is 4.4 years and increases to 7.2 years in Alternative 3. As this payback value is censored at 99 years, average and median payback periods presented above underestimate true fleet-wide payback, though the fraction of total vehicles with long payback periods is small.

Table 6-3 – Payback Times by Regulatory Class (in Years)

	MY 2029					MY 2039				
	Alt. 0	**Alt. 1**	**Alt. 2**	**Alt. 2.5**	**Alt. 3**	**Alt. 0**	**Alt. 1**	**Alt. 2**	**Alt. 2.5**	**Alt. 3**
Mean TCO Payback										
Passenger Car	3.5	4.1	4.7	5.0	5.4	2.2	2.6	2.9	3.0	3.1
Light Truck	3.3	4.0	4.8	4.9	5.5	2.4	2.8	2.9	3.0	3.1
Median TCO Payback										
Passenger Car	3.0	4.0	4.0	4.0	5.0	2.0	2.0	3.0	3.0	3.0
Light Truck	3.0	4.0	4.0	4.0	5.0	2.0	3.0	3.0	3.0	3.0

6.5 Effects on Society

This chapter discusses social benefits and costs associated with the different rulemaking alternatives, including purely external benefits and costs pertaining to the following: GHGs, criteria pollutant emissions, congestion, noise, energy security, and safety. The following chapters (6.5.1 through 6.5.5) discuss the external effects to society. Chapter 6.5.6 summarizes the full accounting of both these external costs and benefits and the costs and benefits experienced by society as a whole, including the effects on consumers and manufacturers described in Chapter 6.3 and Chapter 6.4.

The CAFE Model records costs and benefits for particular model years but also reports these measures over the lifetime of the vehicle. Examining program effects through this lens illustrates the temporal differences in major cost and benefit components. Figure 6-25 displays values for MY 1981 through 2029 vehicles over their lifetimes. For CY 2029 and earlier, costs exceed benefits, driven mostly by costs for applying efficiency-improving technologies. From 2029 onward, benefits exceed costs.

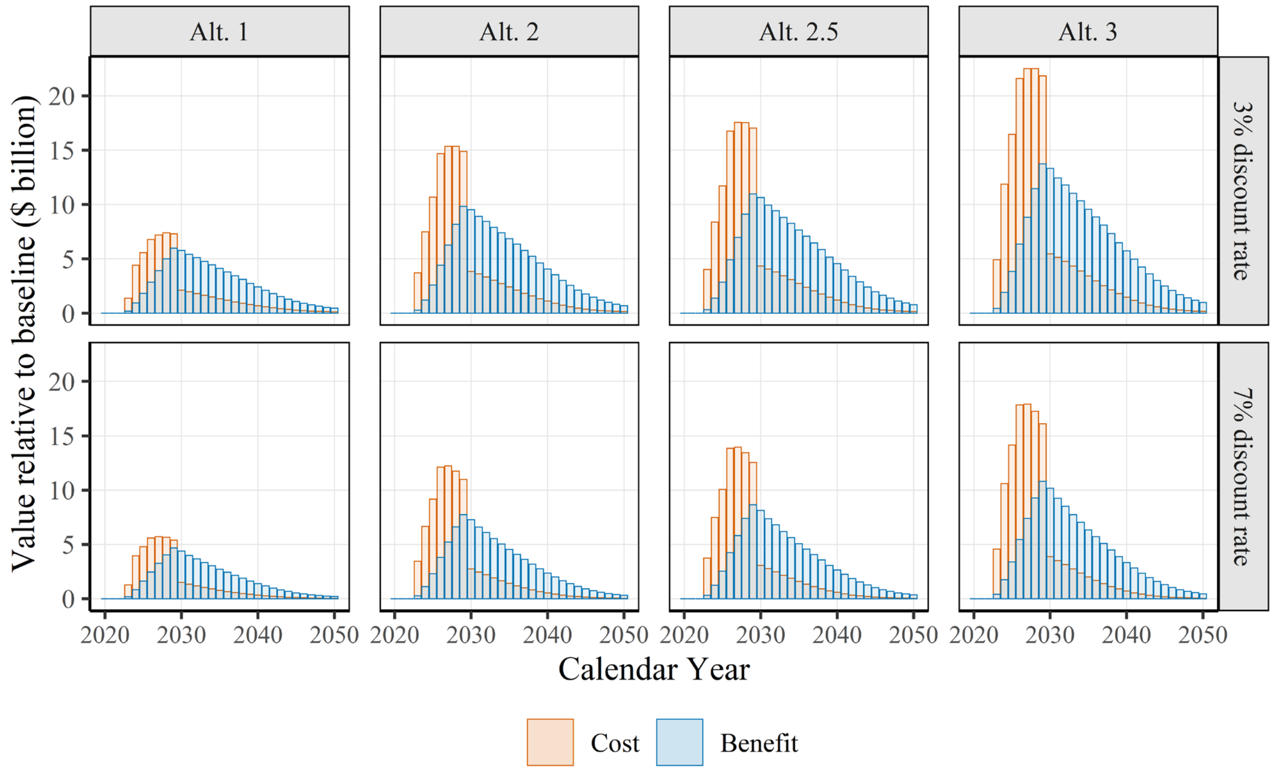


Figure 6-25 – Annual Costs and Benefits of Model Years 1981-2029 (Total fleet), on a Calendar Year Basis[117]

Alternatively, one could also evaluate the impacts of the program from a calendar year accounting perspective rather than tracking the lifetimes of the vehicles directly impacted by the MY 2024-2026 CAFE standards in each alternative. From a calendar year perspective, costs and benefits accrue in each calendar year – as they do in the model year perspective – but we would make no distinction between vehicles produced during the action years, MYs 2024-2026, and vehicles produced in subsequent years when those standards are assumed to be frozen at their MY 2026 levels. This perspective has the benefit of a more intuitive interpretation – costs and benefits associated with the alternatives will be observed annually and appear in the context of the entire on-road fleet, rather than as part of a specific model year cohort. For example, annual fuel consumption is relatively easy to measure, but determining the quantity of fuel consumed by specific model year cohorts is next to impossible (and generally requires the kind of simulation produced in this analysis).

A calendar year accounting perspective also has the effect of incorporating benefits and costs accruing to model years far in the future when a number of important factors that influence costs and benefits may be less certain as compared to the near future when manufacturers and consumers are responding to the standards. For example, some technologies (notably electric technologies that rely on large batteries, or advanced engines) may be considerably less expensive than they will be during the action years, and make additional technology application

[117] For exposition, the figure truncates costs and benefits at 2050. Some costs and benefits accrue out to 2070, though these values are relatively small.

more cost-beneficial farther out in the future. Fuel prices that rise over time, and estimated social costs, like those associated with GHG emissions damages, have a similar effect. While discounting future costs and benefits compensates for this effect somewhat, it cannot fully account for uncertainty in the benefit cost analysis that accrues far in the future, beyond the model years explicitly affected by this rule.

Another limitation to the calendar year accounting approach is that it fails to account for all of the benefits associated with fuel economy technologies added toward the end of the analysis. For instance, consider fuel economy technologies added to MY 2045 vehicles. These technologies would produce benefits in the form of reduced fuel costs, reductions in climate damages, and other benefits until those vehicles are scrapped far into the future and beyond the last year of the analysis. This means that the full cost of these technologies is captured by the analysis, but some benefits are excluded – which biases the net benefits *against* more stringent fuel economy standards, which could potentially discourage the agency from choosing a regulatory alternative that better met EPCA's overarching purpose of energy conservation.

The model year approach has a similar drawback where some impacts associated with fuel economy technologies added to MYs 2030 and beyond are captured by the analysis and some are not. For instance, the analysis keeps track of MY 2026 vehicles after they are sold, and the rates at which they will be driven and scrapped depend on other vehicles on the road. By CY 2030, many of the vehicles on the road will have been produced after MY 2026. These vehicles produced after 2030 will have higher fuel economy levels because of the standards and will have benefited from cost LE that will accrue after 2026. The standards will, in turn, also impact the size and composition (passenger car versus light truck share) of the new vehicle market beyond MY 2026. Acting together with increases in fuel prices, all of this will impact the rates at which MY 2024-2026 vehicles are driven and scrapped – which impacts the cost and benefit estimates of the rule on MY 2024-2026 vehicles.

This section presents some results from both the model year and calendar year perspectives – particularly where the external nature of the cost or benefit more readily lends itself to a calendar year accounting structure. Figure 6-26 aggregates annual cost and benefit streams to produce cumulative net benefits, by calendar year, for the three modeled alternatives. Estimated program compliance and outcomes indicate the industry reaches cumulative positive net benefits for Alternative 1 in 2039 using a 3 percent discount rate (this is pushed to 2040 using a 7 percent discount rate). At the 3 percent discount rate, Alternative 2.5 reaches this threshold in 2042 – and while the depth of the decline in cumulative net benefits is greater for Alternative 3 than either of the others, the net benefits also grow faster once they finally turn positive. The figure illustrates the point above regarding the calendar year accounting perspective; the years closest to the action years look different from years much later, but those later years can be sufficient to dominate the calculation of net benefits (particularly at the 3 percent discount rate).

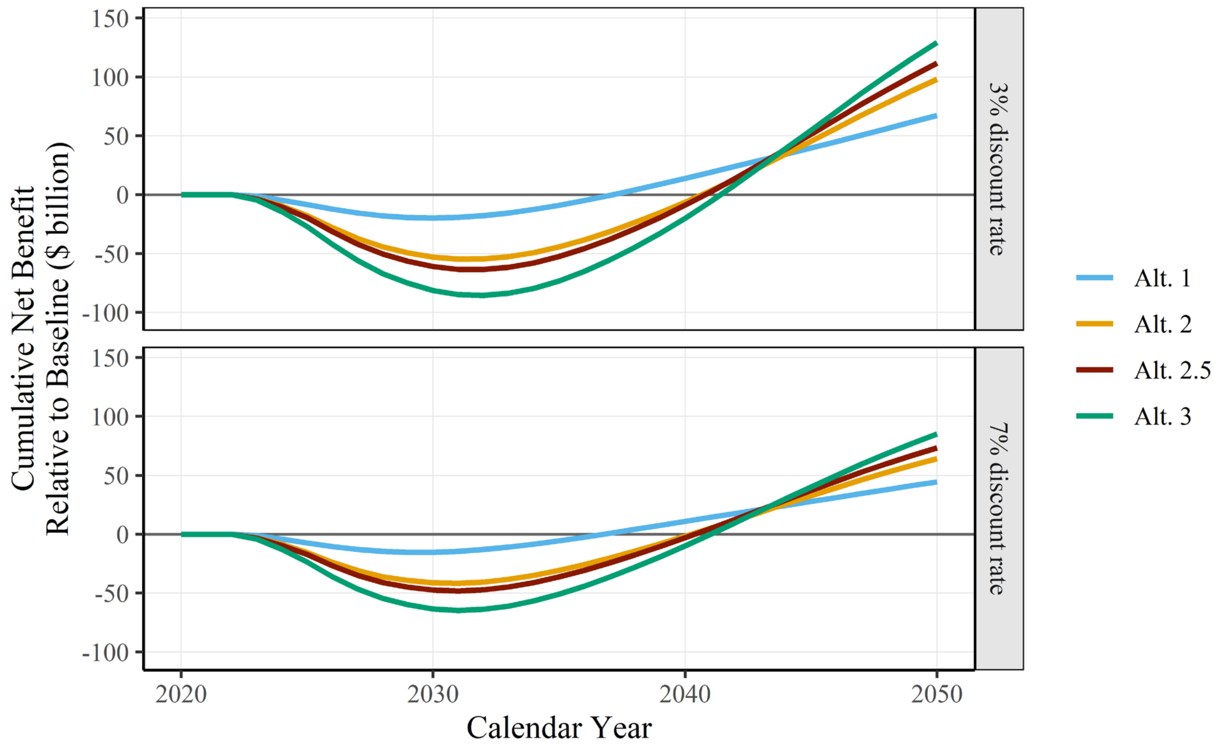


Figure 6-26 – Cumulative Net Benefits, MY 2020-2029

The graphs in this section present certain effects in absolute terms, while others show incremental costs and benefits relative to Alternative 0. Both model year and calendar year perspectives are used in this section depending on the effects discussed. Unless otherwise stated, the model year perspective includes MYs 1981-2029 and the calendar years that correspond to the full lifetimes of models produced in those model years, while the calendar year perspective includes CYs 2020-2050 and all of the model years present in the on-road fleet in each of them.

6.5.1 Social Benefits of Reducing Greenhouse Gas Emissions

NHTSA has determined that the best available and most appropriate values for estimating climate effects are the interim values published by the IWG in February 2021 to represent the social cost per ton of CO_2, methane (CH_4), and nitrous oxide (N_2O).[118] Table 6-4 shows these values for certain calendar years, across discount rates. See Chapter 6.2.1 in the TSD for discussion of how these values were integrated into the CAFE Model inputs.

[118] Interagency Working Group on Social Cost of Greenhouse Gases, U.S. Government. (2021). *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990*, available at https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf. (Accessed: February 14, 2022).

Table 6-4 – Social Cost of GHGs (2018$ per metric ton)

Year	CO_2				CH_4				N_2O			
	5%	3%	2.5%	95th Pct.[119]	5%	3%	2.5%	95th Pct.	5%	3%	2.5%	95th Pct.
2020	14	50	74	148	650	1,456	1,941	3,786	5,630	17,472	26,209	46,593
2025	17	54	81	164	777	1,650	2,136	4,368	6,601	20,384	29,121	52,417
2030	18	60	86	182	912	1,941	2,427	5,048	7,571	22,326	32,033	58,241
2035	21	65	93	200	1,068	2,136	2,718	5,824	8,736	24,267	34,945	65,036
2040	24	71	100	218	1,262	2,427	3,009	6,504	9,707	27,179	37,857	71,831
2045	27	77	107	235	1,456	2,718	3,397	7,280	11,648	29,121	40,769	78,626
2050	31	83	113	252	1,650	3,009	3,689	7,960	12,619	32,033	43,681	85,421

The CAFE Model multiplies the per-ton cost values for each of the three GHGs considered by the total emissions of each. Chapter 5 of the TSD describes the calculation of these total emissions, from both upstream and tailpipe sources. The CAFE Model reports the monetized values of the total GHG emissions in its output reports. All reported cost values in this chapter are in 2018$. Table 6-5 lists the total costs of GHG emissions by alternative, for MYs 1981-2029, based on the four different SC-GHG rates. All values in Table 6-5 are in absolute terms, monetizing the incurred costs of emissions. GHG social costs decrease for all GHGs as stringency increases across the alternatives.[120] As discussed in the preamble, these social cost estimates are very likely underestimates of actual damages, and as such, the benefit numbers provided here are also likely underestimates.

[119] 95th percentile values are discounted at 3 percent.

[120] Climate benefits are based on changes (reductions) in CO_2, CH_4, and N_2O emissions and are calculated using four different estimates of the SCC, SC-CH_4, and SC-N_2O (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). We emphasize the importance and value of considering the benefits calculated using all four estimates. We show two primary estimates for climate benefits in this rule for presentational purposes (model average at 2.5 and 3 percent discount rates). The full range of climate benefits is shown in Chapter 7 of the FRIA. As discussed in the Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990 (IWG 2021)—with which NHTSA agrees—, a consideration of climate benefits calculated using discount rates below 3 percent, including 2 percent and lower, are also warranted when discounting intergenerational impacts.

Table 6-5 – Total Costs of GHG Emissions across Alternatives (2018$, in billions) (1981-2029 MY totals)

	Alternative 0	Alternative 1	Alternative 2	Alternative 2.5	Alternative 3
	5% SC-GHG discount rate				
CO_2	304.5	301.1	298.6	297.9	296.2
CH_4	19.4	19.2	19.0	19.0	18.9
N_2O	4.7	4.7	4.7	4.7	4.6
	3% SC-GHG discount rate				
CO_2	1,150.9	1,137.2	1,127.5	1,124.7	1,117.8
CH_4	47.8	47.3	46.9	46.8	46.5
N_2O	16.2	16.1	16.0	15.9	15.9
	2.5% SC-GHG discount rate				
CO_2	1,743.1	1,722.1	1,707.3	1,703.0	1,692.5
CH_4	64.1	63.3	62.8	62.7	62.3
N_2O	24.3	24.1	24.0	23.9	23.8
	95th percentile at 3% SC-GHG discount rate				
CO_2	3,477.6	3,435.9	3,406.4	3,397.9	3,376.9
CH_4	126.6	125.1	124.1	123.9	123.2
N_2O	43.0	42.6	42.3	42.2	42.0

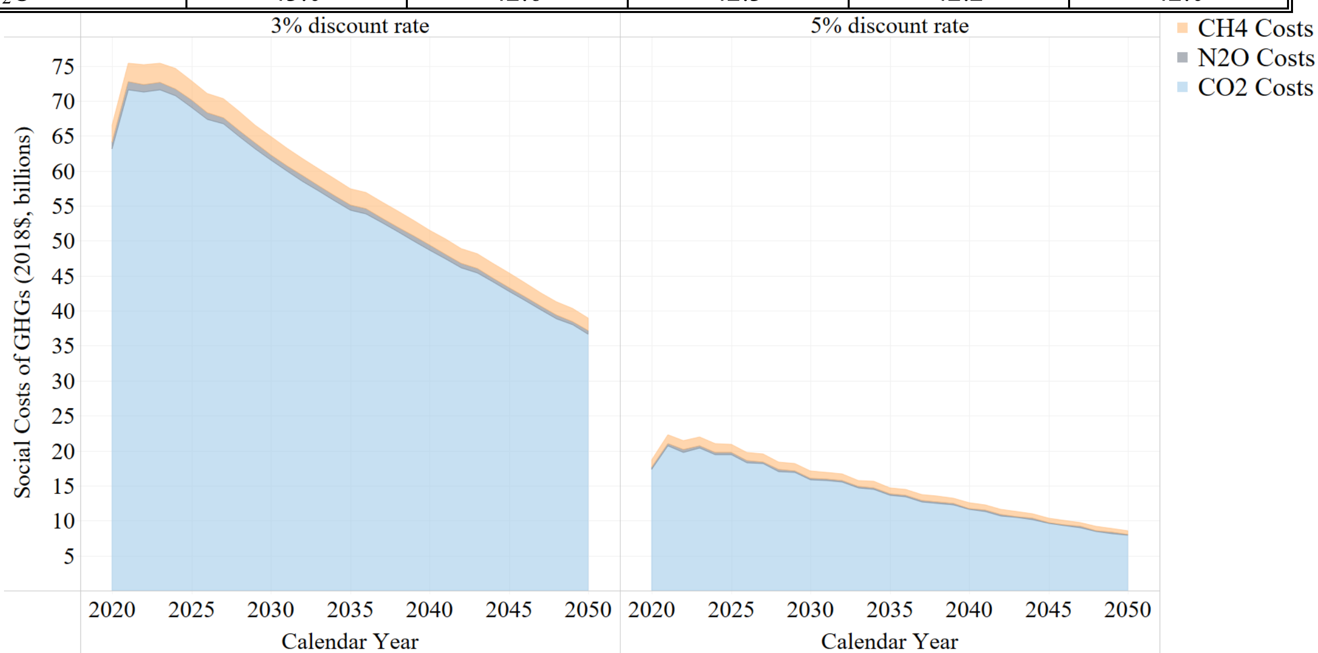


Figure 6-27 and Figure 6-28 show the social costs of GHG emissions in the No-Action Alternative (baseline) scenario for CYs 2020-2050, illustrating the relative magnitudes of each pollutant's monetized costs. Although CH_4 and N_2O have substantially higher social costs per ton compared to CO_2, the quantity of CO_2 emissions is much higher (see Chapter 6.6.2), accounting for the large difference between the three total social cost amounts. Comparing the two figures shows the extent to which discount rates matter for these emissions costs; using the highest social cost estimate (95th percentile values discounted at 3 percent), damage costs due to GHG emissions peak at over 200 billion dollars per year and then decline from there. In contrast, the lowest estimates (discounted at 5 percent) amount to little over 20 billion dollars per year at their highest point, and then decline from there.

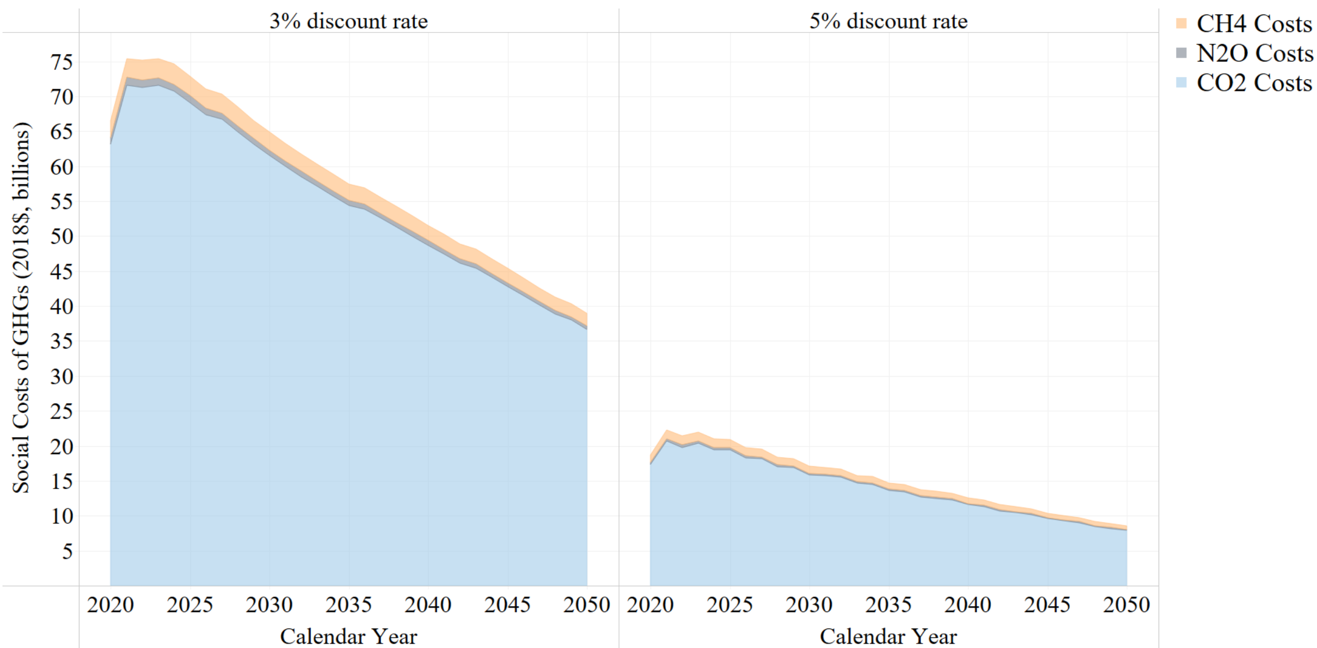


Figure 6-27 – Social Costs of CO_2, CH_4, and N_2O under Alternative 0 (2020-2050), 3 and 5 Percent Discount Rate (2018$, billions)

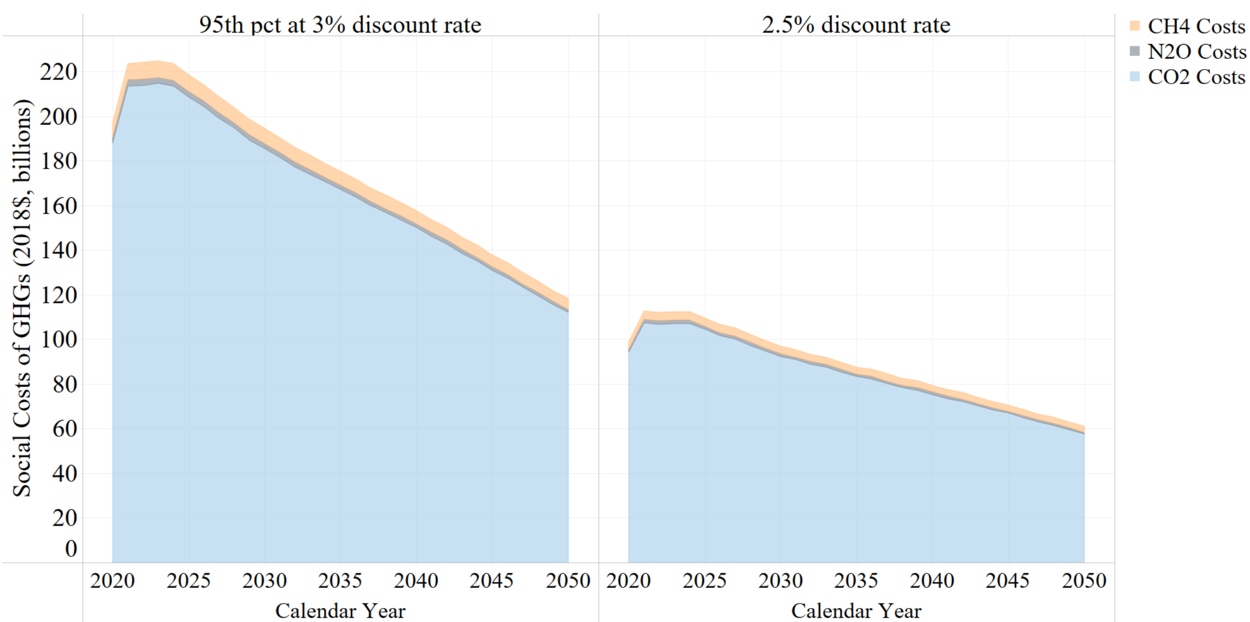


Figure 6-28 – Social Costs of CO_2, CH_4, and N_2O under Alternative 0 (2020-2050), 95th Percentile and 2.5 Percent Discount Rates (2018$, billions)

The following figures illustrate the social costs of GHG emissions relative to Alternative 0, either in terms of incurred costs or avoided costs (also referred to as social benefits). Incurred costs relative to the baseline represent the costs of GHGs in addition to the baseline total cost, as shown in Figure 6-29. In other figures where social benefits are shown, positive values indicate the avoided costs of GHGs not emitted.

Figure 6-29 – GHG Costs Under Alternative 0 and Changes Relative to the Alternative 0 (2018$, billions, discounted at 3 and 5 Percent)

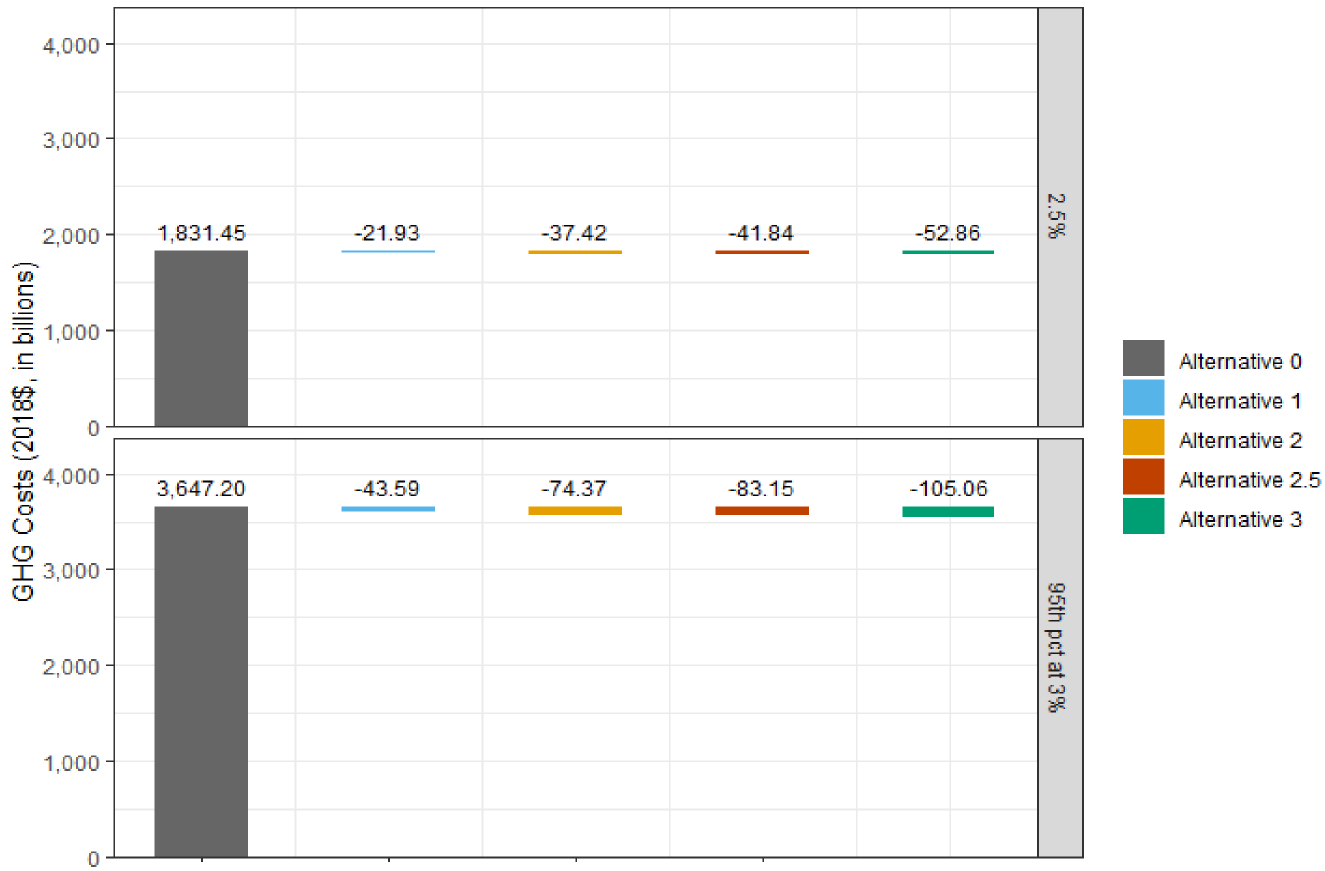


Figure 6-30 – GHG Costs Under the Alternative 0 and Changes Relative to Alternative 0 (2018$, billions, discounted at 2.5 Percent and 95th percentile at 3 Percent)

Figure 6-29 group the GHG costs together, discounted at each of the GHG rates. The GHG emission costs in the baseline are shown in absolutes, while the costs in the three alternatives are shown in terms of incremental reduced costs relative to the baseline. For instance, using the 3 percent discount rate, Alternative 1 reduces costs by $14.4 billion from the baseline (about 1.2 percent of the baseline total), while Alternative 3 reduces costs by $34.76 billion from the baseline (approximately 2.9 percent of the total baseline costs). Alternative 2.5 reduces costs by $27.52 billion.

Figure 6-31 focuses on these reduced costs relative to the baseline, presenting them as benefits in positive terms (avoided costs). Unlike in the previous graphs, this figure shows the distribution of GHG benefits across calendar years, dividing the benefits into three decades: 2021-2030, 2031-2040, and 2041-2050. Through this perspective, we see that most of the monetized benefits of reducing GHG emissions occur after 2030, and the highest benefits, in every alternative, occur in the period between 2041-2050.

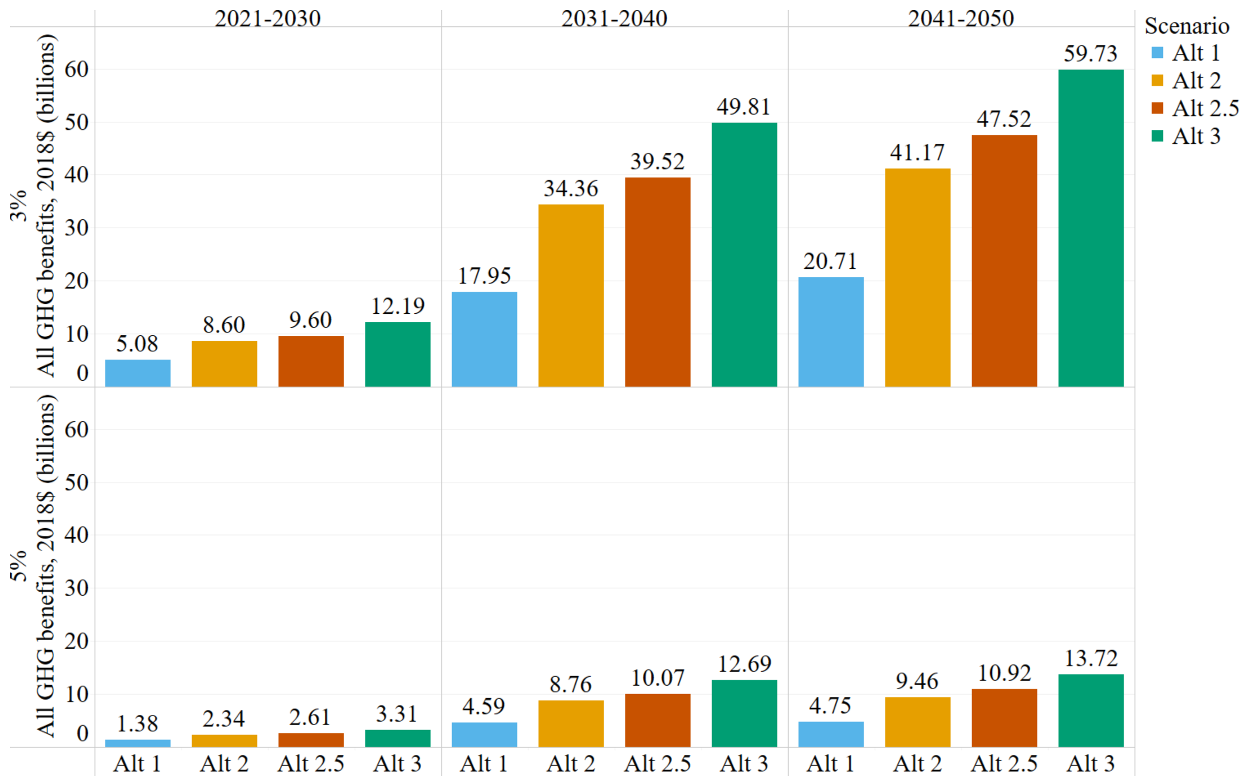


Figure 6-31 – Avoided GHG Costs Relative to the Alternative 0 (2018$, billions, 3 and 5 percent discount rates)

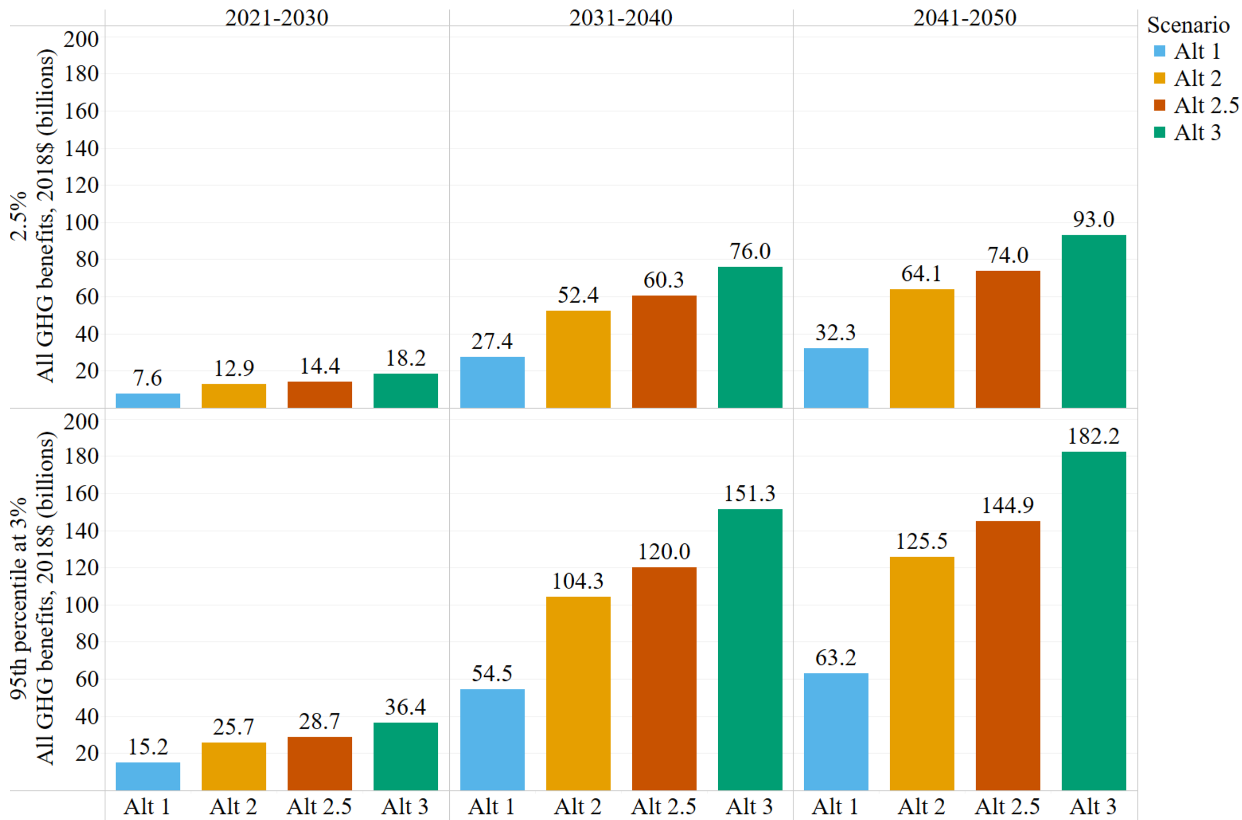


Figure 6-32 – Avoided GHG Costs Relative to the Alternative 0 (2018$, billions, 2.5 percent and 95th percentile at 3 percent discount rates)

6.5.2 Social Benefits of Reducing Criteria Pollutant Emissions

The criteria pollutant emissions computed by the CAFE Model—nitrogen oxide (NO_X), sulfur oxide (SO_X), particulate matter 2.5 microns or less in diameter ($PM_{2.5}$)—are linked to various health impacts (see TSD Chapter 5.4).[121] The model contains per-ton monetized health impact values corresponding to these health impacts (see TSD Chapter 6.2.2). The CAFE Model calculates the total criteria pollutant emissions associated with the fleet in different alternatives, based on the emissions inventory discussed in TSD Chapter 5, and the monetized health impact values per ton are then multiplied by the total tons in the emissions inventory. The resulting total costs associated with criteria pollutant emissions can be found in the CAFE Model outputs. For further information pertaining to these criteria pollutant emissions, see also Final SEIS Chapter 4.

Unless stated otherwise, all costs in the following figures are reported in 2018$ and are associated with MYs 1981-2029 under the model year perspective, and CYs 2020-2050 under the calendar year perspective.

[121] The morbidity health impacts included in the per-ton monetized values are: acute bronchitis, asthma exacerbation, cardiovascular hospital admissions, lower respiratory symptoms, minor restricted activity days, non-fatal heart attacks, respiratory emergency room visits, respiratory hospital admissions, upper respiratory symptoms, and work loss days.

Table 6-6 – Total and Incremental Costs of Criteria Pollutants, by Alternative, Model Year Perspective (2018$, billions)

	Alternative 0 (Baseline)		Alternative 1		Alternative 2		Alternative 2.5		Alternative 3	
	3%	7%	3%	7%	3%	7%	3%	7%	3%	7%
NO_X	79.7	59.9	-0.04	-0.02	0.03	0.03	0.05	0.05	0.10	0.08
SO_X	91.8	64.0	-0.54	-0.30	-0.53	-0.28	-0.52	-0.27	-0.50	-0.26
$PM_{2.5}$	238.8	170.5	-0.64	-0.36	-0.99	-0.54	-1.08	-0.59	-1.32	-0.72

Table 6-6 shows the total and incremental health costs attributable to the three criteria pollutants under each rulemaking alternative, discounted at 3 and 7 percent. In the baseline column, we present these costs in absolute terms, using the model year perspective (MYs 1981-2029). Incremental costs are presented relative to the baseline in the three alternatives while absolute costs are presented in Alternative 0. These social costs increase very slightly for NO_X in some alternatives (relative to the baseline total), due to a number of factors described below, including electrification in some alternatives causing slightly higher upstream emissions, and for downstream emissions, a decrease in sales causing older vehicles to be driven longer, and slightly more VMT due to the rebound effect. Chapter 6.6.4, which describes the changes in the pollutants themselves across alternatives, rather than the changes in costs, also includes further explanation of these effects. However, although total social costs summed across model years in this table show slight increases in NO_X, it is important to underscore that the social costs decrease over calendar years in all alternatives. Furthermore, as seen in later graphs, benefits from avoided criteria pollutant costs relative to Alternative 0 are experienced in every alternative, and they substantially outweigh any slight increases in incremental costs.

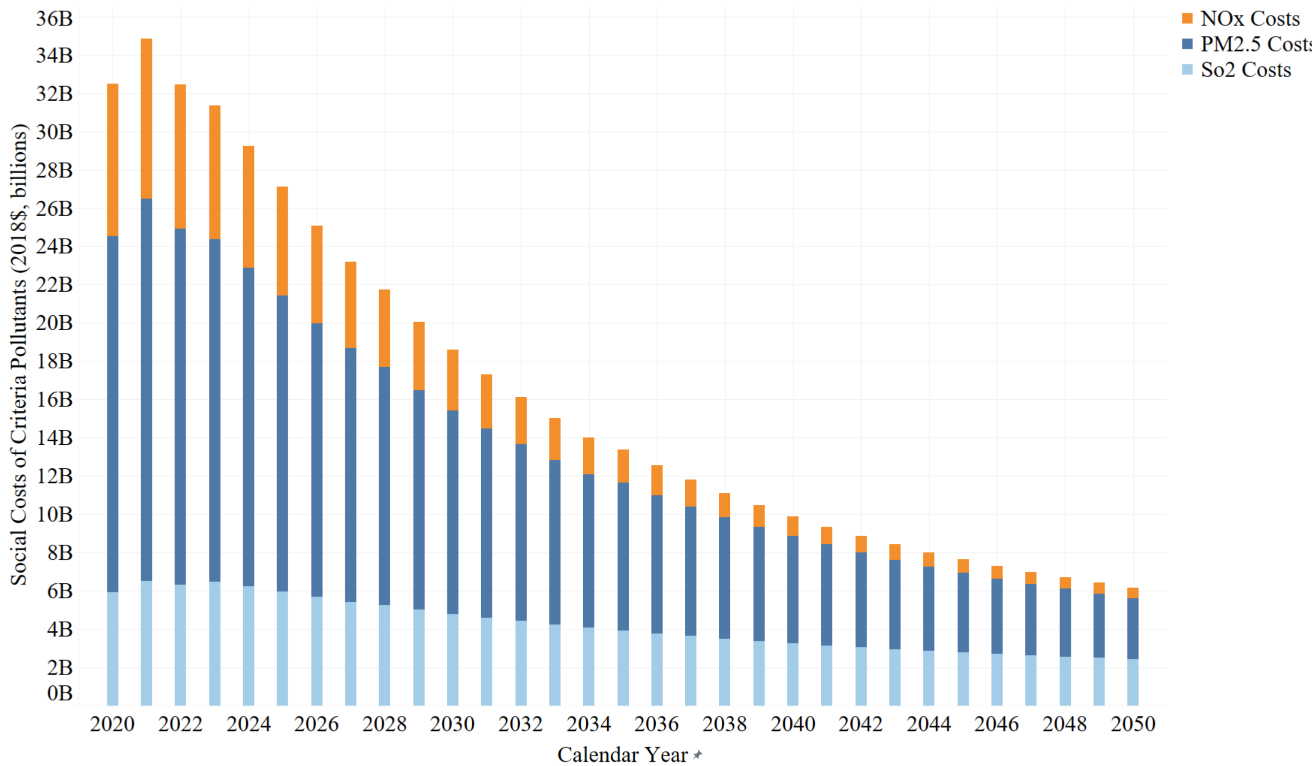


Figure 6-33 – Criteria Pollutant Health Costs under Alternative 0 (3 percent discount rate)

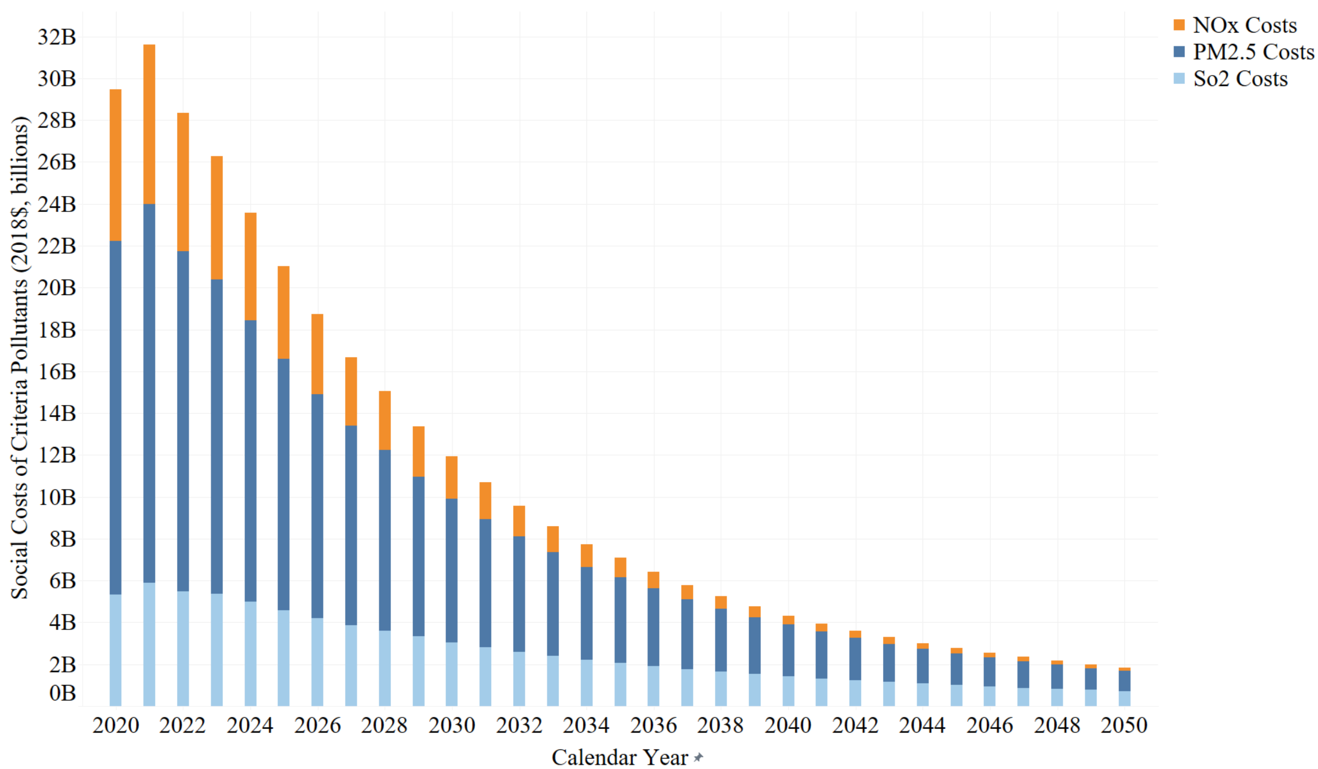


Figure 6-34 – Criteria Pollutant Health Costs under Alternative 0 (7 percent discount rate)

Figure 6-33 and Figure 6-34 (which differ only by discount rate) show how the health costs related to each criteria pollutant change over time in the baseline scenario (Alternative 0 or No-Action Alternative), from CYs 2020-2050. The social costs of criteria pollutants are a function of both the per-ton cost and the amount of each pollutant emitted. As detailed in Chapter 6.2.2 of the TSD, the per-ton costs of some criteria pollutants do increase based on the calendar year. However, as the per-ton costs do not change substantially, the changes in total costs pertain to increases and decreases in tons of emissions. The magnitude changes of each pollutant over the years come from changes in fleet mix and fuel types used. As seen in these two figures, the health costs from criteria pollutants are due largely to $PM_{2.5}$. The health cost per ton is higher for $PM_{2.5}$ than for the other pollutants, which accounts for the relatively large magnitude of its costs. This relatively high cost value does not indicate that tons of $PM_{2.5}$ emissions are the largest, only that the total health costs associated with $PM_{2.5}$ are the largest. See Chapter 6.6.4 for information regarding physical quantities of the pollutants.

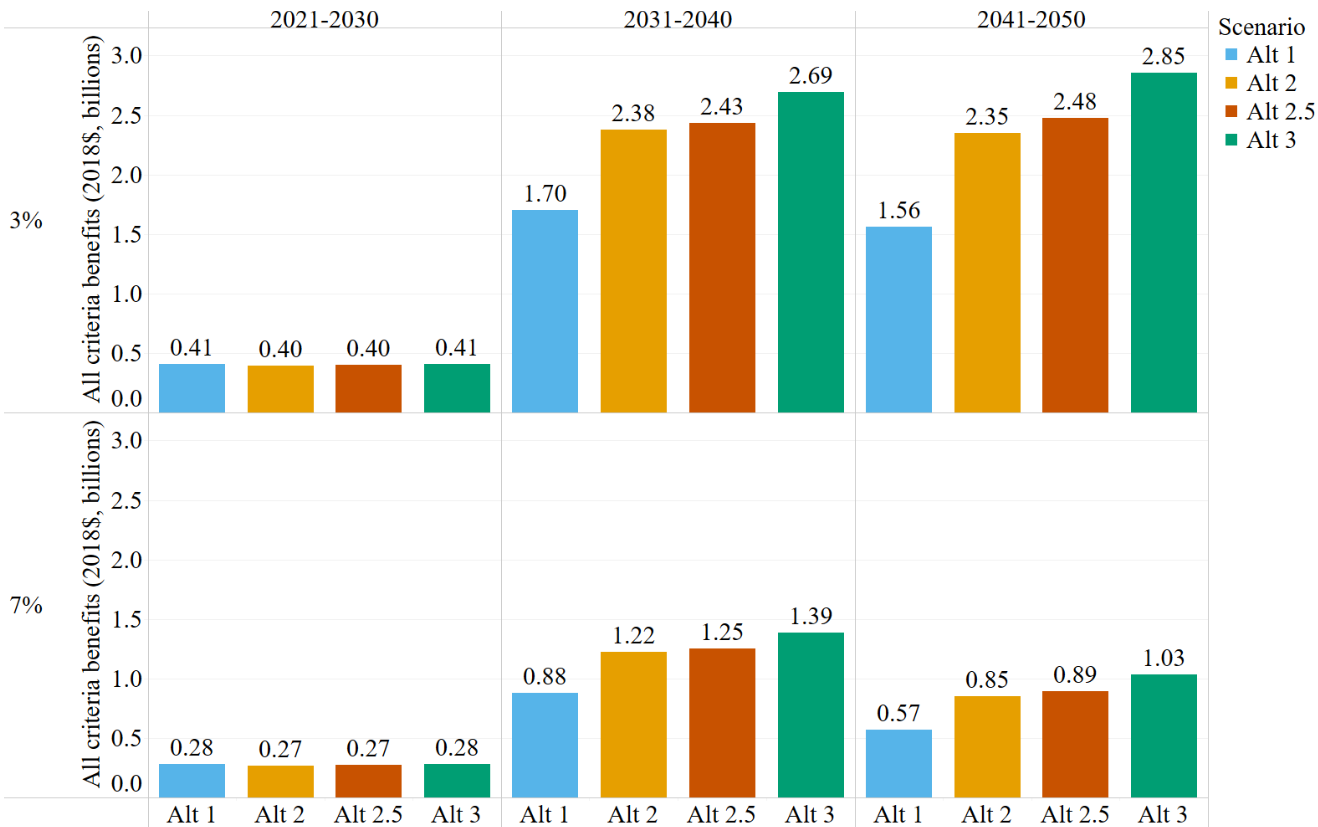


Figure 6-35 – Avoided Health Costs of Criteria Pollutants Relative to the Alternative 0 (3 and 7 percent discount rates)

Figure 6-35 illustrates the differences between alternatives and across calendar year decades, in terms of avoided criteria pollutant health costs relative to the baseline. For example, using a 3 percent discount rate, the health costs associated with criteria pollutant emissions in Alternative 1 from 2021-2030 are 0.41 billion dollars lower than the baseline totals in that decade. We treat these differences from the baseline, the avoided costs, as positive benefits. It is important to note that the incremental changes in avoided health costs are small relative to the total health costs in Alternative 0. Alternatives 1 and 2 experience the greatest incremental benefits in the period from 2031-2040, while the largest incremental benefit under Alternatives 2.5 and 3 falls under the third decade shown, 2041-2050.

These patterns indicate that while overall benefits of avoided criteria pollutant costs relative to Alternative 0 are positive, the majority of benefits occur in later years. For reference, the benefits between 2021-2030 under Alternative 1, using a 3 percent discount rate, have a value equal to approximately 0.1 percent of the total criteria pollutant costs in the baseline. On the higher end, the benefits between 2041-2050 under Alternative 3, using a 3 percent discount rate, are equal in value to about 0.7 percent of the total criteria pollutant costs in the baseline.

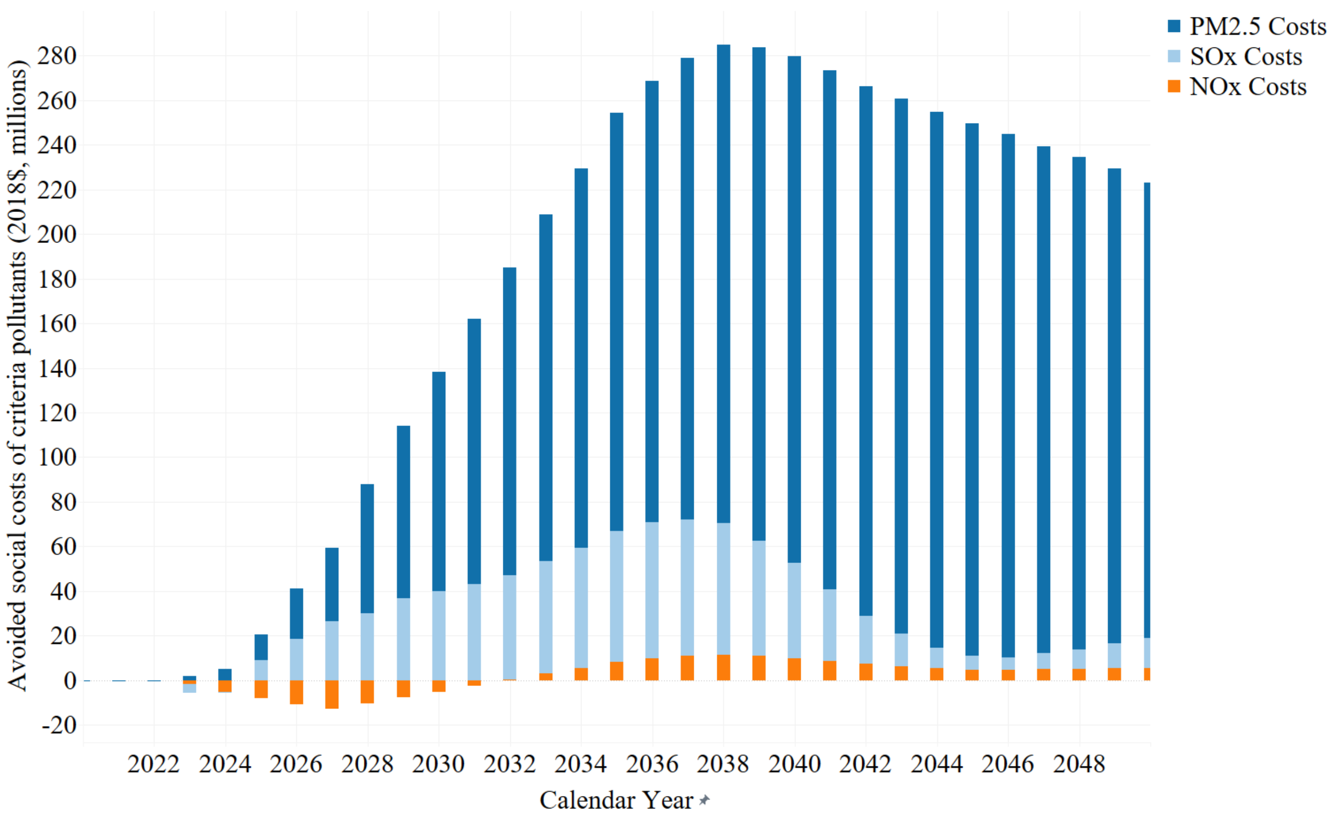


Figure 6-36 – Avoided Costs of Criteria Pollutants under Alternative 3 (3 percent discount rate)

Figure 6-36 provides an example of how benefits from avoided criteria pollutant emissions can be positive or negative when viewed from a calendar year perspective (readers should remember again that costs associated with $PM_{2.5}$ appear high due to the health effects associated with $PM_{2.5}$, rather than because emissions of $PM_{2.5}$ are themselves very high). The health damages associated with NO_X emissions decrease (improve) over time across all of the alternatives as a consequence of EPA's Tier 3 program for criteria pollutant emissions. That program sets new restrictions on NO_X emissions that ramp up from 2017-2025, which affect total emissions across the fleet as vehicles produced in those (and later) model years become the majority of the on-road population. As the fleet turns over, across all scenarios, calendar year emissions of NO_X from automobile tailpipes plummet and the incremental effects between scenarios shrink over time. For a more detailed discussion of criteria pollutant emissions, see Chapter 6.6.

6.5.3 Social Costs of Changes to Congestion and Road Noise

Table 6-7 – Incremental Social Costs of Congestion and Noise across Alternatives (2018$, in billions)

	Alternative 1		Alternative 2		Alternative 2.5		Alternative 3	
	3%	7%	3%	7%	3%	7%	3%	7%
Congestion	6.06	3.87	9.70	6.30	10.72	7.00	12.86	8.46
Noise	0.05	0.03	0.07	0.05	0.08	0.05	0.10	0.06

Table 6-7 reports the incremental social costs of congestion and noise relative to the baseline across alternatives using the model year totals from 1981-2029. Congestion and noise are functions of VMT, and the increases in these costs relate directly to increases in VMT (see Chapter 6.6.1) for each of the model years considered. For information regarding the calculation of congestion and noise costs in the CAFE Model, and how these relate to VMT and other inputs, see Chapter 6.2.3 in the accompanying TSD. Overall, the trend across alternatives consists of small and relatively steady increases in congestion and noise costs as regulatory stringency increases.

Figure 6-37 focuses on these differences in costs between the alternatives relative to the baseline, presenting them in terms of negative benefits. In this figure, noise and congestion costs are combined (due to the relatively small contribution of noise costs), and the calendar year perspective is used, showing how the negative benefits are distributed across decades. For example, in the top panel of the figure (corresponding to the 3 percent discount rate), the bar corresponding to Alternative 3 in the period from 2031-2040 represents a $17.10 billion increase in congestion and noise costs relative to the baseline totals. Most of the incremental costs (negative benefits) are incurred during the second decade, 2031-2040.

It is important to note that the incremental costs presented in Figure 6-37, even at their highest, are equal in value to a relatively small portion of the total congestion and noise costs incurred in Alternative 0. For instance, under Alternative 3, using a 3 percent discount rate, the incremental costs arising from noise and congestion between 2031-2040 were equal in magnitude to about 1.3 percent of the total congestion and noise baseline costs. On the smaller end, the additional costs incurred from congestion and noise under Alternative 1 between 2021-2030 (using a 3 percent discount rate) have a value approximately equal to 0.31 percent of the baseline congestion and noise costs.

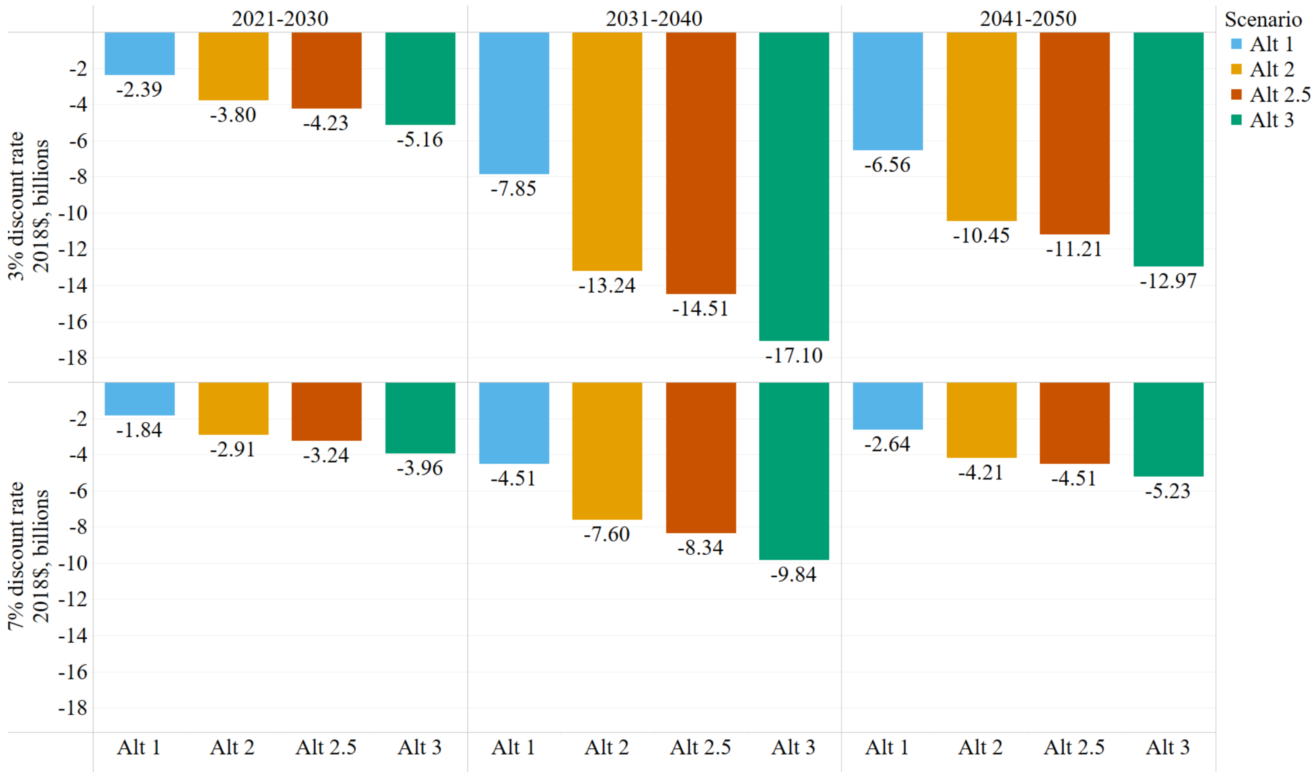


Figure 6-37 – Congestion and Noise Costs (Negative Benefits) Relative to Alternative 0 (2018$, 3 and 7 percent discount)

6.5.4 Benefits of Increased Energy Security

The CAFE Model accounts for benefits of increased energy security by computing changes in social costs of petroleum market externalities. These social costs represent the risk to the U.S. economy incurred by exposure to price shocks in the global petroleum market that are not accounted for by oil prices and are a direct function of gallons of fuel consumed. Chapter 6.2.4 in the accompanying TSD describes the inputs involved in calculating these petroleum market externality costs.

As seen in Table 6-8, social costs of petroleum market externalities decrease (or, the benefits of increased energy security increase) steadily as alternatives become more stringent. The scope of these changes is relatively small; using the 3 percent discount rate, benefits are approximately equal to 1.3 percent (in Alternative 1), 2.3 percent (in Alternative 2), 2.7 percent (in Alternative 2.5), and 3.3 percent (in Alternative 3) of the total petroleum market externality costs in the baseline.

Table 6-8 – Social Costs of Petroleum Market Externalities (2018$, billions) Using the Model Year Perspective (MY 1981-2029)

	Alternative 0 (Baseline)		Alternative 1		Alternative 2		Alternative 2.5		Alternative 3	
	3%	7%	3%	7%	3%	7%	3%	7%	3%	7%
Petroleum Market Externalities	67.5	50.3	66.7	49.8	66.0	49.4	65.8	49.3	65.3	49.0
Difference from Alternative 0	-	-	-0.89	-0.55	-1.58	-0.97	-1.77	-1.09	-2.26	-1.39

Figure 6-38 shows the distribution of these avoided costs (positive benefits) across calendar year decades. The majority of benefits accrue after the first decade, and the largest share correspond to the period between 2041-2050, when the reductions in fuel consumption are largest relative to the baseline. As the figure shows, the benefits in the last decade (2041-2050) actually decrease relative to the preceding decade across all alternatives when discounted at 7 percent, in contrast to the benefits discounted at 3 percent. This occurs because, even though the undiscounted benefits are increasing consistently over time, they are increasing slower than the 7 percent discount rate.

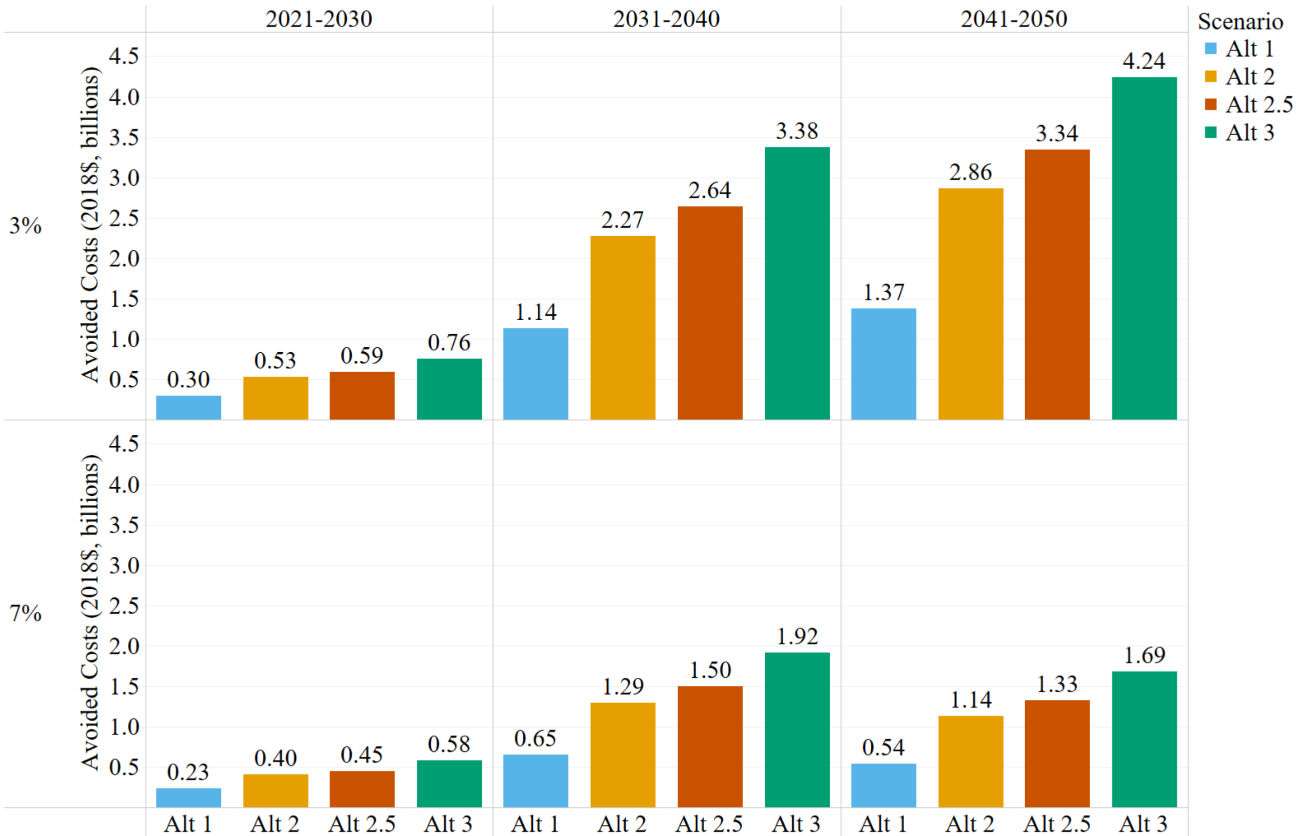


Figure 6-38 – Avoided Costs from Petroleum Market Externalities (2018$, 3 and 7 percent discount rates)

6.5.5 Safety Effects (Economic) of Changing Standards

Table 6-9 reports various safety costs across the different alternatives: fatality costs, non-fatal crash costs, and property damage crash costs, using the model year perspective.

Table 6-9 – Incremental Social Costs of Safety Impacts (2018$, billions), MY 1981-2029, by Alternative (Relative to Alternative 0)

	Alternative 1		Alternative 2		Alternative 2.5		Alternative 3	
	3%	7%	3%	7%	3%	7%	3%	7%
Fatality Costs	4.9	3.2	9.1	6.1	10.2	6.8	13.1	8.8
Non-Fatal Crash Costs	3.8	2.5	6.3	4.2	6.9	4.6	8.7	5.9
Property Damage Crash Costs	0.8	0.5	1.2	0.8	1.4	0.9	1.7	1.2

For a detailed discussion of safety effects and the different mechanisms through which they are estimated, see Chapter 5.

6.5.6 Summary of Social Benefits and Costs

Table 6-10 describes the costs and benefits of increasing CAFE standards in each alternative, as well as the party to which they accrue. Manufacturers are directly regulated under the program and incur additional production costs when they apply technology to their vehicle offerings in order to improve their fuel economy. We assume that those costs are fully passed through to new car and truck buyers, in the form of higher prices. We also assume that any civil penalties – paid by manufacturers for failing to comply with their CAFE standards – are passed through to new car and truck buyers and are included in the sales price. However, those civil penalties are paid to the U.S. Treasury, where they currently fund the general business of government. As such, they are a transfer from new vehicle buyers to all U.S. citizens, who then benefit from the additional Federal revenue. While they are calculated in the analysis, and do influence consumer decisions in the marketplace, they do not contribute to the calculation of net benefits (and are omitted from the tables below).

While incremental maintenance and repair costs would accrue to buyers of new cars and trucks affected by more stringent CAFE standards, we do not carry these costs in the analysis. They are difficult to estimate for emerging technologies, but represent real costs (and benefits in the case of alternative fuel vehicles that may require less frequent maintenance events). They may be included in future analyses as data become available to evaluate lifetime maintenance costs. This analysis assumes that drivers of new vehicles internalize 90 percent of the risk associated with increased exposure to crashes when they engage in additional travel (as a consequence of the rebound effect).

Private benefits are dominated by the value of fuel savings, which accrue to new car and truck buyers at retail fuel prices (inclusive of Federal and state taxes). In addition to saving money on fuel purchases, new vehicle buyers also benefit from the increased mobility that results from a lower cost of driving their vehicle (higher fuel economy reduces the per-mile cost of travel) and fewer refueling events. The additional travel occurs as drivers take advantage of lower operating costs to increase mobility, and this generates benefits to those drivers – equivalent to the cost of operating their vehicles to travel those miles, the consumer surplus, and the offsetting benefit that represents 90 percent of the additional safety risk from travel.

In addition to private benefits and costs—those borne by manufacturers, buyers, and owners of cars and light trucks—there are other benefits and costs from increasing CAFE standards that are borne more broadly throughout the economy or society, which the agency refers to as external costs.[122] Of these external costs, the largest is the loss in fuel tax revenue that occurs as a result of falling fuel consumption.[123] Buyers of new cars and light trucks produced in model years subject to increasing CAFE standards save on fuel purchases that include Federal, state, and sometimes local taxes, so revenues from these taxes decline; because that revenue funds maintenance of roads and bridges as well as other government activities, the loss in fuel tax

[122] Some of these external benefits and costs result from changes in economic and environmental externalities from supplying or consuming fuel, while others do not involve changes in such externalities but are similar in that they are borne by parties other than those whose actions impose them.
[123] Changes in tax revenues are a transfer and not an economic externality as traditionally defined, but we group these with social costs instead of private costs since that loss in revenue affects society as a whole as opposed to impacting only consumers or manufacturers.

revenue represents a social cost.[124] The additional driving that occurs as new vehicle buyers take advantage of lower per-mile fuel costs is a benefit to those drivers, but the congestion (and road noise) created by the additional travel also imposes a small additional social cost to all road users.

Among the purely external benefits created when CAFE standards are increased, the largest is the reduction in damages resulting from GHG emissions. Table 6-10 shows the different social cost results that correspond to each GHG discount rate. The associated benefits related to reduced health damages from criteria pollutants and the benefit of improved energy security are both significantly smaller than the associated change in GHG damages across alternatives. As the tables also illustrate, the overwhelming majority of both costs and benefits are private costs and benefits that accrue to buyers of new cars and trucks, rather than external welfare changes that affect society more generally (with the exception of the 95th percentile SC-GHG case). This has been consistently true in CAFE rulemakings.

The choice of GHG discount rate also affects the resulting benefits and costs. As the tables show, net social benefits are positive for all alternatives when SC-GHG discount rates of 2.5 or 3 percent are used, but are negative under Alternatives 2, 2.5 and 3 when the 5 percent SC-GHG discount rate is applied. Totals in the following table may not sum perfectly due to rounding.

Table 6-10 – Incremental Benefits and Costs Over the Lifetimes of Total Fleet Produced Through 2029 (2018$ Billions), by Alternative

	3% Discount Rate				7% Discount Rate			
	Alt. 1	**Alt. 2**	**Alt 2.5**	**Alt. 3**	**Alt. 1**	**Alt. 2**	**Alt 2.5**	**Alt. 3**
Private Costs								
Technology Costs to Increase Fuel Economy	31.7	67.4	76.4	100.2	25.8	54.7	62.0	81.4
Increased Maintenance and Repair Costs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sacrifice in Other Vehicle Attributes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Consumer Surplus Loss from Reduced New Vehicle Sales	0.0	0.2	0.3	0.5	0.0	0.2	0.2	0.4
Safety Costs Internalized by Drivers	5.0	7.9	8.7	10.7	3.0	4.8	5.3	6.5
Subtotal - Private Costs	36.7	75.4	85.4	111.4	28.8	59.6	67.5	88.2
Social Costs								
Congestion and Noise Costs from Rebound-Effect Driving	6.1	9.8	10.8	13.0	3.9	6.3	7.1	8.5
Safety Costs Not Internalized by Drivers	4.5	8.8	9.7	12.8	3.1	6.3	7.1	9.4
Loss in Fuel Tax Revenue	11.3	20.0	22.4	28.6	7.2	12.7	14.2	18.1
Subtotal - Social Costs	21.9	38.5	43	54.4	14.2	25.3	28.3	36.0
Total Social Costs	58.6	113.9	128.4	165.8	43.0	84.9	95.8	124.3

[124] It may subsequently be replaced by another source of revenue, but that is beyond the scope of this rulemaking to examine.

Private Benefits								
Reduced Fuel Costs	52.5	88.1	98.2	123.5	32.7	54.7	61	76.7
Benefits from Additional Driving	9.9	14.9	16.4	19.8	6.0	9.1	10	12.1
Less Frequent Refueling	0.3	-1.3	-0.8	0.1	0.1	-0.9	-0.6	-0.1
Subtotal - Private Benefits	62.7	101.7	113.8	143.4	38.8	62.9	70.3	88.8
External Benefits								
Reduction in Petroleum Market Externality	0.9	1.6	1.8	2.3	0.5	1.0	1.1	1.4
Reduced Health Damages	1.2	1.5	1.5	1.7	0.7	0.8	0.8	0.9
Reduced Climate Damages								
SC-GHG @ 5% DR[125]	3.7	6.3	7.1	8.9	3.7	6.3	7.1	8.9
SC-GHG @ 3% DR	14.4	24.6	27.5	34.8	14.4	24.6	27.5	34.8
SC-GHG @ 2.5% DR	21.9	37.4	41.8	52.9	21.9	37.4	41.8	52.9
SC-GHG @ 95th pctile at 3% DR	43.6	74.4	83.2	105.1	43.6	74.4	83.2	105.1
Total Social Benefits								
SC-GHG @ 5% DR	68.5	111.1	124.2	156.4	43.8	71.0	79.3	100.0
SC-GHG @ 3% DR	79.2	129.4	144.6	182.2	54.5	89.3	99.7	125.8
SC-GHG @ 2.5% DR	86.7	142.2	158.9	200.3	62.0	102.1	114.1	143.9
SC-GHG @95th pctile at 3% DR	108.4	179.2	200.3	252.5	83.6	139.0	155.4	196.1
Net Social Benefits								
SC-GHG @ 5% DR	9.9	-2.8	-4.2	-9.4	0.8	-13.9	-16.5	-24.3
SC-GHG @ 3% DR	20.6	15.5	16.3	16.4	11.5	4.3	3.9	1.5
SC-GHG @ 2.5% DR	28.1	28.3	30.6	34.5	19.0	17.2	18.3	19.6
SC-GHG @ 95th pctile at 3% DR	49.8	65.2	71.9	86.7	40.6	54.1	59.6	71.8

6.6 Physical and Environmental Effects

Since improvements in vehicle fuel economy typically adds cost to those vehicles, and since added cost often results in higher prices, the sale of new vehicle models may be impacted as consumers prefer to hold on to their existing vehicles for longer if they perceive that the value of fuel savings is less than the increase in purchase price. Additionally, as the older fleet is gradually phased out, a smaller or larger portion may be supplanted by newer models, depending on how car buyers perceive the value of fuel savings relative to the increased cost. Over time, a cumulative change in new vehicle sales would change the annual growth of the overall on-road fleet. Because we assume that consumers value fuel savings over the life of a vehicle as equal to the first 30 months of undiscounted fuel savings, we analyze higher CAFE standards exemplified by the action alternatives as leading to a reduction to the on-road vehicle fleet when compared to the baseline scenario (the No-Action Alternative). Concurrently, increasing fuel economy is assumed to decrease the overall consumption of various fuel sources (and also reduce emissions of CO_2, the primary GHG released during vehicle operation), while also reducing the fuel cost-per-mile of driving, which would increase total demand for travel. As a consequence of reduced

[125] DR = Discount rate.

overall fuel consumption, the on-road fleet also generates fewer emissions resulting from criteria air pollutants. This, in turn, leads to a reduction in adverse health incidents caused by exposure to these pollutants.

The following table and figure demonstrate the cumulative impacts over the next three decades for all alternatives. As can be seen from Table 6-11 and Figure 6-39, the differences in the on-road fleet and VMT between alternatives are marginal; however, the differences in the amount of aggregate fuel consumed and CO_2 emitted are more pronounced in the latter two decades.

Table 6-11 – Cumulative Impacts for All Alternatives

	Alternative 0	Alternative 1	Alternative 2	Alternative 2.5	Alternative 3
*On-Road Fleet (Million Units)*2021-2030	2,545	2,545	2,545	2,545	2,545
2031-2040	2,671	2,667	2,661	2,660	2,656
2041-2050	2,706	2,703	2,697	2,696	2,693
Vehicle Miles Traveled (Billion Miles)					
2021-2030	31,655	31,679	31,692	31,696	31,705
2031-2040	33,390	33,487	33,552	33,567	33,600
2041-205033,174	33,284	33,347	33,360	33,390	
Fuel Consumption (Billion Gallons/GGE)					
2021-2030	1,269	1,260	1,253	1,251	1,246
2031-2040	1,142	1,106	1,073	1,063	1,042
2041-2050	1,021	973	927	913	885
CO_2 Emissions (mmT)					
2021-2030	14,025	13,922	13,851	13,831	13,778
2031-2040	12,594	12,195	11,828	11,713	11,483
2041-2050	11,233	10,706	10,188	10,027	9,716

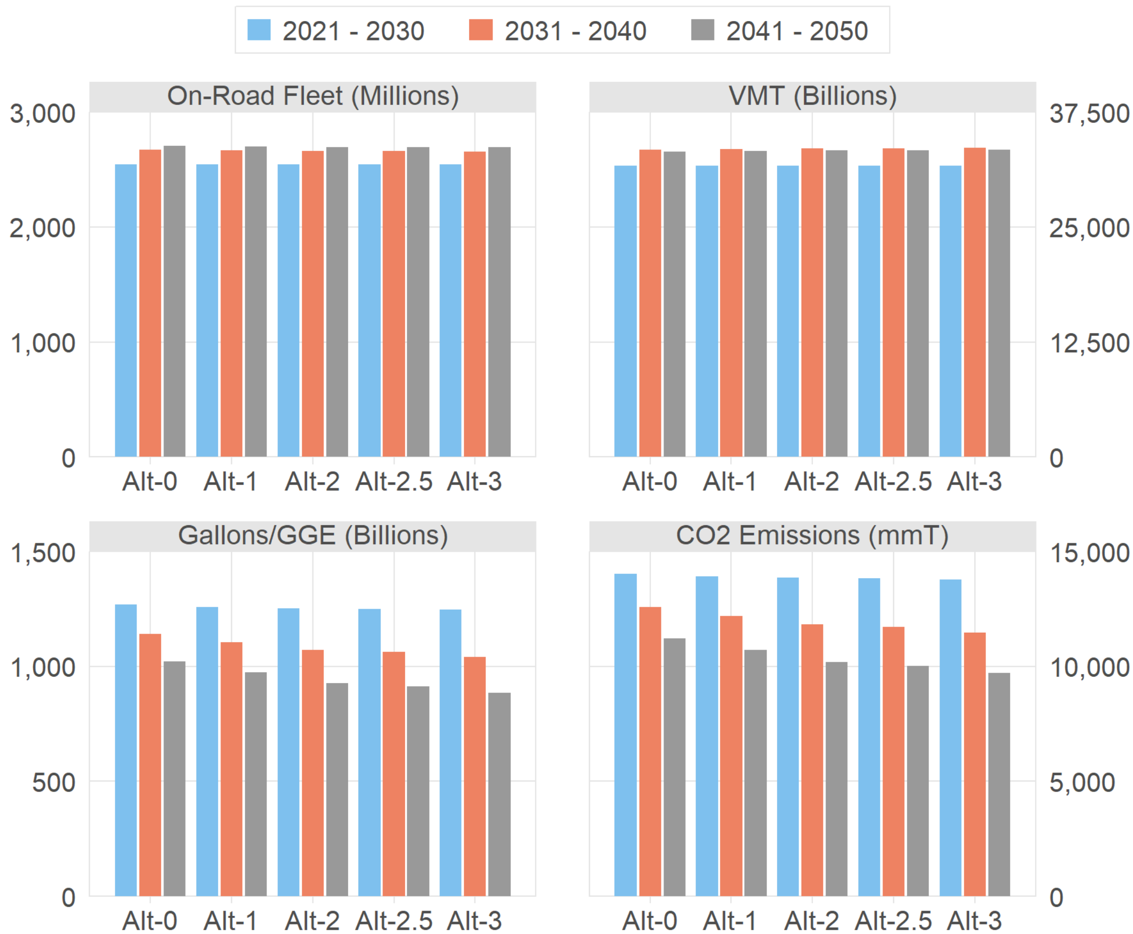


Figure 6-39 – Cumulative Impacts for All Alternatives

The sections that follow provide additional detail of the aforementioned effects, while comparing the outcomes of the action and No-Action Alternatives.

6.6.1 Changes to On-Road Fleet and Vehicle Miles Traveled

The CAFE Model simulates the response of the increasing vehicle prices and fuel economy on the sale of new vehicle models as well as the ancillary impacts these changes pose to the existing vehicle fleet. As CAFE standards become more stringent, the cost of new vehicles is expected to rise, which would cause a decline in new vehicle sales if consumers perceived that the present value of fuel savings did not justify the increase in price. In such a case, over time, this would extend to an overall slowing in the growth of the on-road fleet. Conversely, introducing more fuel-efficient options into the vehicle population is assumed to have an opposite effect on the amount of miles traveled, marginally increasing the total VMT as the cost of travel becomes cheaper.

Figure 6-40 presents the size of the on-road fleet through 2050 under the No-Action Alternative. The vertical bars in the figure denote the annual progression of the passenger car and light truck fleets independently, while the evolution of the combined fleet is depicted by the gray line. As demonstrated by Figure 6-40, the overall fleet continues to grow at a steady pace throughout the analysis (though slowing significantly in the out years), with the passenger car and light truck shares being roughly the same. During the middle set of years (between 2025 and 2040), the on-road truck fleet undergoes faster growth, overtaking the passenger car vehicles by a small margin; however, the car fleet eventually catches up in the later years.

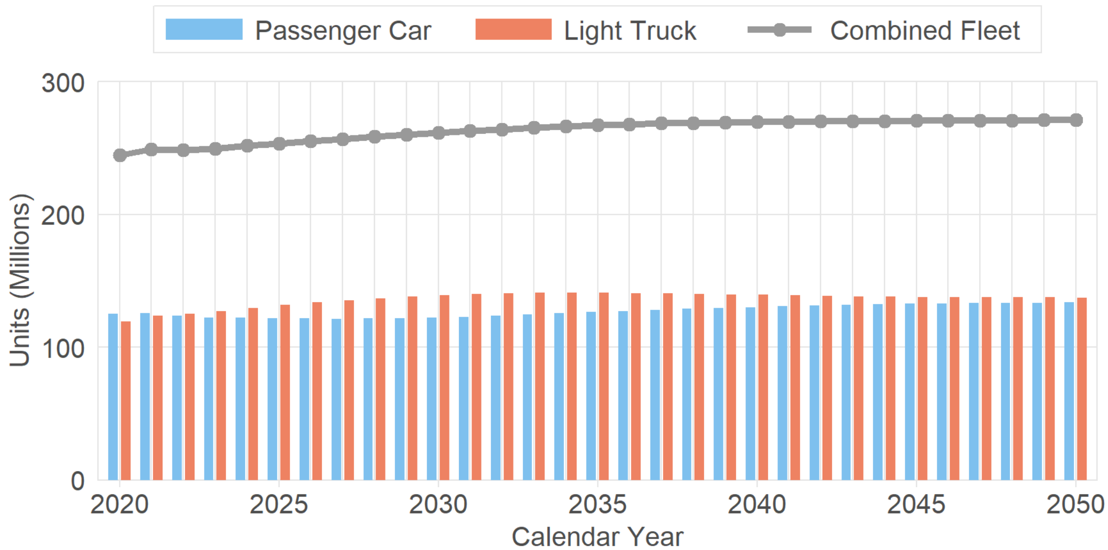


Figure 6-40 – Total On-Road Fleet in the Baseline Scenario

At the onset of analysis for this rulemaking (in MY 2020), the production of light trucks (7.66m units) exceeds that of passenger cars (5.93m units) by about 30 percent. Throughout analysis of the No-Action Alternative, however, as both fleets get progressively more efficient (albeit by less than under the action alternatives), the volume of trucks sold generally declines in response to higher fuel prices. Meanwhile, passenger cars see a sharp rise early on, followed by a plateauing in the amount of units produced and sold in the mid to out years. The initial surplus of truck sales leads to an eventual shift of the on-road fleet from cars to trucks in the middle set of years, as aging vehicles are retired in favor of newer models. However, the subsequent decrease in the production of new light truck models, coupled with the gains realized by the passenger car fleet, results in the on-road fleet gradually shifting some of the volume back to passenger cars. The outcome of this behavior is visualized by Figure 6-40.

Along with the annual growth experienced by the on-road fleet in the No-Action Alternative, the total amount of VMT also increases steadily year over year, as illustrated in Figure 6-41. Around CY 2040, however, the total fleet-wide VMT peaks, and begins a marginal annual descent. The VMT for both passenger car and light truck fleets follows a similar pattern of growth, which was observed for the on-road fleet. The share of miles traveled by the car and truck fleets is roughly the same throughout the years, with trucks showing a stronger presence on the road in the mid years, while passenger cars regain ground in the latter ones.

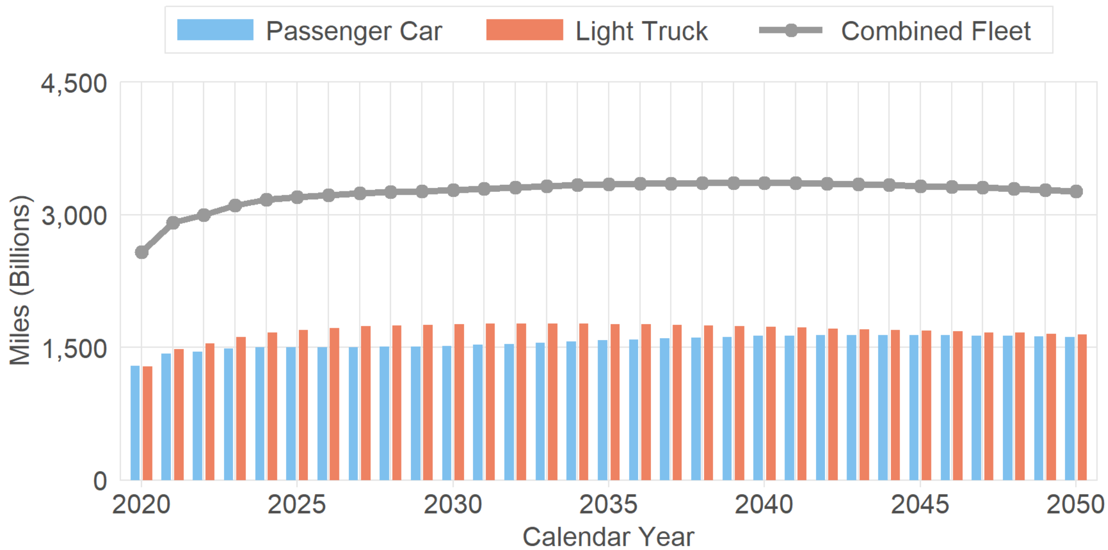


Figure 6-41 – Total VMT in the Baseline Scenario

With the increases in stringency that the action alternatives represent, the number of new vehicles produced and sold during future model years declines slightly as compared to the No-Action Alternative. As with the No-Action Alternative, this reduction generally translates to the cumulative decrease of the on-road population of the combined fleet in most calendar years, as can be seen in Figure 6-42. This figure presents the incremental differences, as compared to the baseline scenario (the No-Action Alternative), for each action alternative evaluated as part of this rulemaking. From this figure, higher CAFE standards, as defined for Alternative 3, lead to a greater reduction of the volume of the on-road fleet as compared to the alternatives with smaller increases of the standards.

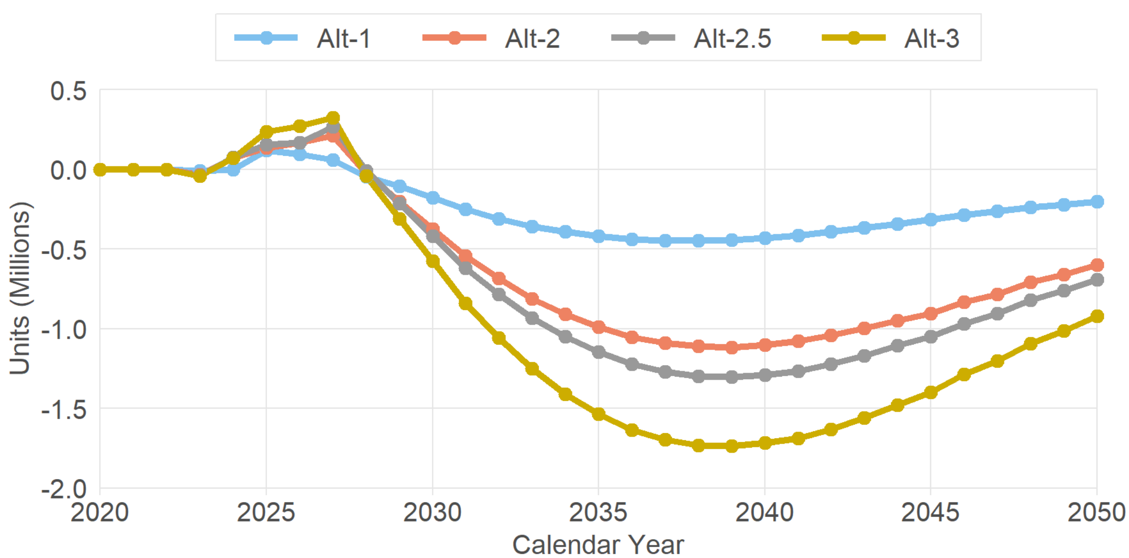


Figure 6-42 – Changes in On-Road Fleet Compared to Baseline (Combined Fleet)

When considering the on-road population of the individual fleets, however, more stringent standards slightly decrease the volume of the passenger car fleet, while also slightly increasing the amount of light trucks on the road, as compared to the No-Action Alternative. Incremental improvements from fuel consumption-improving technologies typically have a greater impact on vehicles that begin with lower fuel economy ratings, as they are able to achieve a greater reduction in the consumption of fuel, than what would have been possible by their higher rated counterparts. Thus, the volume of light trucks is more likely to be impacted by pushing the CAFE standards beyond the baseline level, since the decreases in the cost of travel for the truck fleet are marginally better than for the car fleet. Figure 6-43 and Figure 6-44 show the incremental on-road fleet differences for each alternative over the baseline scenario.

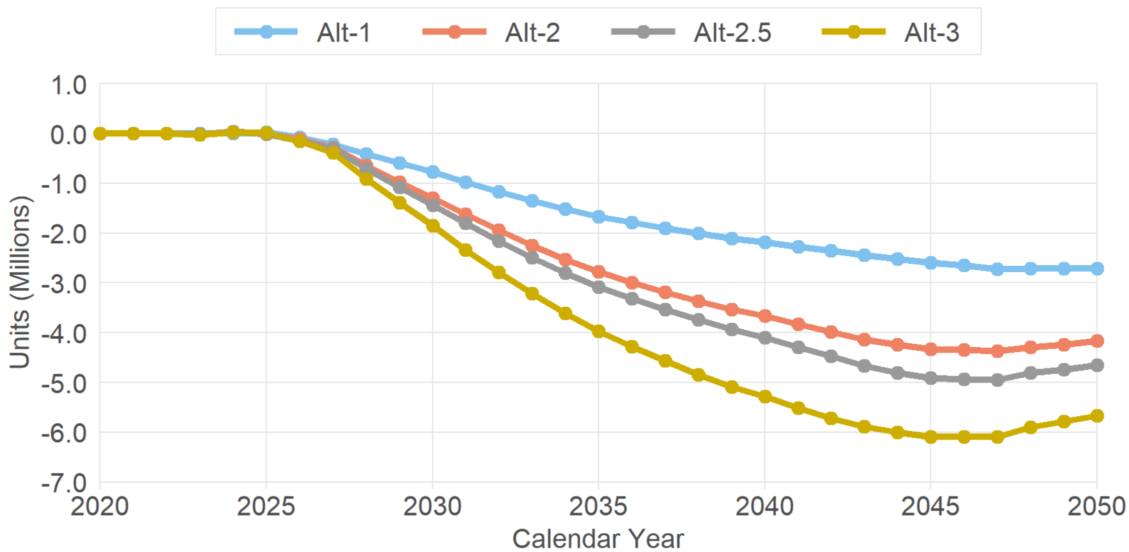


Figure 6-43 – Changes in On-Road Fleet Compared to Baseline (Passenger Car Fleet)

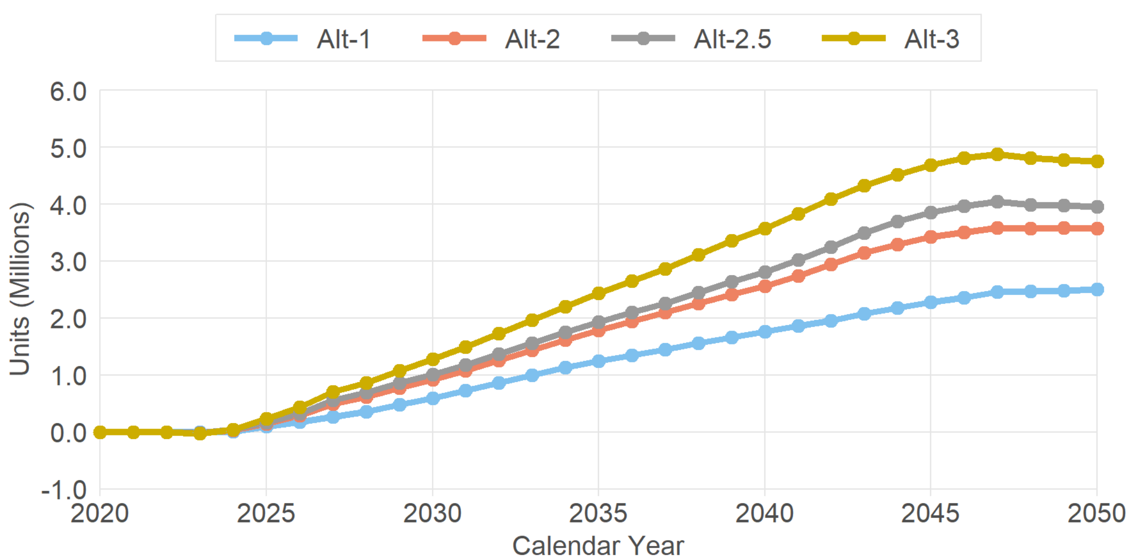


Figure 6-44 – Changes in On-Road Fleet Compared to Baseline (Light Truck Fleet)

While the volume of the on-road fleet decreases slightly as a consequence of the new CAFE standards defined by the action alternatives, the amount of total miles traveled by the entire fleet grows slightly when compared to the No-Action Alternative. The VMT increases, which are attributable to the fuel economy rebound effect, result in an overall greater demand for travel, as the average cost-per-mile reduces. Figure 6-45 illustrates the incremental differences for each calendar year between the action alternatives and the baseline scenario.

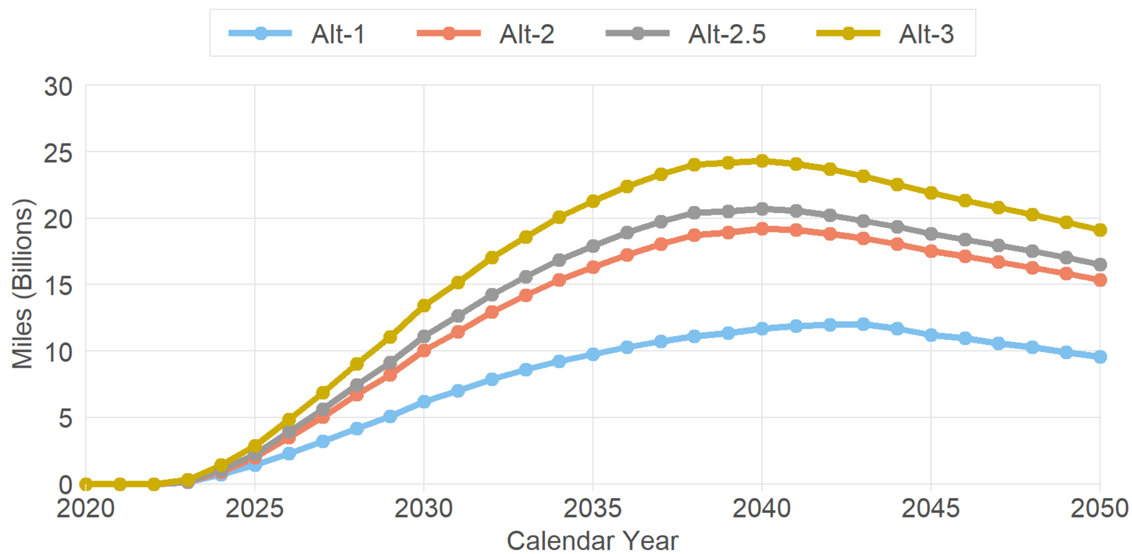


Figure 6-45 – Changes in VMT Compared to Baseline (Combined Fleet)

Although the rebound effect increases VMT for the entire fleet, the decline of the passenger car population in the action alternatives is not enough to offset the greater travel demand ascribed to each individual vehicle. Hence, the car fleet sees a marginal reduction in the total amount of miles traveled against the No-Action Alternative, as shown in Figure 6-46. In contrast, the higher volume of light trucks as compared to the baseline, along with their increases in fuel economy, result in the truck fleet contributing a greater portion of total on-road miles, as presented by Figure 6-47.

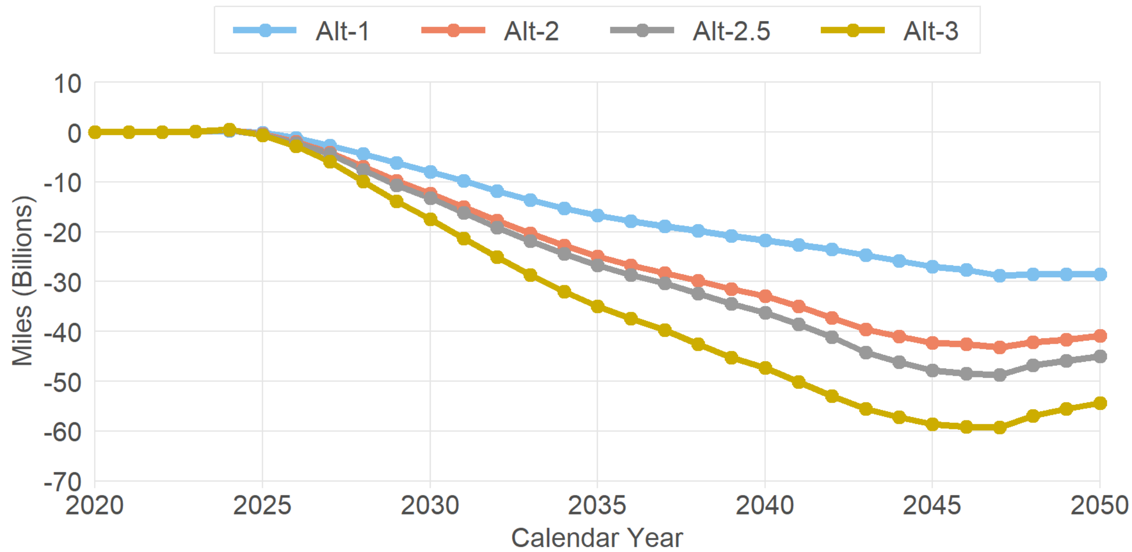


Figure 6-46 – Changes in VMT Compared to Baseline (Passenger Car Fleet)

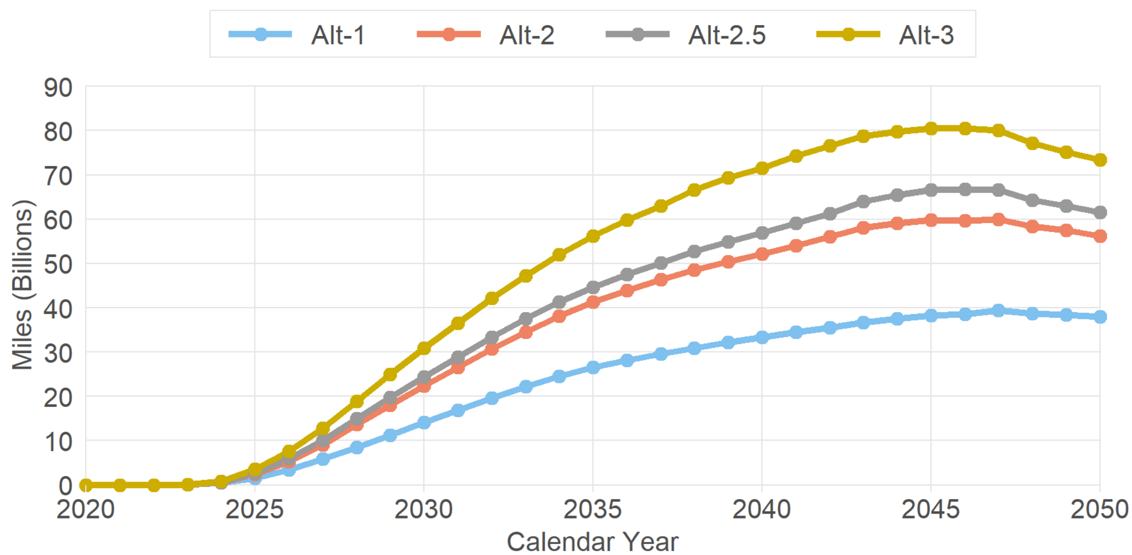


Figure 6-47 – Changes in VMT Compared to Baseline (Light Truck Fleet)

6.6.2 Changes to Fuel Consumption and Impacts on Emissions of Greenhouse Gases

Increases in CAFE standards reduce the total amount of fuel consumed, as more fuel-efficient vehicles enter the market, displacing the older and less efficient models. With the aging fleet gradually turning over with each subsequent calendar year, the benefits of higher standards enforced during earlier model years become even more apparent, as the annual fuel consumption of the U.S. passenger vehicle fleet declines further. Moreover, with the rise of alternative fuel vehicles, specifically PHEVs and BEVs, the use of gasoline within the light-duty fleet is slowly supplanted by electricity. Figure 6-48 presents the consumption of various fuel types in each calendar year for the No-Action Alternative. In Figure 6-48, the consumption of gasoline, E85, and diesel are denominated in gallons of the native fuel (e.g., gallons of E85), while electricity and hydrogen are specified as gasoline gallon equivalent (GGE).

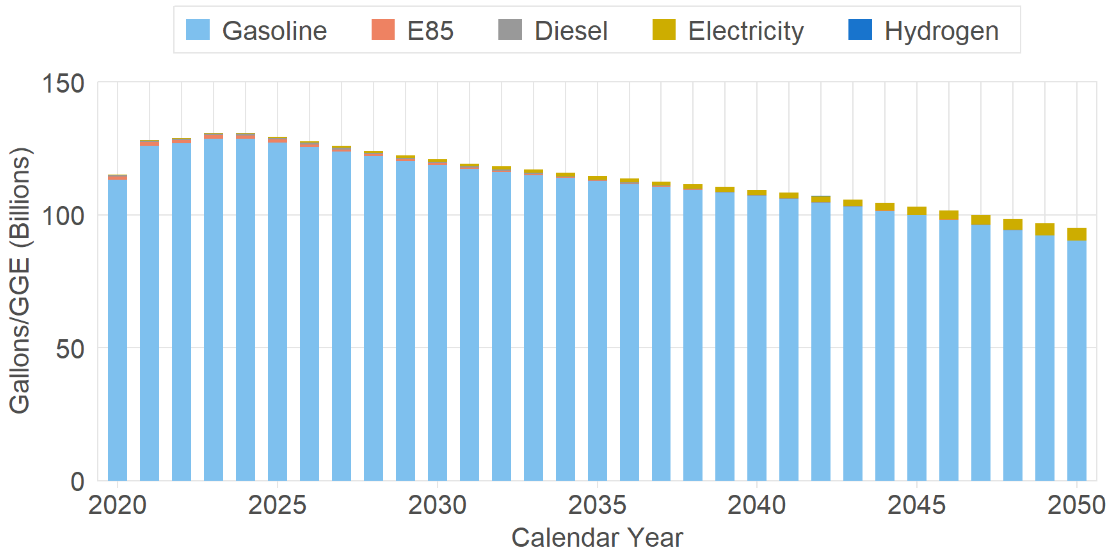
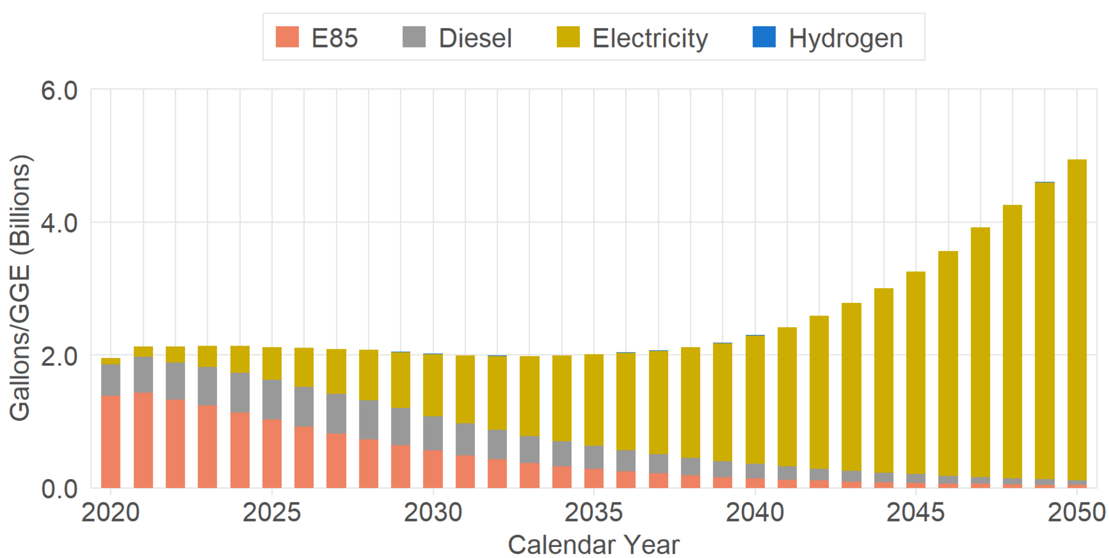


Figure 6-48 – Fuel Consumption in the Baseline Scenario

As illustrated by Figure 6-48, gasoline remains the predominant source of fuel into the future under the No-Action Alternative. Meanwhile, the collective sum of all the other fuel types used by the on-road fleet is only a fraction of the total energy consumed during each calendar year.[126] Hence, most of fuel-related savings are attainable through the reduction of gasoline use. However, as shown in Figure 6-49, electricity has the strongest annual growth among the non-gasoline fuels. Over the same timeframe, the use of E85 and diesel steadily declines.



[126] By CY 2050, the total amount of non-gasoline fuel consumed by the on-road fleet reaches 5.2 percent in the No-Action Alternative.

Figure 6-49 – Consumption of Non-Gasoline Fuels in the Baseline Scenario

Since consumption of fuel by the fleet directly releases CO_2, reducing overall energy consumption also reduces emissions of CO_2. Equally, emissions attributed to the other GHGs – CH_4 and N_2O – see an annual decline as well. Figure 6-50 displays the amount of annual GHG emissions generated by the light-duty fleet under the standards defined by the No-Action Alternative. In the figure, the emissions of CO_2, CH_4, and N_2O are combined and presented using a cumulative total. The amount of CO_2 is measured using million metric tons (mmT), while emissions coming from CH_4 and N_2O are scaled by the l GWP multipliers of 25 and 298 respectively,[127] and are denominated using mmT of CO_2 equivalent emissions. However, CO_2 remains the predominant contributor of GHGs, making up approximately 84 percent of total GHG upstream emissions and 99.6 percent of GHG tailpipe emissions.[128] As shown in Figure 6-50, the upstream emissions, which are attributed to the production and distribution of various types of fuel, stay at a mostly constant level throughout the years, with only a mild amount of fluctuation. The downstream emissions, which occur during vehicle operation, see a declining trend similar to what was observed for the overall annual consumption of fuel.

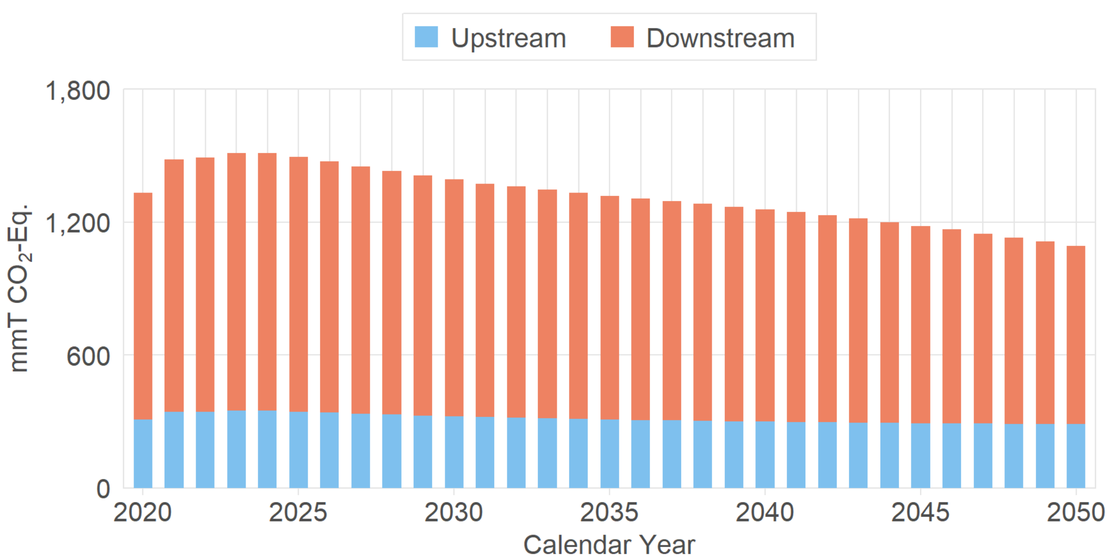


Figure 6-50 – Emissions of GHG in the Baseline Scenario

Fleet-wide fuel consumption and GHG emissions continue to decline further under the action alternatives in response to higher CAFE standards. Figure 6-51 presents the incremental differences to overall energy consumption, as compared to the baseline scenario, for each action alternative. As shown in the figure, the outcome of the progressively increasing stringency

[127] GWP multipliers here are derived from the 4th IPCC Report; NHTSA is aware that the 5th IPCC report changes these values slightly, but tentatively concludes that the difference is not meaningful for purposes of Figure 6-13. NHTSA calculates emissions of CH_4 and N_2O directly in terms of tons emitted for benefits purposes.

[128] Depending on calendar year being considered, the CO_2 share of GHG upstream emissions varies by about 1 percent, while the share of tailpipe emissions varies by about 0.2 percent.

defined by each action alternative is greater reductions in the amount of fuel consumed by the on-road light-duty fleet.

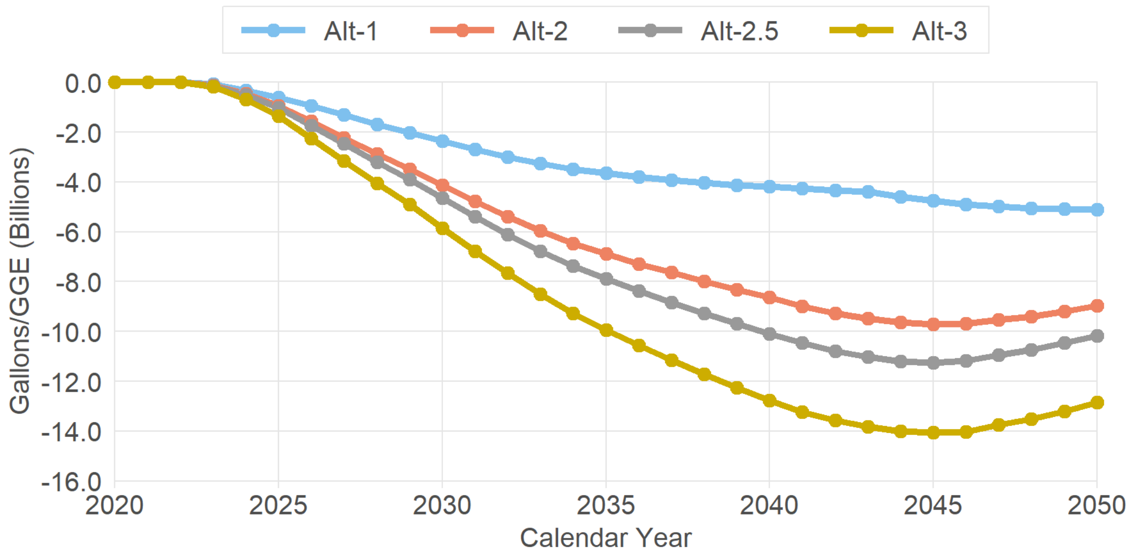


Figure 6-51 – Changes in Fuel Consumption Compared to Baseline

As was the case under the No-Action Alternative, gasoline remains the dominant source of fuel for the light-duty fleet in all calendar years, and for all action alternatives. However, with more stringent standards, gasoline consumption falls by larger margins, while the annual use of electricity increases further. Figure 6-52 separates and presents the incremental changes of gasoline and electricity use, as those had the largest observable difference over the baseline. The differences observed between the action and the No-Action Alternatives for all other fuels were inconsequential, and are hence omitted from the figure.

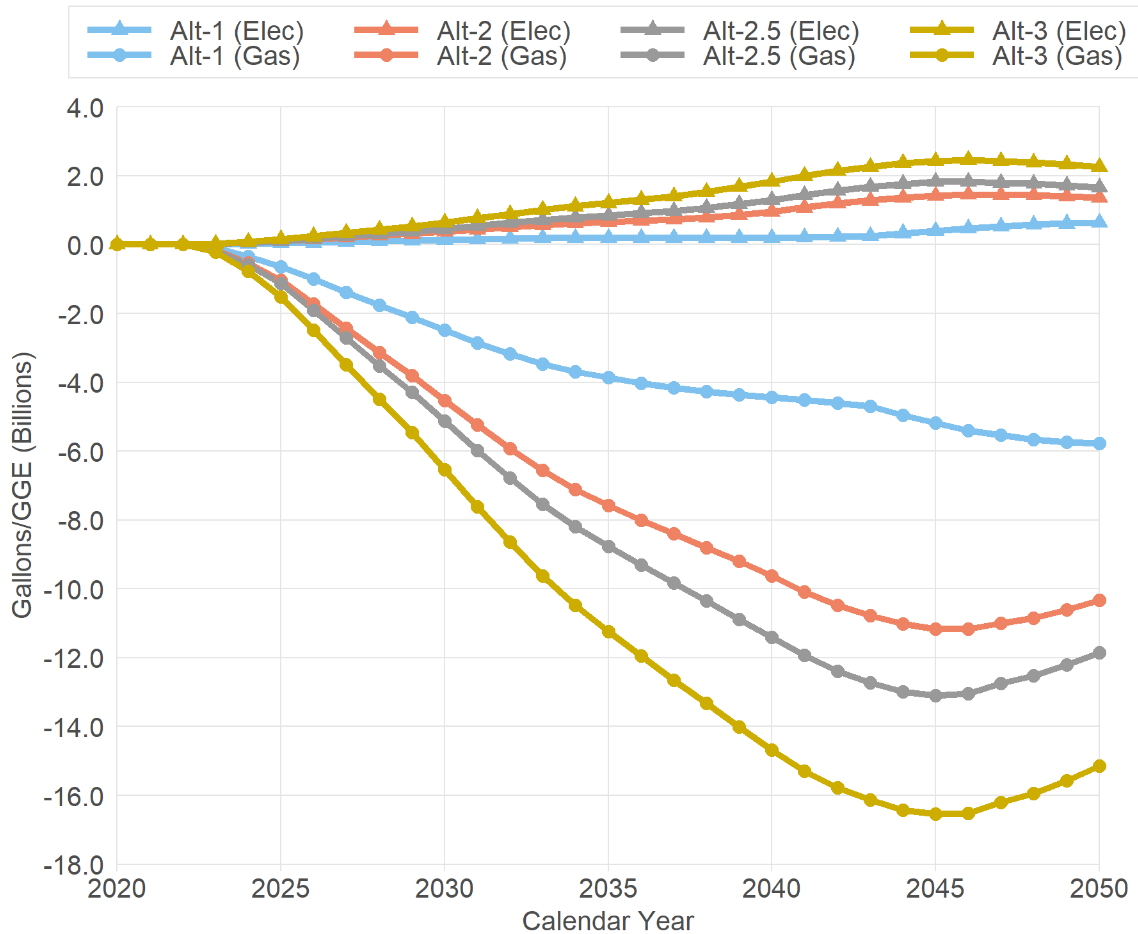


Figure 6-52 – Changes in Gasoline and Electricity Consumption Compared to Baseline by Fuel Type

Along with the reduction of fuel use, the GHG emissions generated by the on-road fleet also decline in each action alternative. As shown in Figure 6-53, the incremental emissions of GHGs decrease at a greater rate as the standards defined by the action alternatives increase in stringency.

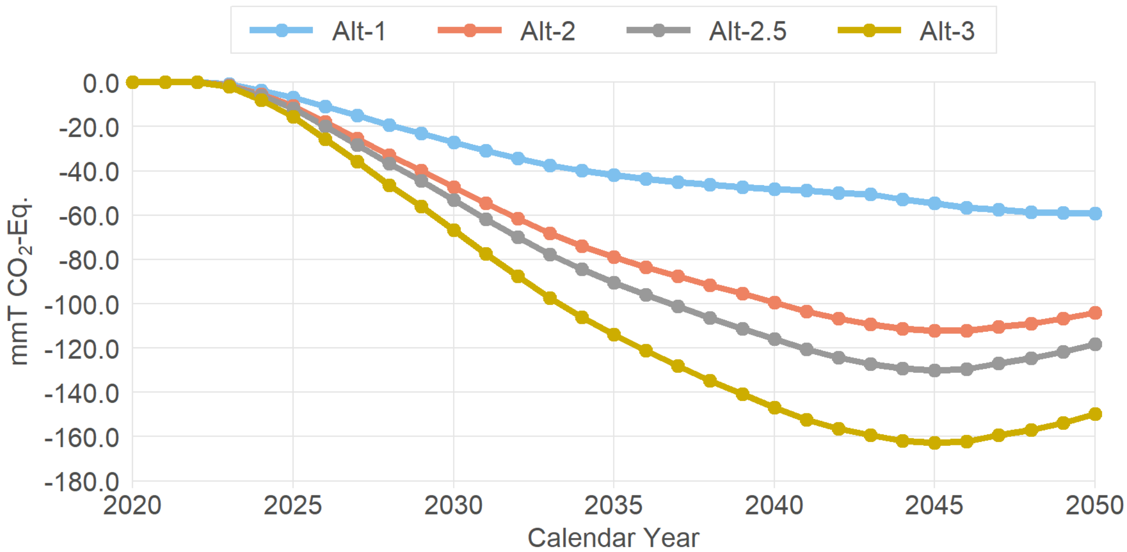


Figure 6-53 – Changes in Total GHG Emissions Compared to Baseline

Figure 6-54 presents the incremental upstream emissions of GHG as compared to the No-Action Alternative. As with the total emissions of GHG, upstream GHG emissions decline with more stringent alternatives. However, the behavior in this rulemaking contrasts with what was observed for the NPRM. For the NPRM, the more stringent alternatives exhibited significantly lower reduction of upstream GHG compared to the baseline, while also being surpassed by Alternative 1 (in the amount of GHG reduced).

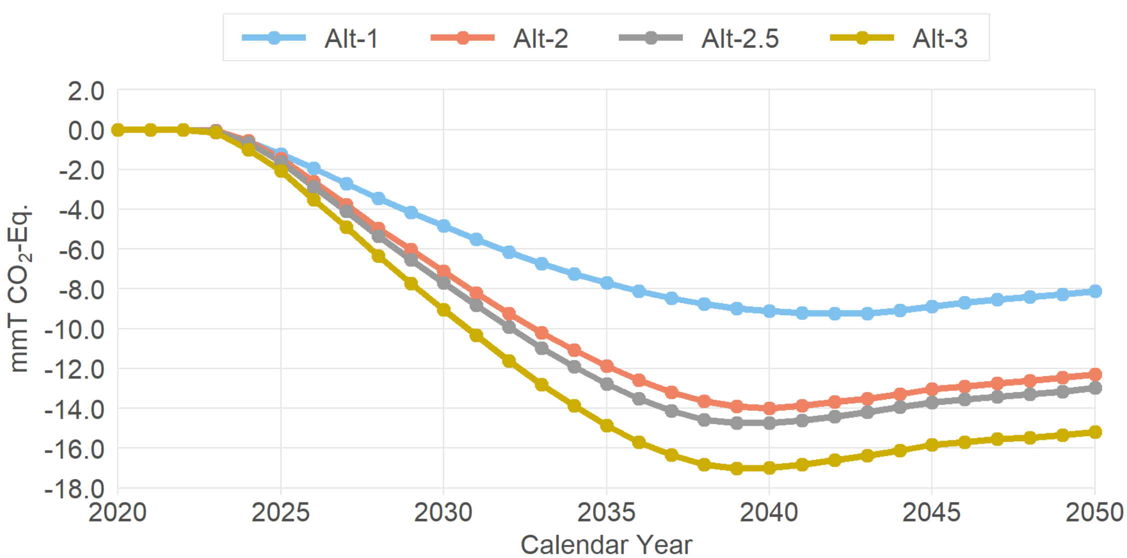


Figure 6-54 – Changes in Upstream GHG Emissions Compared to Baseline

The differences in upstream GHG emissions between the NPRM and final rule occur because: (1) the consumption of electricity for each alternative declined somewhat under the current analysis as compared to the NPRM analysis; and (2) the current analysis uses an updated version of the GREET model, which estimates a 5-10 percent lower amount of CO_2 emitted during generation of electricity than what was used during the NPRM. Nevertheless, according to GREET, the amount of GHGs, in particular CO_2, emitted during electricity generation still remains significantly higher on average than emissions that occur due to production and distribution of gasoline.[129]

Figure 6-55 displays the incremental GHG upstream emissions for gasoline and electricity for each action alternative. As with fuel consumption, the other fuel types do not differ meaningfully here, and are therefore omitted. As shown in the figure, the increases in electricity emissions are comparatively more significant than decreases in gasoline emissions during the mid-to-end years. However, the downward trend in electricity emissions appearing in the last few years for Alternatives 2, 2.5, and 3 are simply the effect of the baseline catching up with its own electricity use (see Figure 6-49) and diminishing the incremental impacts from these three alternatives. Conversely, the annual rise in consumption of electricity for Alternative 1 follows closer in line with the baseline, therefore forgoing the downward trend seen for the other alternatives.

[129] Readers should note that this sentence refers only to *upstream* emissions, not to *total* emissions.

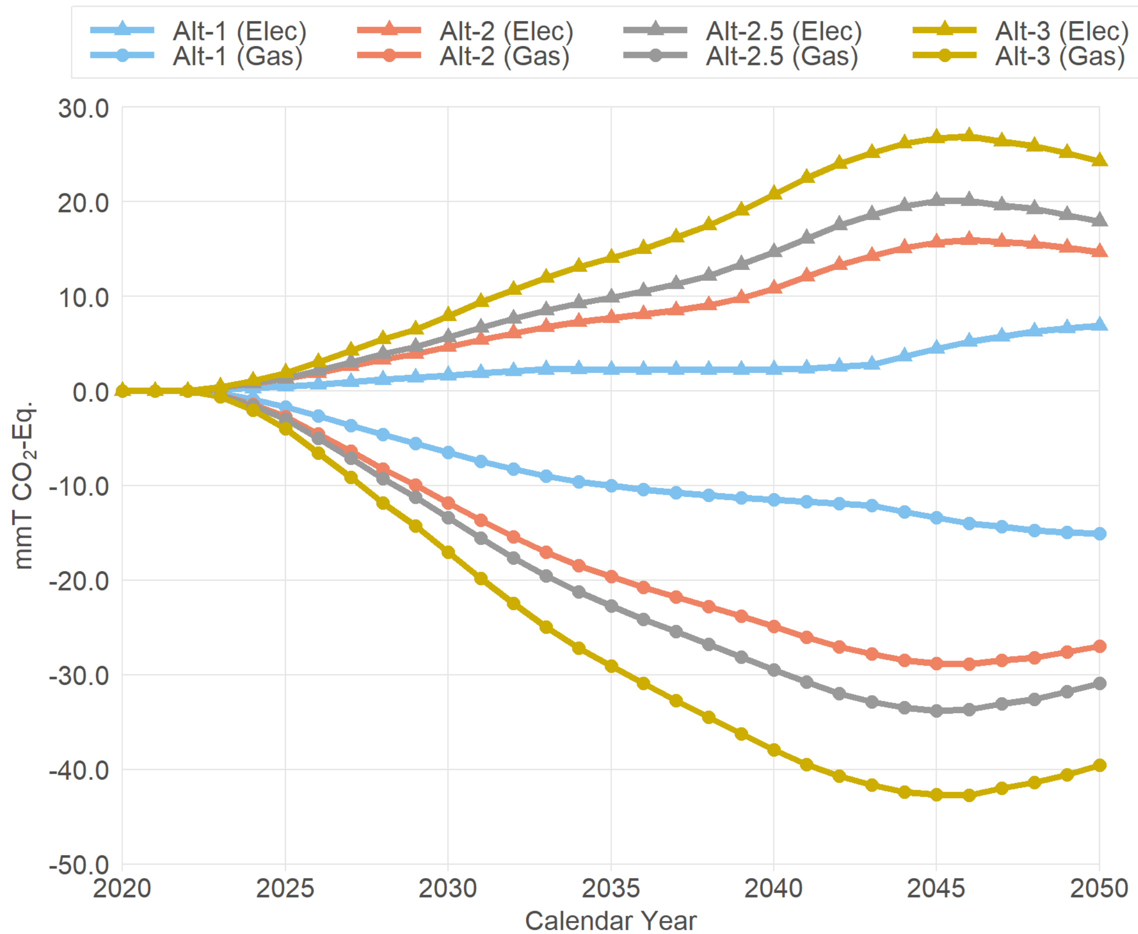


Figure 6-55 – Changes in Upstream Gasoline and Electricity GHG Emissions Compared to Baseline

The incremental differences in downstream GHG emissions between the action alternatives and the baseline follow a similar trend to the total and upstream counterparts, as demonstrated by Figure 6-56. The highest CAFE standards, defined by Alternative 3, lead to the greatest reduction of downstream emissions of GHG occurring during vehicle operation.

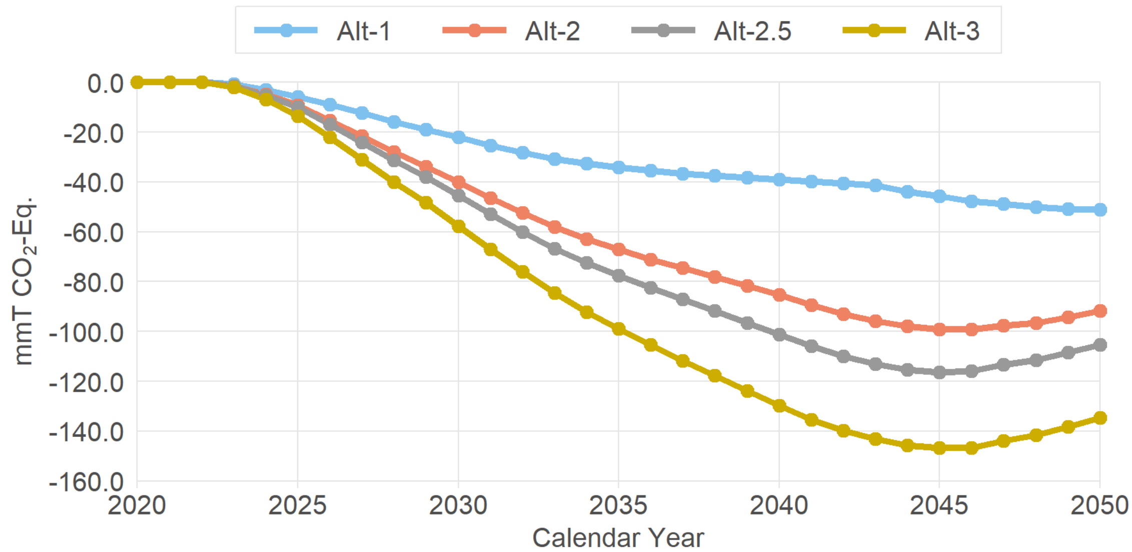


Figure 6-56 – Changes in Downstream GHG Emissions Compared to Baseline

6.6.2.1 Impacts of Select Sensitivity Cases on Fuel Consumption and Greenhouse Gas Emissions

Varying certain input assumptions, such as fuel prices, may change the mix of technologies that the CAFE Model selects in order to achieve compliance. Additionally, the degree of voluntary over-compliance may be affected if, for example, the cost of technology application becomes cheaper or fuel savings increase with respect to the reference input assumptions. As a result, fuel consumption and emissions of GHGs may change as well. In this section, the impacts of several sensitivity cases are examined and compared to the central analysis (or the reference case). Specifically, three cases with different fuel price forecasts are considered, as well as two additional ones where the learning rate of battery costs is decreased or increased by 20 percent. These and other sensitivity analysis cases are described in greater detail in Chapter 7. The following listing provides brief summaries of the cases presented here, along with the abbreviations used by the various figures throughout this section.

- Central: Central analysis case.
- Low FP: EIA low fuel price forecast.
- High FP: EIA high fuel price forecast.
- GI FP: Global Insight (GI) fuel price forecast.
- Battery -20 Percent: Battery costs learn down at a 20 percent slower rate.
- Battery +20 Percent: Battery costs learn down at a 20 percent faster rate.

Figure 6-57 shows a comparison of fuel consumption between sensitivity cases for the No-Action Alternative. The overall consumption from all fuel types is presented in the larger chart at the top, while the left and right portions at the bottom provide separate views of gasoline and electricity consumption, respectively. For all sensitivity cases, gasoline still remains the dominant source of fuel, following a steady annual decline, while electricity use rapidly increases year after year.

The *high fuel price* case shows the fastest annual reduction in fuel consumption, while the *low fuel price* case is the slowest. These differences can be attributed to the degree of voluntary over-compliance that the CAFE Model employees during analysis. Under the *high fuel price* case, the fuel savings resulting from technology application increase, leading to a greater selection of cost-effective technologies[130] and to additional over-compliance. For the *low fuel price* case, however, the potential for fuel savings diminishes, which, in turn, reduces the amount of voluntary over-compliance. Readers may also note that under the *high fuel price* case, electricity use rises significantly when compared to the central analysis. Once again, this can be attributed to much higher fuel savings, resulting in PHEVs and BEVs becoming more attractive options.

As shown in Figure 6-57, the *faster battery cost learning* case results in the greater reduction to overall annual fuel consumption, as compared to the central case, while also having significantly greater adoption of electric-powered vehicles. Meanwhile, the *slower battery cost learning* case falls just below the central analysis for overall fuel use, but also shows a noticeably larger reduction to the amount of electricity consumed. These results can be explained by the cumulative impacts of battery cost learning beginning to amplify and influence PHEV and BEV technology utilization starting around CY 2035, as the two cases are shown diverging from the central analysis during that timeframe.

[130] Cost-effective technologies are defined as those where fuel savings resulting from application of a specific technology are greater than the cost of that technology. For more information on how the CAFE Model calculates cost-effectiveness refer to Section S5.3.2 of the CAFE Model Documentation.

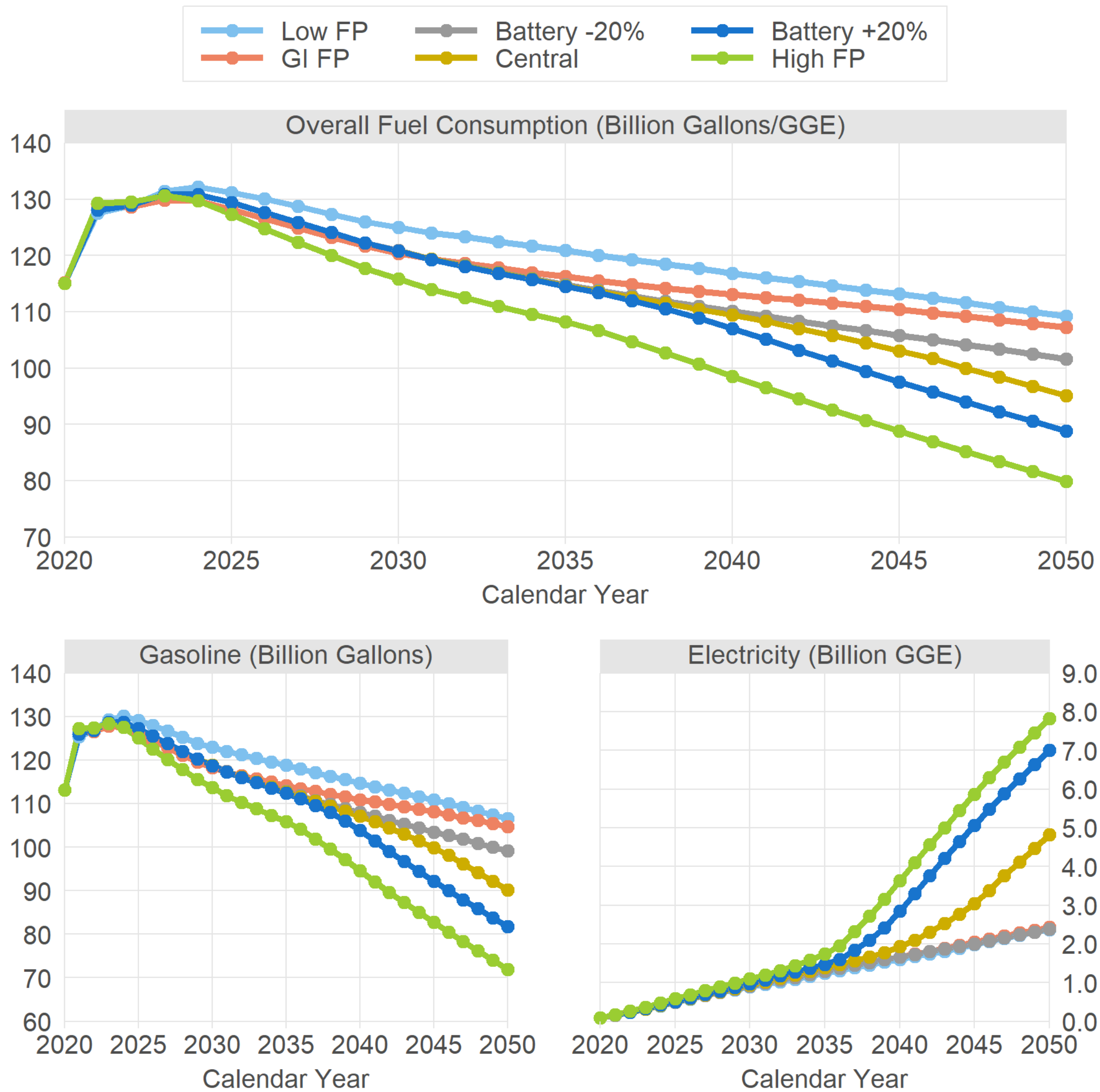


Figure 6-57 – Comparison of Fuel Consumption Across Sensitivity Cases in the Baseline Scenario

As noted earlier, fuel consumed by the vehicles during vehicle operation emits GHGs. Hence, as demonstrated in Figure 6-58, the overall and downstream GHG emissions for all sensitivity cases under the No-Action Alternative show the same patterns and annual trends that were observed for the total fuel consumption. For the upstream GHG emissions (bottom-left chart in Figure 6-58), however, the two cases with alternative battery cost learning rates have swapped the relative positions with respect to the central case. As stated previously, according to GREET, upstream GHG emissions from electricity generation are higher than from production and distribution of gasoline. Hence, the significantly greater electricity consumption under the *faster battery cost learning* case results in an increase of upstream emissions when compared to the central analysis. For the *slower battery cost learning* case, however, the reduction in electricity use has the opposite effect, decreasing the upstream emissions with respect to the central case. Even though the *high fuel price* case also shows a surge in the use of electricity, the significant reduction in gasoline consumption for that sensitivity case contributes to the lowest *net* amount of upstream emissions.

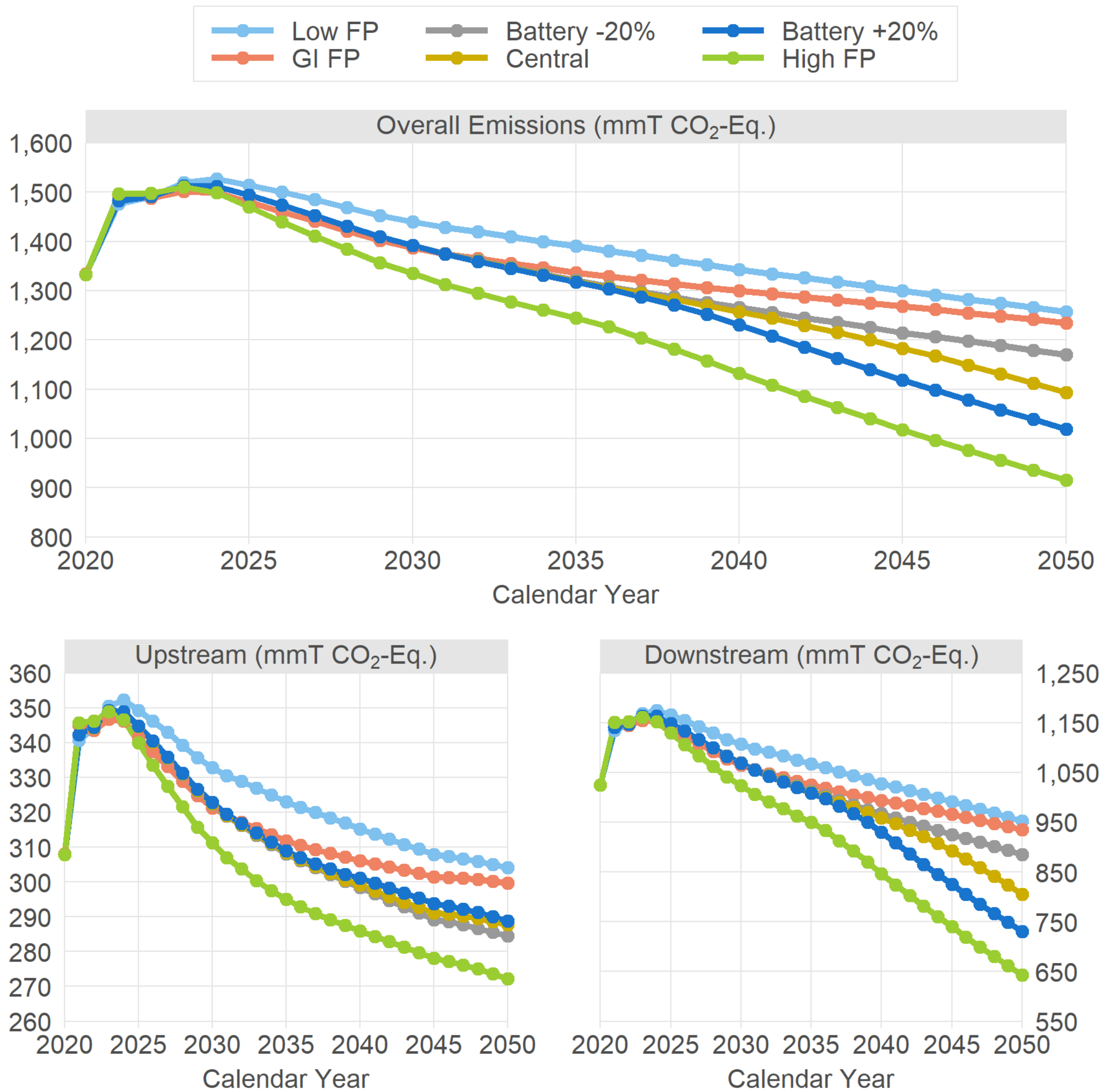


Figure 6-58 – Comparison of GHG Emissions Across Sensitivity Cases in the Baseline Scenario

For the rest of the action alternatives, when considering the values on an absolute basis, the patterns of behavior and relative ordering of sensitivity cases were identical to the No-Action Alternative, although with lower overall fuel consumption and GHG emissions. Figure 6-59 and Figure 6-60 present the comparison of cumulative impacts to fuel consumption and GHG emissions over the next three decades for all sensitivity cases and action alternatives.

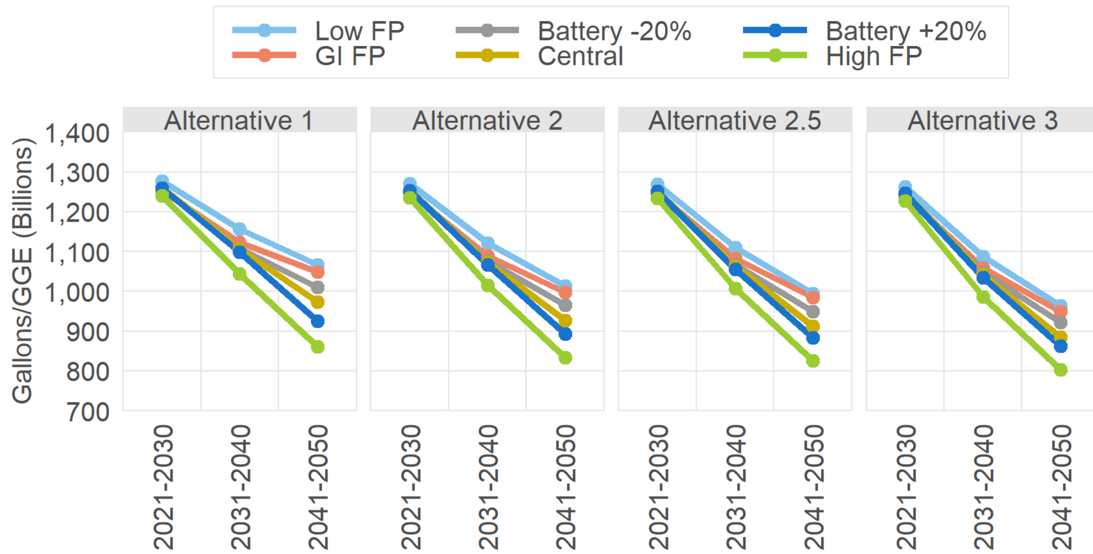


Figure 6-59 – Comparison of Fuel Consumption Across Sensitivity Cases in the Action Alternatives

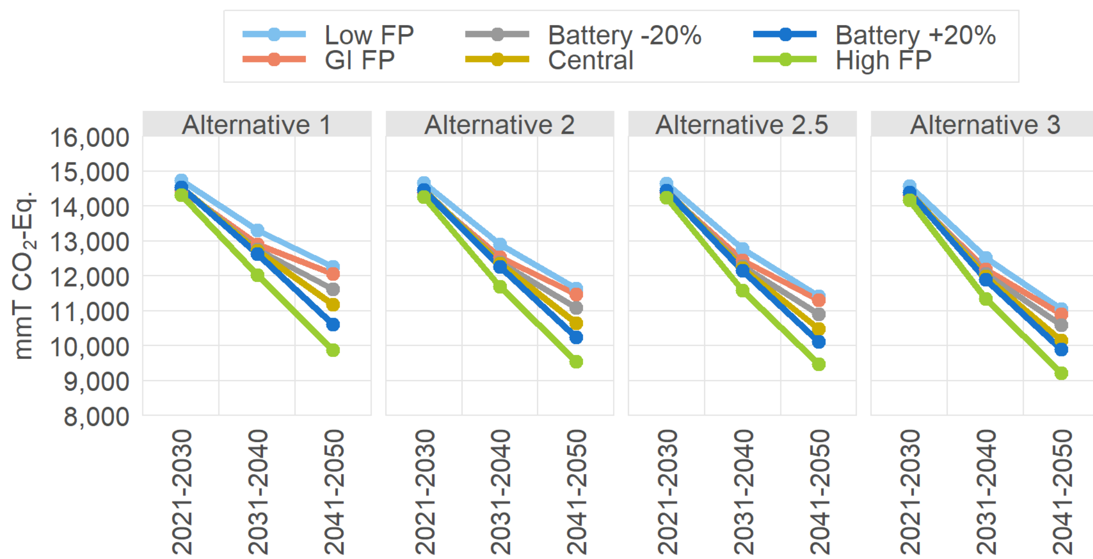


Figure 6-60 – Comparison of GHG Emissions Across Sensitivity Cases in the Action Alternatives

However, when considering the incremental changes in fuel consumption and GHG emissions compared to the No-Action Alternative, the relative ordering of sensitivity cases reverses as illustrated by Figure 6-61 and Figure 6-62. Here, the *high fuel price* case is shown as having the lowest incremental reduction of fuel consumption and GHG emissions when compared to the baseline scenario, while the *low fuel price* case shows the greatest reduction of these values. Under the *high fuel price* case, as the baseline scenario absorbs additional cost-effective technologies due to voluntary over-compliance, the potential for improvements in the action alternatives (with respect to the baseline) reduces. Hence, the incremental changes to fuel consumption and GHG emissions reduce as well. Conversely, for the *low fuel price* case, as the degree of voluntary over-compliance in the baseline scenario declines, the potential for improvements in the action alternatives increases. Thus, the incremental changes go up in each alternative in the *low fuel price* case.

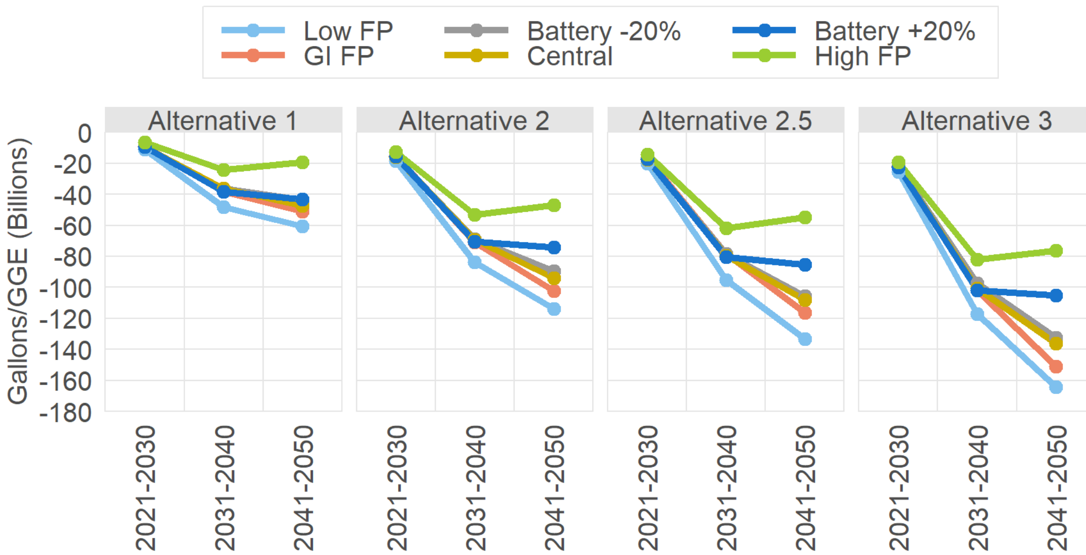


Figure 6-61 – Comparison of Changes in Fuel Consumption Across Sensitivity Cases

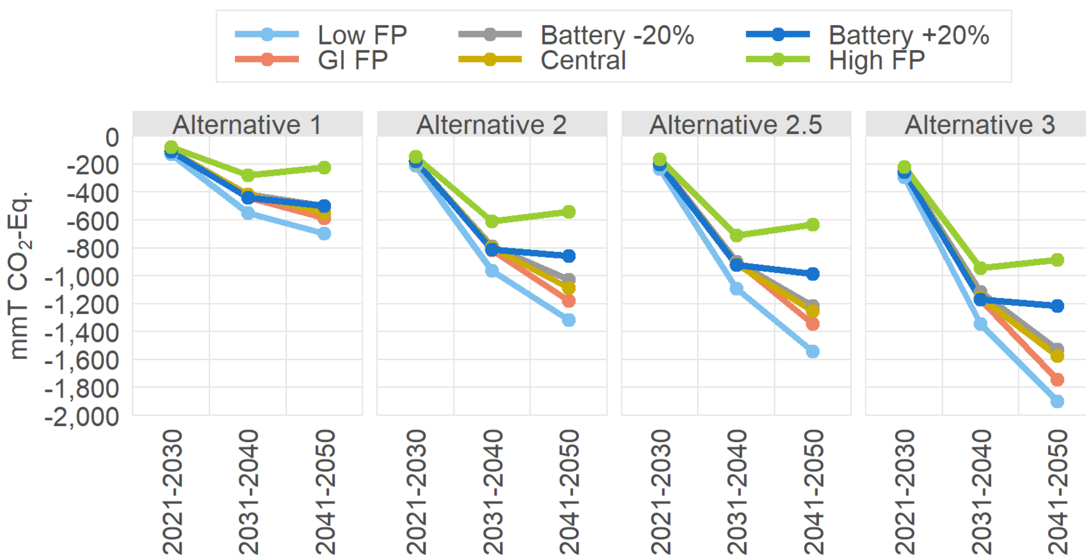


Figure 6-62 – Comparison of Changes in GHG Emissions Across Sensitivity Cases

6.6.3 Changes to Emission of Criteria Air Pollutants

Reduction in the total amount of fuel consumed by the on-road vehicle fleet may result in either increases or decreases to upstream emissions from criteria air pollutants. These upstream changes depend mainly on the magnitude by which the alternative fuel sources (specifically electricity) supplant more traditional options (of which gasoline is the dominant one). Since the production and distribution of gasoline in the United States is significantly cleaner than generation of electricity for most pollutants according to GREET, introducing even small volumes of PHEVs and BEVs into the on-road population tends to have a disproportionally negative impact on the *upstream* emissions resulting from criteria air pollutants. Conversely, stricter vehicle emission standards, which are defined on a per-mile basis and are adopted by the new fleet, greatly reduce the amount of *downstream* pollutants that are emitted into the atmosphere from vehicle operation. This section presents changes in emissions for a subset of criteria air pollutants that are supported by the CAFE Model. Specifically, upstream and downstream emissions related to NO_X, SO_X, and $PM_{2.5}$ are examined. As a consequence of changes to emissions, the magnitude of adverse health incidents caused by exposure to these pollutants typically reduces, as discussed in Chapter 6.6.4.

Figure 6-63 and Figure 6-64 present annual upstream and downstream emissions of NO_X and $PM_{2.5}$ respectively, which are attributed to the light-duty fleet under the standards defined by the No-Action Alternative. As the older vehicles are retired and replaced by models compliant with stricter emissions standards, a rapid decline of NO_X and $PM_{2.5}$ downstream emissions can be seen from both figures. However, the relative impacts on upstream emissions for both pollutants are significantly less pronounced, showing small growth until CY 2023, followed by gradual and marginal decline thereafter. The initial upsurge in upstream emissions correlates with the higher demand for fuel that was presented in Figure 6-48. Likewise, the subsequent decline also follows the overall annual reduction to fuel consumption. Although the No-Action Alternative sees a larger shift to electric-powered vehicles in the latter years, the additional upstream emissions from electricity do not outweigh the larger cumulative savings from improved gasoline models. As such, the upstream emissions of NO_X and $PM_{2.5}$ plateau in the last several years.

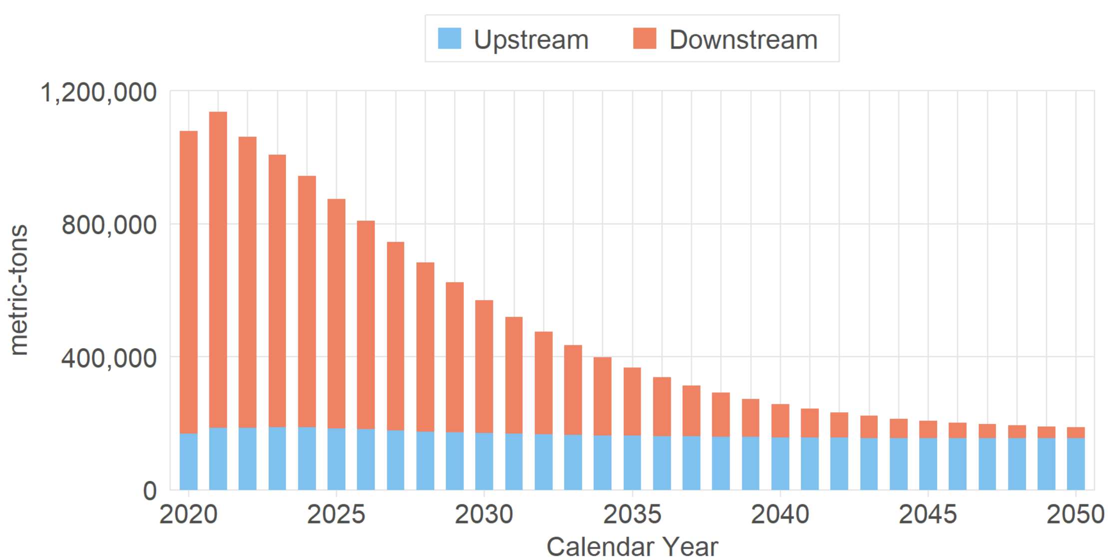


Figure 6-63 – Emissions of NO_X in the Baseline Scenario

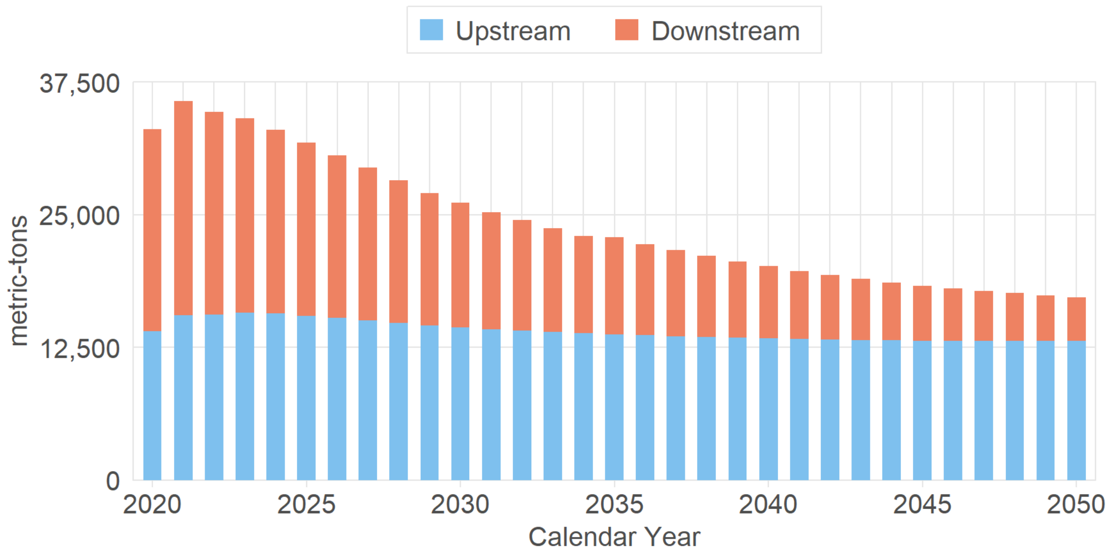


Figure 6-64 – Emissions of $PM_{2.5}$ in the Baseline Scenario

Figure 6-65 shows the annual SO_X emissions for the on-road fleet under the No-Action Alternative. Contrary to the previous two pollutants, downstream emissions of SO_X are measured based on the consumption of fuel, rather than on a per-mile basis dictated by the vehicle emissions standards. Hence, SO_X emissions are influenced directly by changes to the amount of fuel consumed, rather than the total miles traveled by the light-duty fleet. As can be seen from Figure 6-65, the downstream component provides a marginal contribution to the overall SO_X emissions, and generally undergoes a downward trend as fuel consumption decreases. The inner plot in the bottom-right corner of Figure 6-65 presents a magnified view of downstream SO_X emissions for clarity. The upstream SO_X emissions see a similar pattern as was observed for NO_X and $PM_{2.5}$ pollutants. Here, emissions peak in CY 2023 due to increasing fuel consumption, then steadily decline over the next 20 years, before ultimately increasing once again after CY 2045 due to greater presence of EVs in the fleet.

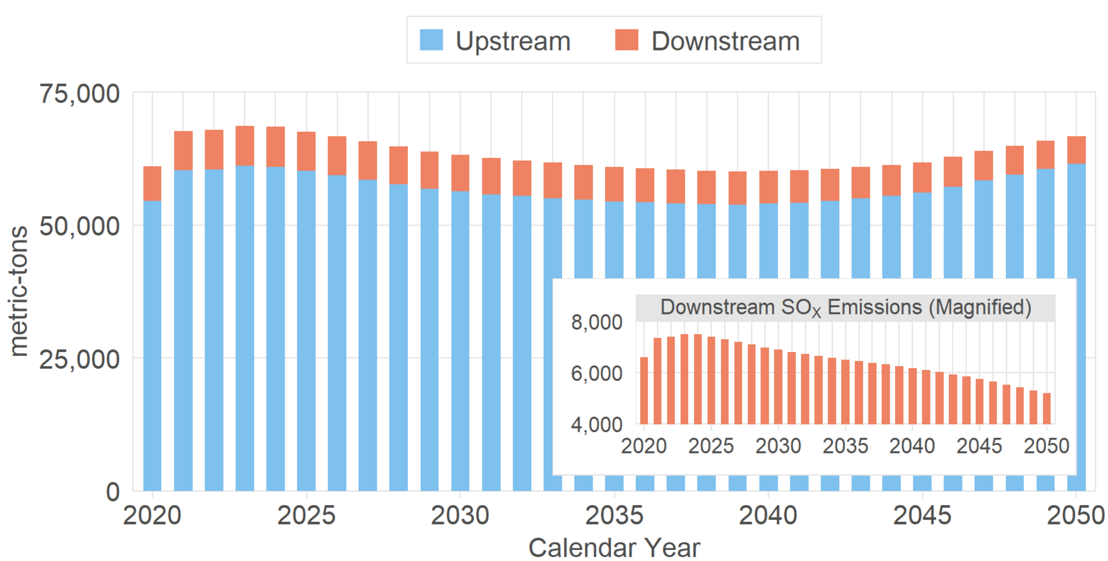


Figure 6-65 – Emissions of SO_X in the Baseline Scenario

As demonstrated in the next several figures, increases in CAFE standards generally lead to decreases in overall emissions of NO_X and $PM_{2.5}$ for all alternatives evaluated. As was the case for GHG emissions discussed earlier, this contrasts with what was presented for the NPRM analysis. In the NPRM analysis, emissions of NO_X and $PM_{2.5}$ for the more stringent alternatives surpassed the baseline (No-Action Alternative) and Alternative 1 in most calendar years. The differences between the NPRM and final rule are largely due to changes in the upstream emission estimates of NO_X and $PM_{2.5}$ from the updated GREET model (roughly 5-10 percent decline), as well as the lower consumption of electricity estimated in the final rule analysis. For SO_X, however, the current analysis shows a similar trend to the NPRM, with overall emissions rising under the three most stringent alternatives, when compared to the baseline, while also marginally decreasing during a few of the middle years and then going up in the latter years for Alternative 1.

Figure 6-66 shows the incremental changes to NO_X emissions in the action alternatives verses the baseline scenario. The larger chart at the top presents the overall emissions of NO_X, while the left and right portions at the bottom provide deconstructed views of upstream and downstream components, respectively. The upstream emissions for all action alternatives follow a sharp decline in the early to middle years versus the baseline. The increases starting around CY 2043 (for Alternative 1) and CY 2037 (all others), however, occur due to faster adoption of electric-powered vehicles in the alternatives than the baseline. Additionally, while NO_X upstream emissions in Alternatives 2, 2.5, and 3 are close to one another, the minor fluctuations in their relative ordering can be attributed to the higher penetration of electricity-consuming vehicles (PHEVs and BEVs) in the light-duty fleet in one alternative versus the other.

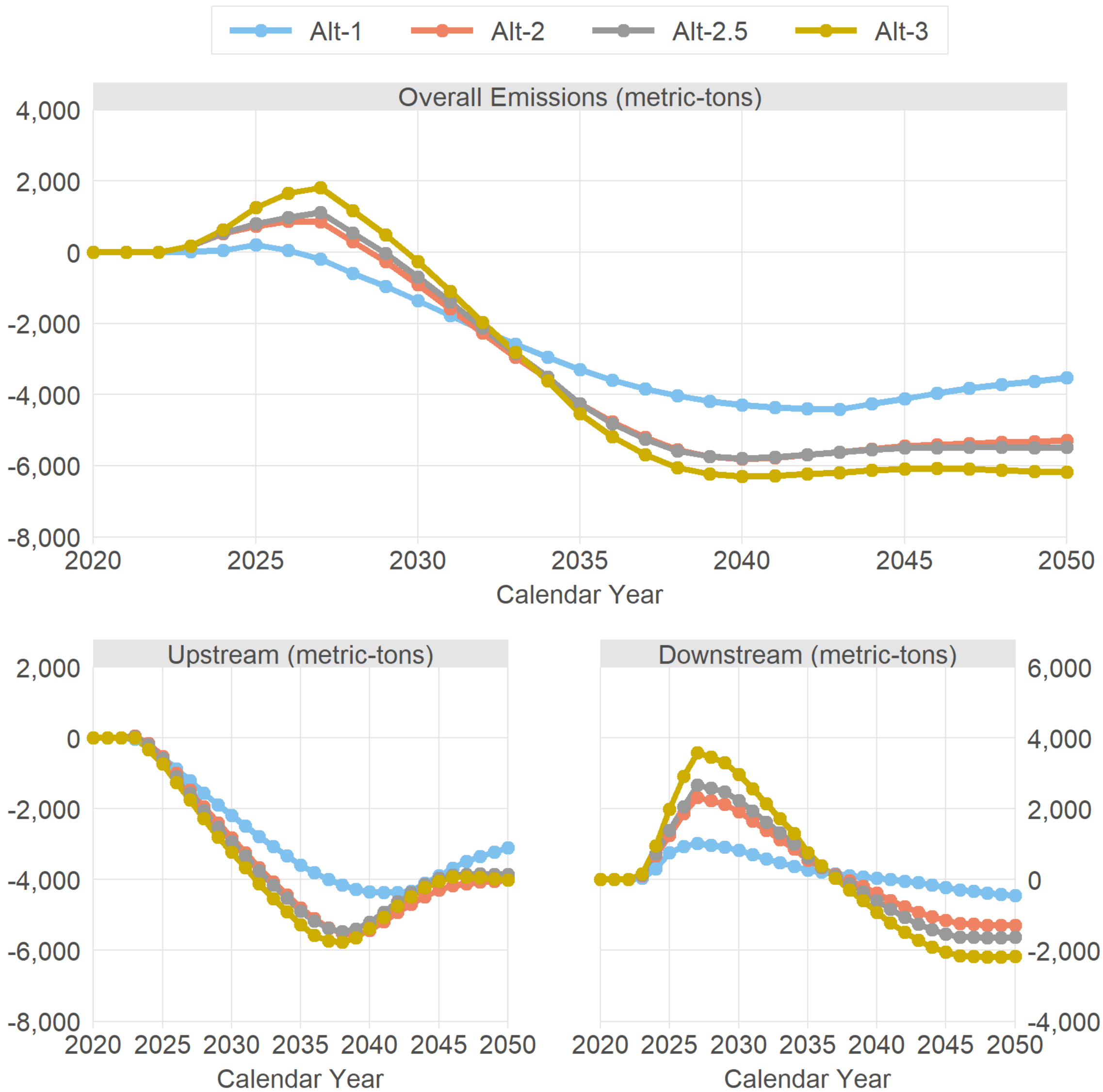


Figure 6-66 – Changes in NO_X Emissions Compared to Baseline

The downstream emissions in Figure 6-66 show an increase in the earlier years under all action alternatives as compared to the baseline, before leading to a net decrease in the later years. In response to the higher standards under the action alternatives, the CAFE Model simulates a slight reduction of new vehicle sales, causing a slight shift in the VMT from newer vehicles to older models. With the downstream emission standards enforced for future vehicle models being significantly more stringent than that for older vehicles,[131] the net downstream NO_X emissions rise while the on-road fleet gradually turns over. As the older models are replaced in the later years, NO_X emissions begin to fall, eventually declining to below baseline levels.

[131] Readers should refer to the parameters input file for the current assumptions of the annual downstream emission inputs for various pollutants.

Figure 6-67 presents the incremental changes to $PM_{2.5}$ emissions in the action alternatives as compared to the baseline scenario. The upstream and downstream emissions trends for $PM_{2.5}$ criteria air pollutant are similar to that of NO_X, while also having the same underlying root causes for the observed behavior. However, since the magnitude and the model-year differences of per-mile emissions of $PM_{2.5}$ are not as significant as they were for NO_X, the negative impacts on downstream $PM_{2.5}$ emissions in the action alternatives are less prominent. As a result, the incremental overall emissions of $PM_{2.5}$ decline in all alternatives as compared to the baseline.

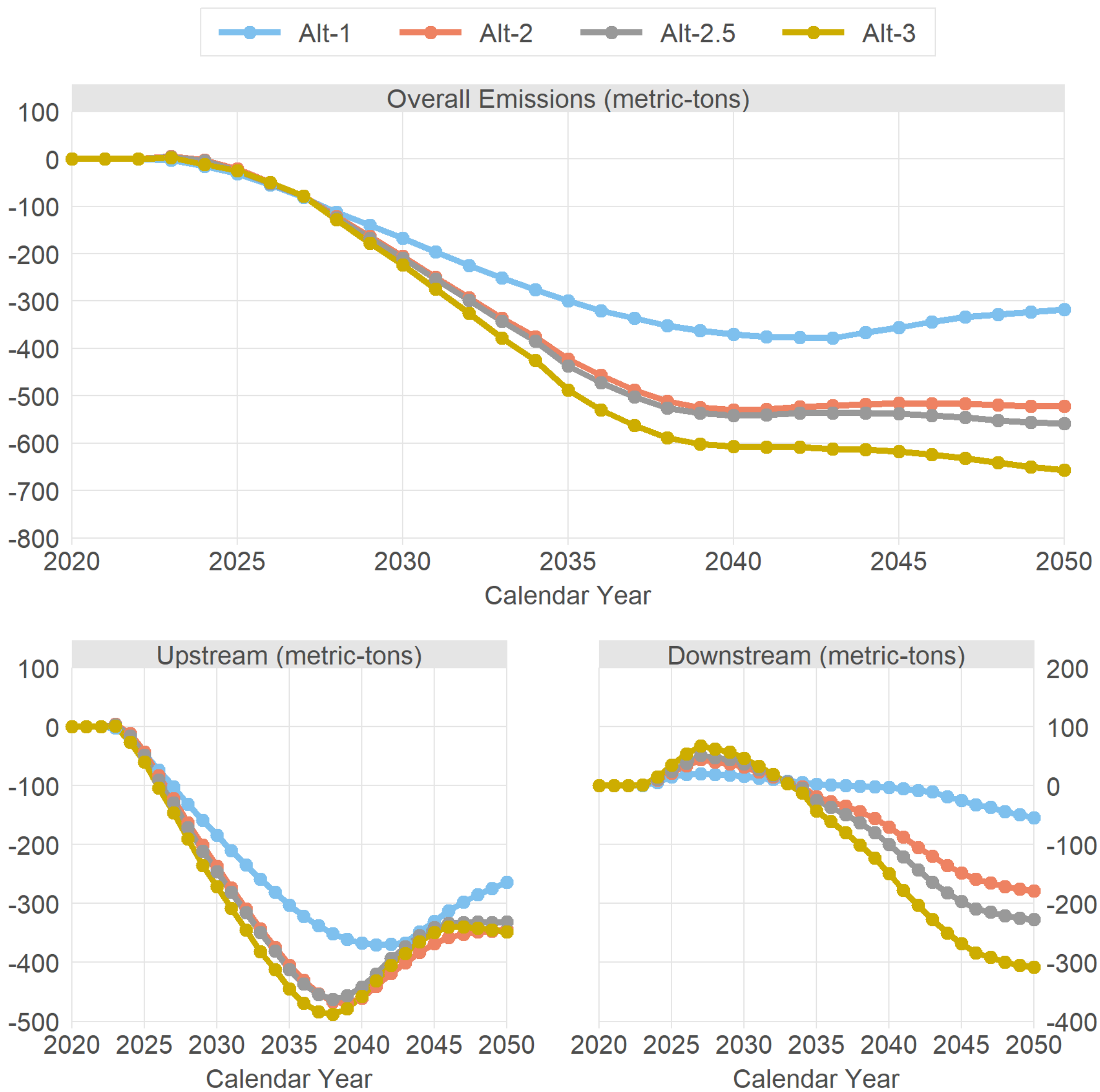


Figure 6-67 – Changes in $PM_{2.5}$ Emissions Compared to Baseline

Figure 6-68 illustrates the incremental emission changes for SO_X for the action alternatives versus the baseline. As was noted earlier, the SO_X downstream emissions are measured based on the total consumption of fuel, rather than on per-mile basis. Thus, the reduction in fuel use in the action alternatives reduces the downstream emissions as compared to the No-Action Alternative. Conversely, the upstream emissions of SO_X are higher than the baseline in all action alternatives (with the exception of a few calendar years in Alternative 1). This also leads to a net increase in the overall SO_X emissions over the baseline.

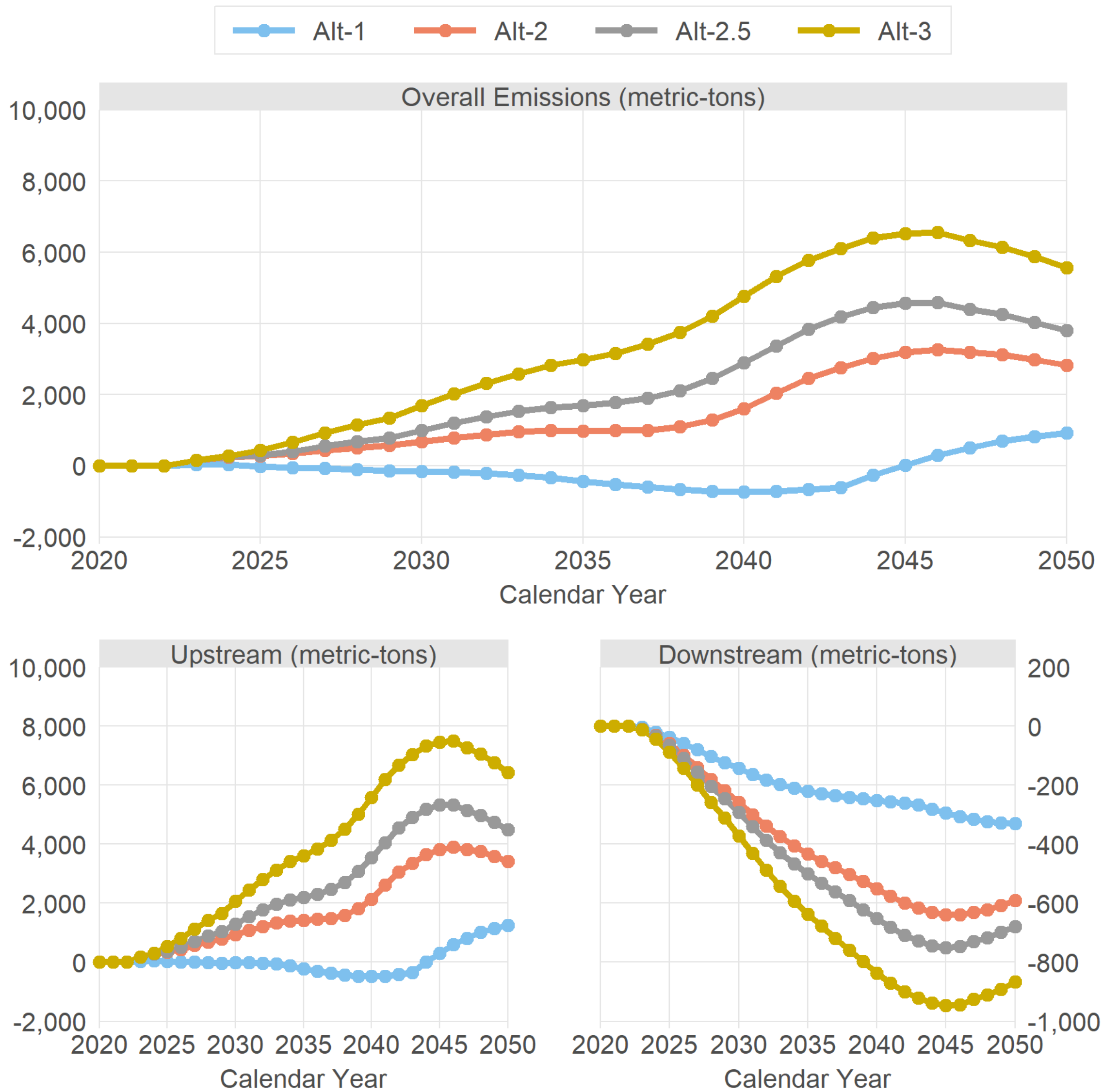


Figure 6-68 – Changes in SO_X Emissions over Baseline

As demonstrated in this section, while the emissions of NO_X and $PM_{2.5}$ generally decrease in all action alternatives, SO_X emissions increase under the three most stringent alternatives as compared to the baseline scenario. Though these results may appear counterintuitive, they are a direct consequence of the input assumptions used for this analysis, as well as the uncertainty surrounding these assumptions. When estimating the upstream emissions, the CAFE Model relies on the upstream emission rates provided by the GREET 2021 Model for the various supported fuel types. These input emission rates may change over time (and between rulemaking analyses) depending on the version of the GREET Model used and the internal assumptions a particular GREET version uses regarding the production and distribution of various petroleum-based feedstocks.

In addition to the upstream emission rates obtained from GREET, the CAFE Model also relies on the various fuel import assumptions, which apply certain weighting to the GREET values, thus introducing additional uncertainty. These fuel import assumptions define what portion of total emissions, which arise from the various stages of fuel production and distribution, are assumed to occur domestically. When considering gasoline and diesel fuels, this analysis conservatively assumes that only 5 percent of the total emissions related to crude oil extraction and transportation to refining facilities occur within the United States. Currently, 60 percent of the crude oil refined in the United States is transported to the refinery from domestic sources.

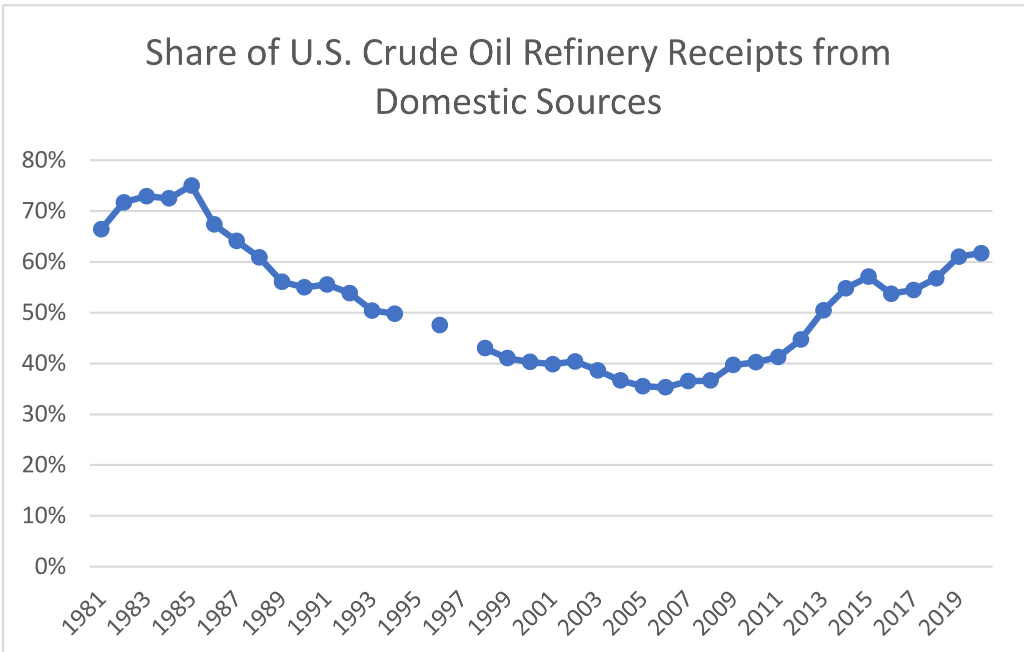


Figure 6-69 - Share of U.S. Crude Oil Receipts from Domestic Resources

Furthermore, 50 percent of the total emissions generated during the petroleum refining process are assumed to occur domestically. This is a conservative estimate. While the amount of domestically produced crude that is also consumed in the United States is unknown, currently the amount of finished motor gasoline exported from the United States exceeds the amount imported by a factor of 17. Lastly, emissions occurring during transportation, storage, and distribution of refined gasoline and diesel (Fuel TS&D) are assumed to occur in the United States in their entirety. Hence, the cumulative upstream emissions attributed to the various stages of gasoline or diesel production and distribution depend on the fuel import assumptions that are specified as inputs to the CAFE Model. Conversely, all of the upstream emissions resulting from generation and distribution of electricity are assumed to occur domestically.

When estimating the downstream emissions, the CAFE Model relies on the emission rates provided by the MOVES3 Model, which are defined on a per-mile basis (except for the SO_X pollutant), independently for the light-duty passenger vehicle (LDV) and light-duty trucks (LDT) class of vehicles. Hence, the differences in the downstream emissions between various alternatives largely depend on the total VMT attributed to the on-road population from each vehicle class. However, some uncertainty also exists regarding the impacts of increasing standards on new vehicle sales, the mix shifting between cars and trucks, and the longevity of the historic population. Hence, the number of miles traveled by the resulting on-road fleet may change in such a way that it may increase the amount of downstream criteria air pollutants emitted during some calendar years under the more stringent alternatives.

6.6.4 Changes to Adverse Health Outcomes Caused by Exposure to Criteria Pollutants

The magnitude of adverse health incidents caused by exposure to criteria air pollutants reduces as the consumption of gasoline by the light-duty fleet drops between calendar years and more stringent alternatives. Figure 6-70 presents the proportions of each of the various emission health impacts, which were considered during this rulemaking, occurring during CY 2020. The pie chart on the left provides a subset of the health impacts where the count of incidents numbers in the tens of thousands and beyond, while the pie chart on the right includes the remainder of the health outcomes with incident counts fewer than ten thousand. For both charts, the emission health impacts with relatively small amounts (shown as a green slice in the left pie and a dark red slice in the right pie) were pooled together and presented in a stacked column.

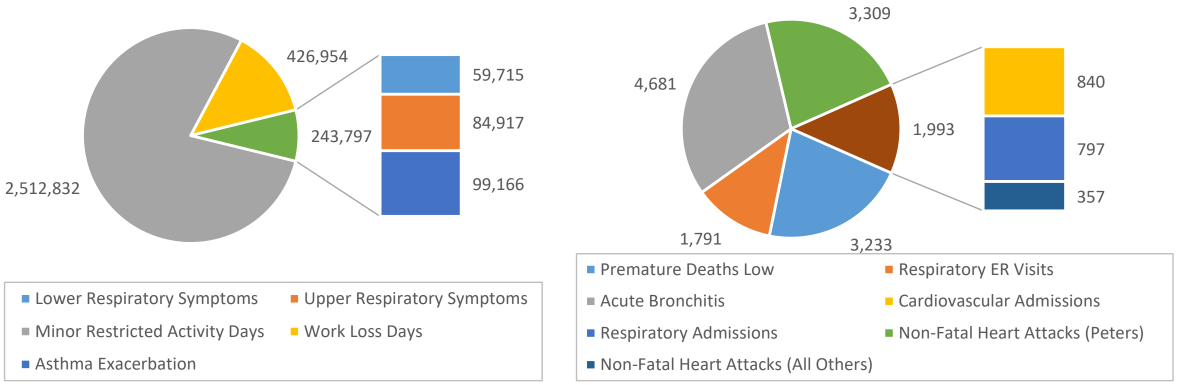


Figure 6-70 – Emission Health Impacts in CY 2020

As demonstrated by Figure 6-70, the "Minor Restricted Activity Days" category significantly outweighs the cumulative total of all the other health-related incidents. Conversely, the respiratory and cardiovascular hospital admissions categories are least significantly affected by exposure to emissions from criteria air pollutants. Throughout the analysis of all alternatives, the proportions of each category remained mostly the same during each calendar year, although moderately declining with each subsequent year.

The emission health impacts attributed to the No-Action Alternative for the remainder of the calendar years are presented as cumulative impacts over the next three decades in Figure 6-71 and Figure 6-72. Once again, the figures were split into subsets of high incident counts (above ten thousand) and low incident counts (below ten thousand) to aid with interpretation. As revealed by both figures, the health-related outcomes in every single category follow a significant downward trend between the decades in response to significantly declining overall emission of NO_X and $PM_{2.5}$ pollutants (discussed in Chapter 6.6.2.1).

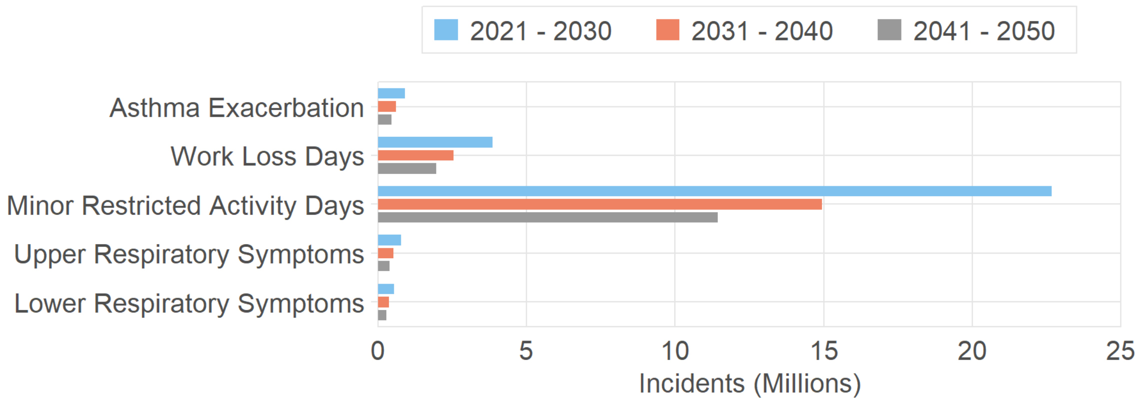


Figure 6-71 – Cumulative Emission Health Impacts in the Baseline Scenario (1)

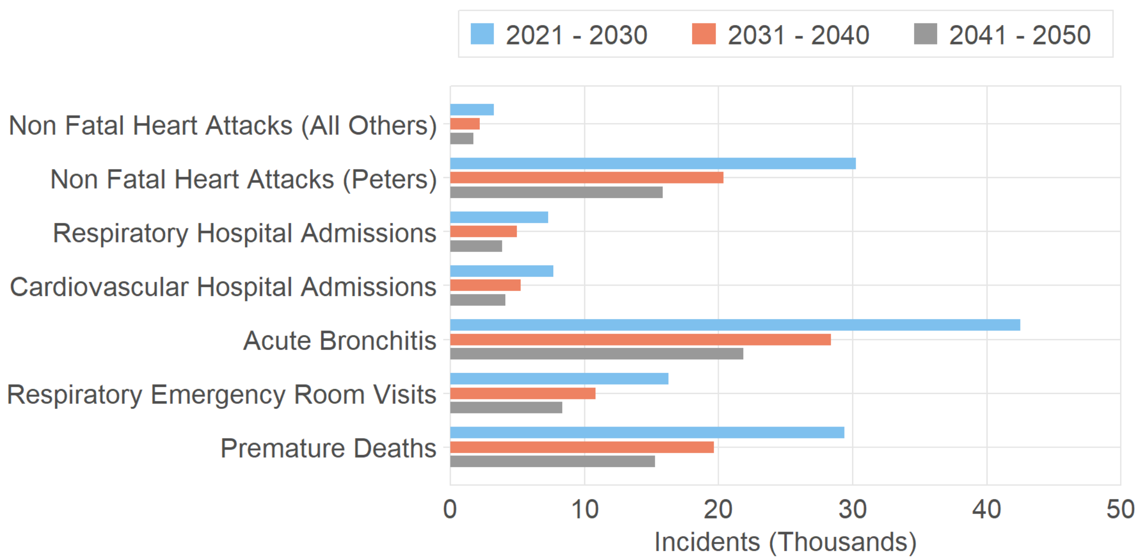


Figure 6-72 – Cumulative Emission Health Impacts in the Baseline Scenario (2)

With increasing CAFE standards under the action alternatives, health-related incidents are further decreased in response to an even greater reduction of fuel consumed. Although the net emissions of SO_X increase in some action alternatives, the decreases in net NO_X and particulate matter (PM) emissions, the reduction in the consumption of gasoline, and the subsequent reduction in exposure to upstream and downstream emissions attributed to gasoline fuel use, lead to an eventual decline in adverse health outcomes. Figure 6-73 and Figure 6-74 illustrate the incremental changes in emission health impacts for each alternative over the baseline scenario for the next three decades. With the most stringent CAFE standards, Alternative 3 sees the greatest reduction in the number of incidents among all alternatives evaluated, although, the differences between all alternatives during the first decade (2021-2030) are marginal.

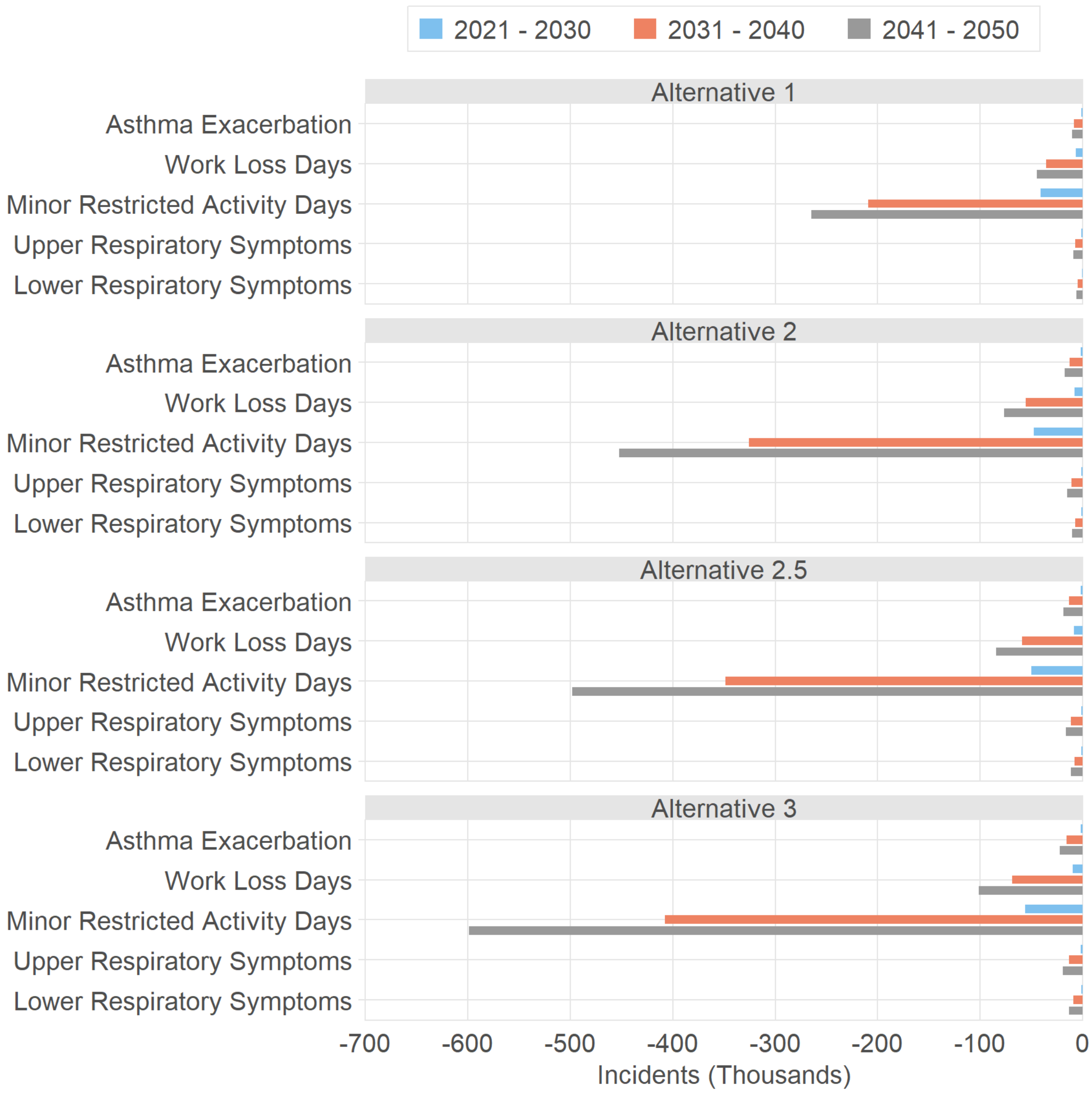


Figure 6-73 – Changes in Cumulative Emission Health Impacts over Baseline (1)

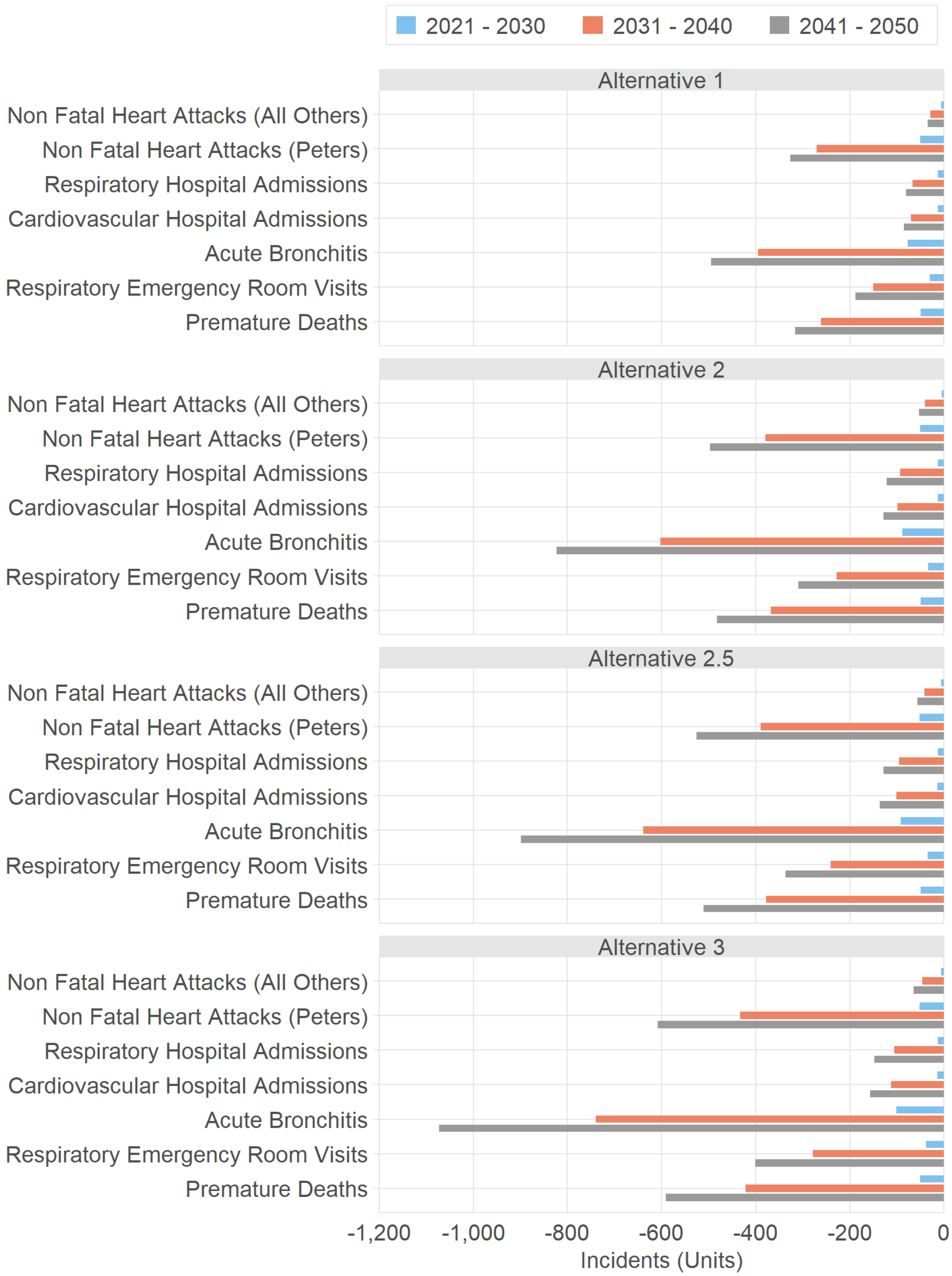


Figure 6-74 – Changes in Cumulative Emission Health Impacts over Baseline (2)

7. Expanded Sensitivity Analysis

7.1 Description of Sensitivity Cases

Results presented in this analysis reflect the agency's best judgments regarding many different factors. As with all the past CAFE rulemakings, NHTSA recognizes that some analytical inputs are especially uncertain, some are likely to exert considerable influence over specific types of estimated impacts, and some are likely to do so for the bulk of the analysis. Additional model runs with alternative assumptions explored a range of potential inputs and the sensitivity of estimated impacts to changes in model inputs. Sensitivity cases in this analysis span assumptions related to technology applicability and cost, economic conditions, consumer preferences, externality values, and safety assumptions, among others. In contrast to an uncertainty analysis, where many assumptions are varied simultaneously, the sensitivity analyses included here (typically) vary a single assumption and provide information about the influence of each individual factor, rather than suggesting that an alternative assumption would have justified a different Preferred Alternative. This analysis contains hundreds of assumptions and most of them are uncertain – particularly several years in the future. However, assumptions are inevitable in analysis, generally, and a sensitivity analysis can identify two critical pieces of information: *how big an influence* does each parameter exert on the analysis, and *how sensitive are the model results* to that assumption?

For example, if the cost of battery packs for BEVs learn down at a faster or slower rate than the levels projected in the central analysis (also called the "reference case" or "Preferred Alternative"), then incremental technology costs are affected slightly, and net benefits are affected somewhat. By contrast, if fuel prices are either higher or lower than the projections in the central case (represented by the EIA high and low oil price cases in AEO 2021), the set of alternatives considered today produce significantly different results across a variety of metrics, including net social benefits. In that respect, it might be said that the learning rate for batteries turns out to exert less influence on the analysis, as technology costs, the primary metric affected by application of BEV technology for the model years in question, are not much affected by the alternative assumptions. By contrast, the furl price cases demonstrate that many different metrics are affected by alternative fuel price projections – market adoption of fuel economy improving technologies, the value of gallons saved, buyer payback periods for fuel economy investments, and VMT. The sensitivity analysis thus demonstrates that fuel prices can have significant impacts on a number of relevant metrics (i.e., model results are sensitive to this assumption), and alternative assumptions can change the sign on measures like net benefits and consumer costs – meaning that this assumption *significantly* influences the analysis. That said, influence is different from likelihood. NHTSA does not mean to suggest that any one of the sensitivity cases presented here is inherently more likely than the collection of assumptions that represent the reference case in the figures and tables that follow. Nor is this sensitivity analysis intended to suggest that only one of the many assumptions made is likely to prove off-base with the passage of time or new observations. It is more likely that, when assumptions are eventually contradicted by future observation (e.g., deviations in observed and predicted fuel prices are nearly a given), there will be *collections* of assumptions, rather than individual parameters, that simultaneously require updating. For this reason, we do not interpret the sensitivity analysis as necessarily providing justification for alternative regulatory scenarios to be preferred. Rather, the analysis simply provides an indication of which assumptions are most impactful, and the extent to which future deviations from central analysis assumptions could affect the actual future costs and future benefits of this rule.

Results of NHTSA's sensitivity analysis are summarized below, and detailed model inputs and outputs are available on the agency's website.[132] These are reported as incremental values for the rule relative to the baseline No-Action Alternative. They compare to the measures presented in the central analysis, above, using the reference case assumptions. The reference case values are also reported in the tables for easier comparison. It is important to note that results (e.g., absolute CO_2 emissions) under both the No-Action Alternative and the Preferred Alternative (i.e., the new CAFE standards) change for each sensitivity case; the incremental changes are not due solely to a change in the absolute outcomes of the regulatory alternative, but also due to changes in the absolute outcomes in the No-Action case. This can sometimes lead to counterintuitive incremental impacts of changing some of the reference assumptions. We discuss these as they arise.

Table 7-1 lists and briefly describes the cases included in the sensitivity analysis. All sensitivity cases with the exception of the Environmental Impact Statement reference case (EIS-RC) are variants of the standard-setting reference case (RC) that includes statutory restrictions (e.g., treatment of dedicated alternative fuel vehicles).

Table 7-1 – Cases Included in Sensitivity Analysis

Sensitivity Case	Description
RC	Reference case
EIS-RC	Reference case for Environmental Impact Statement
MR5/6 skip (>100k)	MR5 and MR6 skipped for platforms with 100k or more units
MR5/6 skip (>2k)	MR5 and MR6 skipped for platforms with 2k or more units
No MR5/6 skip	No "SKIP" entries preventing application of MR5 or MR6 to specific platforms[133]
2020 Final Rule MR5/6 costs	Cost values for MR5 and MR6 at levels from 2020 Final Rule
One-year redesign cadence	Vehicles redesigned every year
Battery direct costs (-20%)	Battery direct manufacturing cost decreased by 20%, battery learning cost at reference case levels
Battery direct costs (+20%)	Battery direct manufacturing cost increased by 20%, battery learning cost at reference case levels

[132] https://www.nhtsa.gov/corporate-average-fuel-economy/compliance-and-effects-modeling-system. (Accessed: February 14, 2022).
[133] "SKIP" refers to the method of constraining technology application in the analysis; see TSD Chapter 6.1.1 for additional information.

Sensitivity Case	Description
Battery learning rate (-20%)	Year-over-year percentage rate of learning has been decreased by 20%, resulting in higher battery costs than reference levels. Battery direct manufacturing cost at reference case levels
Battery learning rate (+20%)	Year-over-year percentage rate of learning has been increased by 20%, resulting in lower battery costs than reference levels. Battery direct manufacturing cost at reference case levels
Flat AC/OC	No additional AC or OC credit accumulation after MY 2021 levels.
Limited HCR skip	Except for HCR2, HCR engine is applicable for all OEMs and technology classes
Limited conventional tech. improvement	SKIP application of advanced engines and transmissions, and highest levels of AERO and MR
Oil price (EIA AEO 2021 low)	Input oil price series based on EIA low forecast from AEO 2021
Oil price (Global Insight)	Input oil price series based on Global Insight October 2021 forecast
Oil price (EIA AEO 2021 high)	Input oil price series based on EIA high forecast from AEO 2021
No payback period	Payback period eliminated
24-month payback period	Payback period set to 24 months
36-month payback period	Payback period set to 36 months
60-month payback period	Payback period set to 60 months
30-month fuel-savings value (70k miles)	Valuation of fuel savings at 30 months for technology application, 70k miles for sales and scrappage models
Implicit opportunity cost	Includes a measure that estimates possible opportunity cost for forgone vehicle attribute improvements that exceed the reference case 30-month payback period.
Rebound (5%)	Rebound effect set at 5 percent
Rebound (15%)	Rebound effect set at 15 percent
Sales-scrappage response (η = -0.1)	Sales-scrappage model with price elasticity multiplier = -0.1
Sales-scrappage response (η = -0.5)	Sales-scrappage model with price elasticity multiplier = -0.5
NPRM sales-scrappage response (η = -1)	Sales-scrappage model with price elasticity multiplier = -1 (as in the NPRM)
Low GDP	Low economic growth (Global Insight October 2021 pessimistic forecast)

Sensitivity Case	Description
High GDP	High economic growth (Global Insight October 2021 optimistic forecast)
Low GDP (+ fuel prices)	Low economic growth with corresponding gasoline and diesel price forecast (Global Insight October 2021 pessimistic forecast)
High GDP (+ fuel prices)	High economic growth with corresponding gasoline and diesel price forecast (Global Insight October 2021 optimistic forecast)
NPRM macro forecast	Macroeconomic inputs retained at NPRM levels
Alt. DFS model (fixed)	Alternative dynamic fleet share model, with shares fixed across alternatives
Alt. DFS model (varying)	Alternative dynamic fleet share model, with shares varying across alternatives
Mass-size-safety (low)	The lower bound of the 95% confidence interval (CI) for all mass-size-safety model coefficients
Mass-size-safety (high)	The upper bound of the 95% CI for all mass-size-safety model coefficients
Crash avoidance (low effectiveness)	Lower-bound estimate of effectiveness of 6 current crash avoidance technologies at avoiding fatal, injury, and property damage
Crash avoidance (high effectiveness)	Upper-bound estimate of effectiveness of 6 current crash avoidance technologies at avoiding fatal, injury, and property damage
Reduced power plant emissions	Upstream emission factors reflecting reduced emissions from electricity generation, consistent with lower future costs for renewables
Lepeule criteria pollutant BPT estimates	Criteria pollutant benefit-per-ton (and health impact per ton) estimates based on Lepeule
No ZEV mandates	Exclude representation of ZEV mandates
Fixed nominal fine rate	CAFE fine rate remains $14 per 0.1 mpg in nominal dollars (as for NPRM analysis)
Unadjusted MDPCS stringency	MDPCS computed dynamically, using 92% value specified in 49 U.S.C. 32902 (b)(4)(B)
EPCA constraints throughout MYs 2023-2029	EPCA “standard setting” constraints on consideration of AFVs and application of compliance credits imposed throughout MYs 2023-2029
No response of domestic crude production	No changes in domestic crude oil extraction in response to changes in domestic refining activity
Constrained PHEV FE compliance values	Limit PHEV fuel efficiency compliance ratings for compliance calculations in MYs 2024-2026

7.2 Summary of Sensitivity Results

7.2.1 Effect of Assumptions on Primary Cost and Benefit Measures

A number of the input parameters for the CAFE Model lend themselves to a comparison of program effects for input values both above and below those of the central case. A selection of these scenarios is presented in Figure 7-1. Where relevant, the figure notes the parameter values associated with high (H) and low (L) cases. The two cases with the largest deviation from the net benefit level of the reference case are cases that vary oil prices, and cases that vary direct battery costs. We reiterate caution in interpreting these ranges as indicative of the role each parameter has on the results as the difference in parameter inputs in the high and low cases may not be comparable across scenarios. Instead, these serve to illustrate effects of varying assumptions about particular model inputs.

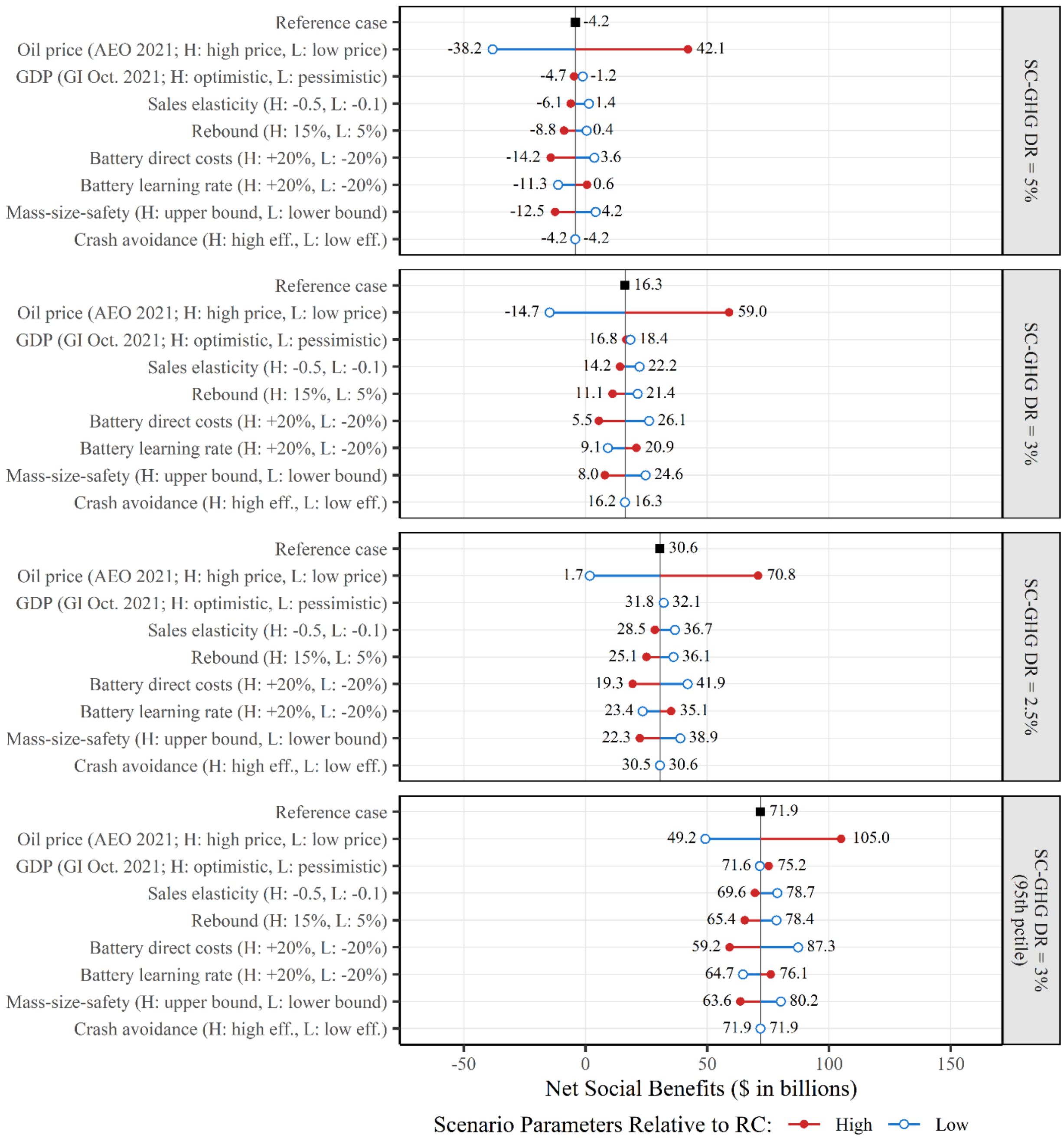


Figure 7-1 – Relative Magnitude of Sensitivity Effect on Net Benefits

To identify alternative assumptions that produce the greatest deviation from reference case results, Figure 7-2 reports the percent difference between total social benefits (costs) for the reference case and total social benefits (costs) for each scenario in Alternative 2.5. While differences in the relative magnitude of the input parameter perturbation may prevent rigorous comparison across scenarios, and standardization is not possible in many cases, the results in Figure 7-2 can highlight some of the more significant fluctuations in model estimates. Most variation from the central case comes from oil price forecasts. Certain technology assumptions produce large differences in benefits or costs, but—for reasons explained below—these scenarios test model logic more than represent likely real-world settings.

The remaining sub-sections offer additional context to this scenario analysis, focusing on the scenarios that lead to greater differences in aggregate social costs and benefits over the central case. Table 7-2 and Table 7-3 present the full suite of sensitivity case results and summarize key output measures including fuel consumption and associated emissions, consumer costs[134] and benefits, and aggregate social benefits, costs, and net benefits. Table 7-4 reports technology penetration rates for a selection of engine technologies and powertrain electrification types.

The largest components of estimated program costs and benefits include reduced fuel expenditures that result from improved fuel economy, and increased technology and other regulatory costs required to meet fuel economy standards. Unsurprisingly, input parameters that alter these cost and benefits categories have the potential to change the cost-benefit results. In the broader context of total social costs and benefits, the assumed payback period over which new car buyers value fuel economy improvements, battery cost metrics, and global oil price forecast assumptions are significant drivers of overall net social benefits.

[134] As in Chapter 6.4.2, vehicle costs include insurance costs, taxes and fees, foregone consumer sales surplus, maintenance and repair cost, and implicit opportunity costs.

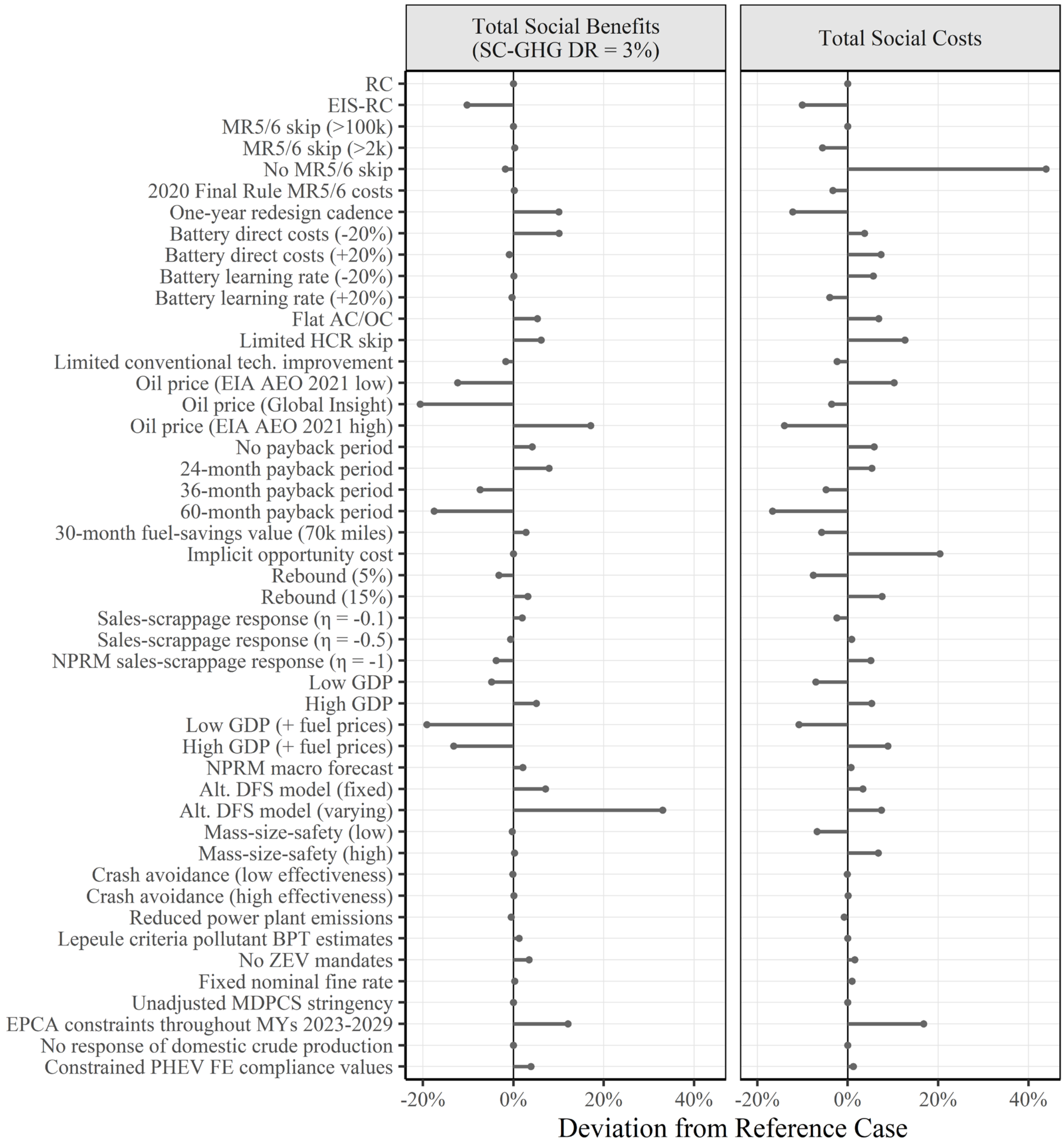


Figure 7-2 – Relative Deviation in Total Social Costs and Total Social Benefits from Reference Case

Table 7-2 – Summary of Social Costs and Benefits for Sensitivity Cases (MYs 1981-2029, Alt. 2.5, 3 Percent Discount Rate)

Sensitivity Case	Total Social Costs	Total Social Benefits				Net Social Benefits				% diff from RC (at 3%)		
		5%	3%	2.5%	3% @ 95th	5%	3%	2.5%	3% @ 95th	Costs	Benefits	Net benefits
RC	128.4	124.2	144.6	158.9	200.3	-4.2	16.3	30.6	71.9	-	-	-
EIS-RC	115.5	110.3	129.8	143.5	182.9	-5.2	14.3	28.0	67.5	-10%	-10%	-12%
MR5/6 skip (>100k)	128.4	124.2	144.6	158.9	200.3	-4.2	16.3	30.6	71.9	0%	0%	0%
MR5/6 skip (>2k)	121.2	124.6	145.1	159.4	200.9	3.3	23.8	38.2	79.6	-6%	0%	47%
No MR5/6 skip	184.7	121.9	142.0	156.1	196.8	-62.8	-42.7	-28.6	12.1	44%	-2%	-363%
2020 Final Rule MR5/6 costs	124.2	124.5	145.0	159.3	200.7	0.3	20.8	35.1	76.5	-3%	0%	28%
One-year redesign cadence	112.8	138.5	159.2	173.7	215.5	25.7	46.4	60.9	102.7	-12%	10%	186%
Battery direct costs (-20%)	133.2	136.8	159.3	175.0	220.5	3.6	26.1	41.9	87.3	4%	10%	61%
Battery direct costs (+20%)	137.8	123.6	143.3	157.2	197.0	-14.2	5.5	19.3	59.2	7%	-1%	-66%
Battery learning rate (-20%)	135.6	124.4	144.8	159.1	200.3	-11.3	9.1	23.4	64.7	6%	0%	-44%
Battery learning rate (+20%)	123.3	123.9	144.2	158.4	199.4	0.6	20.9	35.1	76.1	-4%	0%	29%
Flat AC/OC	137.1	131.1	152.3	167.1	209.9	-6.0	15.1	30.0	72.8	7%	5%	-7%
Limited HCR skip	144.6	131.3	153.5	169.1	214.1	-13.4	8.9	24.5	69.5	13%	6%	-45%
Limited conventional tech. improvement	125.3	122.2	142.2	156.3	196.8	-3.2	16.9	30.9	71.5	-2%	-2%	4%
Oil price (EIA AEO 2021 low)	141.5	103.3	126.8	143.3	190.7	-38.2	-14.7	1.7	49.2	10%	-12%	-191%
Oil price (Global Insight)	123.8	95.6	114.8	128.2	167.0	-28.2	-9.0	4.4	43.2	-4%	-21%	-155%
Oil price (EIA AEO 2021 high)	110.4	152.5	169.4	181.2	215.4	42.1	59.0	70.8	105.0	-14%	17%	263%
No payback period	135.8	128.2	150.6	166.4	211.7	-7.6	14.8	30.5	75.9	6%	4%	-9%
24-month payback period	135.2	134.0	156.1	171.6	216.3	-1.3	20.9	36.4	81.1	5%	8%	28%
36-month payback period	122.2	115.1	134.0	147.3	185.7	-7.2	11.8	25.1	63.5	-5%	-7%	-27%
60-month payback period	107.0	103.1	119.3	130.6	163.4	-3.9	12.3	23.7	56.4	-17%	-18%	-24%
30-month fuel-savings value (70k miles)	120.9	127.7	148.7	163.4	205.8	6.7	27.7	42.4	84.9	-6%	3%	71%
Implicit opportunity cost	154.5	124.2	144.6	158.9	200.3	-30.3	-9.9	4.4	45.7	20%	0%	-161%
Rebound (5%)	118.6	119.1	140.0	154.7	197.0	0.4	21.4	36.1	78.4	-8%	-3%	32%

Sensitivity Case	Total Social Costs	Total Social Benefits				Net Social Benefits				% diff from RC (at 3%)		
		5%	3%	2.5%	3% @ 95th	5%	3%	2.5%	3% @ 95th	Costs	Benefits	Net benefits
Rebound (15%)	138.1	129.3	149.3	163.2	203.5	-8.8	11.1	25.1	65.4	8%	3%	-32%
Sales-scrappage response (η = -0.1)	125.3	126.7	147.4	162.0	204.0	1.4	22.2	36.7	78.7	-2%	2%	36%
Sales-scrappage response (η = -0.5)	129.5	123.4	143.7	157.9	199.0	-6.1	14.2	28.5	69.6	1%	-1%	-12%
NPRM sales-scrappage response (η = -1)	134.9	119.4	139.1	153.0	192.9	-15.5	4.3	18.1	58.1	5%	-4%	-74%
Low GDP	119.3	118.1	137.6	151.4	190.9	-1.2	18.4	32.1	71.6	-7%	-5%	13%
High GDP	135.2	130.5	152.0	167.0	210.4	-4.7	16.8	31.8	75.2	5%	5%	3%
Low GDP (+ fuel prices)	114.5	98.7	116.9	129.7	166.5	-15.8	2.4	15.2	51.9	-11%	-19%	-85%
High GDP (+ fuel prices)	139.7	103.3	125.5	141.1	186.1	-36.4	-14.2	1.4	46.3	9%	-13%	-187%
NPRM macro forecast	129.3	126.8	147.6	162.3	204.5	-2.5	18.3	33.0	75.2	1%	2%	13%
Alt. DFS model (fixed)	132.6	132.8	154.9	170.5	215.2	0.1	22.3	37.8	82.6	3%	7%	37%
Alt. DFS model (varying)	137.9	164.7	192.4	211.9	268.0	26.8	54.5	74.0	130.1	7%	33%	236%
Mass-size-safety (low)	119.7	123.8	144.3	158.6	199.9	4.2	24.6	38.9	80.2	-7%	0%	51%
Mass-size-safety (high)	137.0	124.6	145.0	159.3	200.6	-12.5	8.0	22.3	63.6	7%	0%	-51%
Crash avoidance (low effectiveness)	128.3	124.0	144.5	158.8	200.1	-4.2	16.2	30.5	71.9	0%	0%	0%
Crash avoidance (high effectiveness)	128.5	124.3	144.8	159.1	200.4	-4.2	16.3	30.6	71.9	0%	0%	0%
Reduced power plant emissions	127.4	123.3	143.9	158.4	200.0	-4.1	16.6	31.0	72.7	-1%	0%	2%
Lepeule criteria pollutant BPT estimates	128.4	126.0	146.5	160.8	202.1	-2.3	18.1	32.4	73.7	0%	1%	11%
No ZEV mandates	130.3	128.7	149.7	164.4	206.8	-1.7	19.3	34.0	76.5	2%	3%	19%
Fixed nominal fine rate	129.6	124.6	145.1	159.4	200.8	-5.0	15.5	29.8	71.2	1%	0%	-5%
Unadjusted MDPCS stringency	128.4	124.2	144.6	158.9	200.3	-4.2	16.3	30.6	71.9	0%	0%	0%
EPCA constraints throughout MYs 2023-2029	150.0	140.3	162.1	177.4	221.6	-9.7	12.2	27.5	71.6	17%	12%	-25%

Sensitivity Case	Total Social Costs	Total Social Benefits				Net Social Benefits				% diff from RC (at 3%)		
		5%	3%	2.5%	3% @ 95th	5%	3%	2.5%	3% @ 95th	Costs	Benefits	Net benefits
No response of domestic crude production	128.4	124.2	144.7	159.0	200.3	-4.2	16.3	30.6	71.9	0%	0%	0%
Constrained PHEV FE compliance values	130.0	129.6	150.3	164.7	206.5	-0.3	20.3	34.8	76.6	1%	4%	25%

Table 7-3 – Summary of Selected Model Metrics for Sensitivity Cases (MYs 1981-2029, Alt. 2.5, 3 Percent Discount Rate)

Sensitivity Case	Gasoline consumption (billion gallons)	Electricity consumptio n (TWh)	CO_2 emission s (MMT)	Fatalitie s	Fleet avg curb weight (MY 2029, lbs)	Regulator y cost (MY 2029, \$/vehicle)	Vehicle cost (MY 2029, \$/vehicle)	Retail fuel outlay (MY 2029, \$/vehicle)
RC	-60	179	-607	1,335	-32.9	1,087	1,276	-1,377
EIS-RC	-59	236	-580	1,143	-30.7	999	1,175	-1,320
MR5/6 skip (>100k)	-60	179	-607	1,335	-32.9	1,087	1,276	-1,377
MR5/6 skip (>2k)	-60	181	-608	1,251	-31.8	1,021	1,200	-1,381
No MR5/6 skip	-59	176	-598	2,000	-42.6	1,767	2,069	-1,338
2020 Final Rule MR5/6 costs	-60	180	-608	1,297	-32.9	1,046	1,229	-1,381
One-year redesign cadence	-57	41	-616	1,356	-19.6	971	1,146	-1,651
Battery direct costs (-20%)	-67	215	-668	1,295	-35.5	1,041	1,224	-1,507
Battery direct costs (+20%)	-58	169	-585	1,608	-50.2	1,195	1,406	-1,359
Battery learning rate (-20%)	-60	180	-605	1,543	-43.5	1,156	1,359	-1,382
Battery learning rate (+20%)	-60	172	-602	1,240	-30.0	1,045	1,226	-1,362
Flat AC/OC	-62	165	-629	1,466	-35.8	1,160	1,362	-1,397
Limited HCR skip	-67	227	-662	1,406	-34.2	1,153	1,354	-1,439

Sensitivity Case	Gasoline consumption (billion gallons)	Electricity consumption (TWh)	CO_2 emissions (MMT)	Fatalities	Fleet avg curb weight (MY 2029, lbs)	Regulatory cost (MY 2029, $/vehicle)	Vehicle cost (MY 2029, $/vehicle)	Retail fuel outlay (MY 2029, $/vehicle)
Limited conventional tech. improvement	-60	203	-596	1,307	-36.0	1,106	1,299	-1,331
Oil price (EIA AEO 2021 low)	-68	179	-697	1,768	-45.3	1,191	1,402	-1,174
Oil price (Global Insight)	-57	183	-570	1,503	-32.7	1,049	1,231	-1,079
Oil price (EIA AEO 2021 high)	-51	175	-502	876	-31.3	958	1,121	-1,647
No payback period	-70	298	-668	1,424	-34.2	1,158	1,361	-1,482
24-month payback period	-66	221	-657	1,392	-42.0	1,152	1,354	-1,549
36-month payback period	-56	170	-564	1,279	-30.2	1,051	1,233	-1,287
60-month payback period	-46	90	-480	1,113	-31.2	928	1,090	-1,088
30-month fuel-savings value (70k miles)	-62	179	-623	803	-32.9	1,087	1,274	-1,403
Implicit opportunity cost	-60	179	-607	1,335	-32.9	1,087	1,676	-1,377
Rebound (5%)	-62	179	-622	1,037	-32.9	1,087	1,276	-1,419
Rebound (15%)	-59	179	-592	1,632	-32.9	1,087	1,276	-1,334
Sales-scrappage response (η = -0.1)	-61	181	-616	984	-32.9	1,088	1,275	-1,428
Sales-scrappage response (η = -0.5)	-60	178	-604	1,452	-32.9	1,087	1,277	-1,357
NPRM sales-scrappage response (η = -1)	-59	176	-588	2,042	-32.9	1,087	1,281	-1,272
Low GDP	-58	182	-582	1,319	-32.3	1,090	1,280	-1,460
High GDP	-63	187	-637	1,347	-27.9	1,087	1,276	-1,366
Low GDP (+ fuel prices)	-54	167	-542	1,430	-34.4	1,049	1,229	-1,247
High GDP (+ fuel prices)	-65	194	-660	1,665	-33.7	1,106	1,299	-1,071
NPRM macro forecast	-62	185	-620	1,378	-33.8	1,088	1,278	-1,426
Alt. DFS model (fixed)	-65	198	-659	1,307	-50.7	1,127	1,299	-1,538

Sensitivity Case	Gasoline consumption (billion gallons)	Electricity consumption (TWh)	CO_2 emissions (MMT)	Fatalities	Fleet avg curb weight (MY 2029, lbs)	Regulatory cost (MY 2029, $/vehicle)	Vehicle cost (MY 2029, $/vehicle)	Retail fuel outlay (MY 2029, $/vehicle)
Alt. DFS model (varying)	-81	214	-826	989	-112.5	1,113	1,180	-1,888
Mass-size-safety (low)	-60	179	-607	780	-32.9	1,087	1,276	-1,377
Mass-size-safety (high)	-60	179	-607	1,886	-32.9	1,087	1,276	-1,377
Crash avoidance (low effectiveness)	-60	179	-607	1,333	-32.9	1,087	1,276	-1,377
Crash avoidance (high effectiveness)	-60	179	-607	1,335	-32.9	1,087	1,276	-1,377
Reduced power plant emissions	-60	187	-612	1,304	-33.1	1,088	1,277	-1,373
Lepeule criteria pollutant BPT estimates	-60	179	-607	1,335	-32.9	1,087	1,276	-1,377
No ZEV mandates	-61	168	-623	1,438	-52.0	1,133	1,333	-1,466
Fixed nominal fine rate	-60	177	-607	1,345	-32.1	1,078	1,267	-1,362
Unadjusted MDPCS stringency	-60	179	-607	1,335	-32.9	1,087	1,276	-1,377
EPCA constraints throughout MYs 2023-2029	-64	166	-649	1,538	-37.2	1,264	1,483	-1,458
No response of domestic crude production	-60	179	-607	1,335	-32.9	1,087	1,276	-1,377
Constrained PHEV FE compliance values	-59	103	-613	1,455	-39.4	1,072	1,260	-1,403

Table 7-4 – Summary of Technology Penetration Rates for Sensitivity Cases (MY 2029)

Sensitivity Case	Engine						Hybrid/Electrification					
	Turbo		HCR/HCR2		Advanced cyl. deactivation		SHEV		PHEV		BEV	
	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0
RC	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5
EIS-RC	40.0	-2.5	22.2	-0.9	33.5	-1.3	13.3	+7.4	0.3	+0.1	10.3	+4.6
MR5/6 skip (>100k)	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5
MR5/6 skip (>2k)	41.4	-3.9	21.6	-1.5	35.2	+2.8	21.2	+14.0	3.1	+2.4	6.7	+1.5
No MR5/6 skip	41.4	-3.9	21.7	-1.4	35.1	+2.8	21.2	+14.0	3.1	+2.4	6.7	+1.5
2020 Final Rule MR5/6 costs	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5
One-year redesign cadence	37.5	-7.0	25.2	+0.9	38.2	+3.5	27.4	+20.8	0.1	+0.1	6.5	+1.6
Battery direct costs (-20%)	35.9	-6.3	22.9	-0.4	32.1	+3.3	23.4	+16.1	2.7	+2.2	8.7	+2.4
Battery direct costs (+20%)	37.9	-5.8	23.0	-0.2	32.5	-0.5	17.9	+11.0	3.7	+2.8	6.0	+1.2
Battery learning rate (-20%)	40.1	-3.6	21.2	-1.9	32.6	-0.3	21.0	+13.7	3.2	+2.4	6.4	+1.5
Battery learning rate (+20%)	40.0	-3.2	21.6	-1.4	34.9	+2.6	21.1	+13.8	3.1	+2.4	7.0	+1.4
Flat AC/OC	36.9	-8.9	22.3	-1.0	34.7	+5.3	24.0	+16.6	3.6	+2.4	6.8	+1.2
Limited HCR skip	28.2	-7.4	36.2	-1.4	21.0	-1.0	21.6	+13.9	2.8	+2.1	7.4	+2.2

Sensitivity Case	Engine						Hybrid/Electrification					
	Turbo		HCR/HCR2		Advanced cyl. deactivation		SHEV		PHEV		BEV	
	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0
Limited conventional tech. improvement	48.1	-0.5	8.1	-2.6	14.1	-5.1	25.3	+15.5	4.2	+3.5	6.4	+0.9
Oil price (EIA AEO 2021 low)	38.6	+0.2	19.7	+1.7	36.5	+4.5	21.0	+14.1	3.2	+2.4	6.2	+1.6
Oil price (Global Insight)	39.9	-1.8	23.2	-1.7	32.4	+0.9	20.8	+13.6	3.0	+2.3	6.7	+1.8
Oil price (EIA AEO 2021 high)	37.1	-6.0	27.1	-3.2	29.5	+0.4	19.9	+12.4	3.3	+2.8	7.6	+1.1
No payback period	32.9	-5.9	22.3	+5.2	32.0	+4.8	14.7	+8.5	7.0	+5.1	6.6	+1.6
24-month payback period	36.8	-1.3	22.7	+3.1	35.0	+3.8	18.2	+11.4	4.2	+3.2	6.8	+1.7
36-month payback period	37.0	-6.4	24.9	-2.6	32.4	+2.4	21.7	+14.3	2.9	+2.3	6.8	+1.4
60-month payback period	38.3	-6.2	26.1	-3.7	34.6	-3.1	26.1	+18.6	1.8	+1.5	6.9	+1.0
30-month fuel-savings value (70k miles)	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5
Implicit opportunity cost	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5
Rebound (5%)	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5

Sensitivity Case	Engine						Hybrid/Electrification					
	Turbo		HCR/HCR2		Advanced cyl. deactivation		SHEV		PHEV		BEV	
	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0
Rebound (15%)	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5
Sales-scrappage response (η = -0.1)	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5
Sales-scrappage response (η = -0.5)	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5
NPRM sales-scrappage response (η = -1)	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5
Low GDP	39.9	-3.5	21.7	-1.4	34.8	+2.6	20.7	+13.4	3.3	+2.5	6.9	+1.5
High GDP	41.3	-4.2	21.5	-1.6	35.1	+2.5	21.7	+14.4	3.0	+2.3	6.7	+1.5
Low GDP (+ fuel prices)	39.6	-2.0	23.6	-2.2	32.4	-0.5	20.6	+13.5	3.0	+2.3	6.8	+1.7
High GDP (+ fuel prices)	41.7	+2.8	21.3	-0.7	36.0	+4.3	21.0	+13.6	3.0	+2.3	6.5	+1.6
NPRM macro forecast	41.4	-3.9	21.7	-1.4	35.3	+2.9	21.0	+13.8	3.2	+2.3	6.7	+1.6
Alt. DFS model (fixed)	38.9	-4.1	21.9	+0.3	39.7	+2.5	21.0	+13.6	3.2	+2.5	6.0	+1.7
Alt. DFS model (varying)	38.1	-4.9	22.9	+1.3	37.3	+0.1	21.0	+13.6	3.2	+2.6	6.3	+2.0
Mass-size-safety (low)	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5

Sensitivity Case	Engine						Hybrid/Electrification					
	Turbo		HCR/HCR2		Advanced cyl. deactivation		SHEV		PHEV		BEV	
	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0
Mass-size-safety (high)	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5
Crash avoidance (low effectiveness)	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5
Crash avoidance (high effectiveness)	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5
Reduced power plant emissions	40.0	-3.5	21.7	-1.4	35.0	+2.6	20.7	+13.5	3.2	+2.5	6.7	+1.5
Lepeule criteria pollutant BPT estimates	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5
No ZEV mandates	37.6	-6.1	23.6	+0.1	35.2	+2.9	22.3	+14.8	3.6	+2.4	5.4	+1.5
Fixed nominal fine rate	39.4	-6.0	23.3	+0.2	35.2	+2.8	20.9	+13.8	3.2	+2.3	6.6	+1.4
Unadjusted MDPCS stringency	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5
EPCA constraints throughout MYs 2023-2029	38.3	-4.5	21.7	-2.5	34.7	+2.7	23.9	+17.1	4.9	+3.8	4.6	-0.1

Sensitivity Case	Engine						Hybrid/Electrification					
	Turbo		HCR/HCR2		Advanced cyl. deactivation		SHEV		PHEV		BEV	
	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0	Alt 2.5	Chg from Alt. 0
No response of domestic crude production	41.4	-3.9	21.7	-1.4	35.0	+2.7	21.2	+14.0	3.1	+2.4	6.7	+1.5
Constrained PHEV FE compliance values	38.4	-5.2	23.4	+0.3	36.9	+4.3	27.0	+19.0	0.5	+0.3	6.9	+1.5

7.2.2 Effect of Technology-Related Parameters

7.2.2.1 Mass Reduction

The assumptions we make about specific technology pathways inputs, technology constraints, or technology availability during the simulation can produce fluctuations in social net benefit totals as well. For example, high-level (and high cost) mass reduction technologies, if applied broadly, could theoretically strain existing supply networks for carbon fiber. We restrict MR5 and MR6 application to platforms with fewer than 40 thousand units in the central analysis. We further explored this constraint by running several sensitivity cases.[135]

- **MR5/6 skip (>100k)** – We raise the unit limit where MR5 and MR6 are applied to 100 thousand.
- **MR5/6 skip (>2k)** – We lower the unit limit where MR5 and MR6 are applied to 2 thousand.
- **No MR5/6 skip** – We remove all constraints on the application of the MR5 and MR6
- **MR Cost 2020FR** – We re-applied the costs for application of the MR5 and MR6 technologies used in the analysis for the 2020 final rule.

We saw small effects, most less than a 1 percent change, on overall program costs or benefits from expanding the limit or using the same costs from the 2020 final rule. Constraining the limit to platforms with 2,000 units produces minimal change to social benefits but decreases estimated social costs by 6 percent. This corresponds to a drop in average per-vehicle purchase cost.

When we remove all constraints on the MR5 and MR6 technologies, application of the high-level mass reduction technology nearly doubles average per vehicle costs and increases social costs by over 43 percent. This scenario does demonstrate the role that high-priced, advanced technologies can play, but the likelihood of this scenario playing out in practice is exceedingly small. It happens here when the analytical constraint is removed because the simulation is run with "standard setting" constraints, under which the model is limited in how it may apply (relatively less expensive) electrification, and thus chooses more expensive mass reduction to increase compliance fuel economy when given the opportunity to use MR. In practice, and even under the "unconstrained" runs discussed in the accompanying Final SEIS, electrification is likely to be a more viable option for significantly increasing fuel economy than high-level mass reduction, at least in the near- to mid-term.

7.2.2.2 Redesign Schedules

As discussed in Chapter 2.2.1.7 of the TSD, vehicle manufacturers establish redesign cadences for their vehicles considering the availability of capital and other resources, competitive position in certain market segments, the sales volume for each of the manufacturer's vehicle models, and the influence of regulatory requirements. As discussed in the preamble and elsewhere in this FRIA, NHTSA used an informed, historical review of redesign and refresh intervals to estimate

[135] For a discussion about how technology is constrained from a particular vehicle model or "skipped," see TSD Chapter 6.1.1.

future redesign and refresh intervals. However, the nature of automotive refresh and redesign cycles is not always consistent and can vary by model type, segment competitiveness, new entrants, or a manufacturer's capital availability, among other factors. To test an extreme case of redesign flexibility, one sensitivity allowed for annual vehicle redesigns. In this setting, the pool of available vehicle and technology combinations appears significantly greater for each manufacturer. This increases the likelihood of more optimal technology solutions being selected by the CAFE Model in each model year. This, in turn, could lead to a more optimal overall solution, producing higher overall consumer and social benefits, while at the same time lowering technology costs (if there were no costs associated with a redesign cadence this rapid, which the agency does not believe is likely). Table 7-2 shows the social benefits to increase by about 10 percent over the reference case and the costs declined by 10 percent. Similarly, Table 7-3 shows a similar trend in other metrics with increased benefits and decreased costs. For example, there is a 6 percent decrease in fuel consumption and an average of $90 per-vehicle cost decrease compared to reference case. This reflects the immediate adoption of fuel saving technology for manufactures in unrealistic year-over-year redesigns for each vehicle and avoids adoption of costly technologies in the future years. While this demonstrates the value of nimble manufacturer response to fuel efficiency requirements, it is an unrealistic representation of manufacturers' ability to modify their vehicle portfolios. This case does not account for the costs of stranded capital from such high frequency, nor scaling up of the facilities and development and design teams required to implement annual redesign schedules across the portfolio. These costs would likely be significant, and the CAFE Model does not currently estimate or incorporate these into overall program cost estimates.

7.2.2.3 Battery Costs

Sensitivity results in Table 7-2 include cases for two determinants of electrification technology costs: direct costs of batteries and battery learning costs. The sensitivity analysis includes versions of the model with battery DMCs 20 percent higher and lower than their reference case levels. Similarly, we analyze scenarios where the rate of battery learning is 20 percent higher and lower than its reference case level. Figure 7-3 includes indexed cost values for battery cost trajectories under all four scenarios along with the reference case. As discussed in TSD Chapters 3.3.5.1.3 and 3.3.5.1.4, we compared our projected battery pack costs to the projected pack costs from other sources to assess the learning rate applied in the central analysis. The survey of other sources' projected pack costs showed that most projected costs fell within ±20 percent of our costs, including any potential increases in any raw material cost. Therefore, we determined that limiting sensitivity cases to examining the impacts of increasing and decreasing the direct cost of batteries and battery learning costs by 20 percent from their reference case levels was reasonable. The measure presented in the figure is BEV300 battery cost indexed to the MY 2020 battery pack cost. The curves in the graph illustrate the differences in the two battery cost categories over time. Battery direct costs are a fixed ratio of the reference cost values. Learning cost scenarios gradually deviate from the reference level. This is especially important to note when coupled with the timing of most electrification technology application. Model runs with greater levels of electrification earlier will see a smaller effect from accelerated learning cost changes.

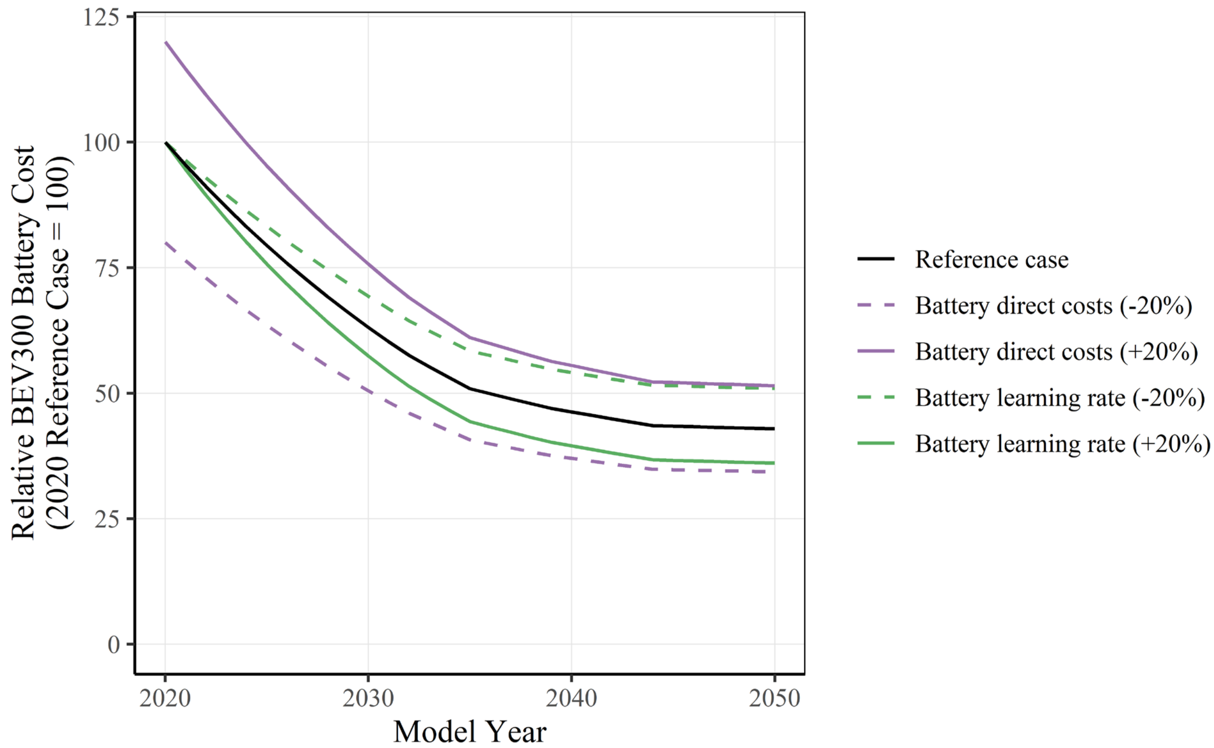


Figure 7-3 – Battery Cost Sensitivity Cases

Lower battery DMCs have the largest effect on electrification technology application, especially the role of BEVs and PHEVs. When comparing the extreme cases, the electrification technology adoption is within 1.4 percent of the central case. However, in the case of BEV300, lower battery DMCs have marginally more effect on electrification technology adoption by 2030. This is expected, as manufacturers could choose broader application of BEVs and reduce the number of PHEVs and SHEVs offered. Across all battery cost scenarios, social benefits do not deviate from the reference case by large amounts; there is less than a 1 percent difference in PHEV and BEV technology penetration rates between the reference case sensitivity No-Action and Preferred Alternative deltas, versus the four battery sensitivity No-Action and Preferred Alternative deltas. For example, the baseline standard versus the Preferred Alternative for Total BEV and FCV was 1.5 percent, whereas the difference for the Battery DMC -20 percent case between the baseline and preferred case was 2.4 percent. See Table 7-4 for changes in technology penetrations for all sensitivity cases and further discussion of the results in Chapter 6.3.1 . The average difference in vehicle cost between the reference case and four battery sensitivity cases ranged from an average per vehicle cost of $57 less than reference case, to an increase of $143. The DMC -20 percent case had the lowest per-vehicle cost while the DMC +20 percent case had the largest vehicle cost difference, indicating that the learning rate had less of an impact on the per-vehicle cost. The scenario with direct battery cost reductions of 20 percent reduces social costs by 4 percent compared to the reference case, while battery costs 20 percent higher than reference case levels increase social costs by 7 percent. This results in net benefits of approximately $26.1 billion and $5.5 billion, respectively, compared to the $16.3 billion for the reference case. Though smaller in magnitude, adjustments to battery learning rate assumptions are also of note, with 20 percent faster learning producing net benefits of $9.1

billion and 20 percent slower learning at approximately $20.9 billion. There is a notable difference in gasoline consumption and electricity consumption for DMC -20 percent and DMC +20 percent cases. The DMC -20 percent case resulted in a 11 percent reduction in gasoline consumption and a 20 percent increase in electricity consumption. Conversely, the DMC +20 percent resulted in a 2 percent increase in gasoline consumption and 6 percent reduction in electricity consumption. The learning rate cases produce insignificant results in gasoline consumption—less than 1 percent. The DMC decrease of 20 percent case resulted in 20 percent increase in electricity consumption where the DMC increase of 20 percent case resulted in 6 percent reduction of electricity. The two learning rate cases showed a similar trend, but had smaller magnitude in electricity consumption. The 20 percent decrease in learning rate case resulted in 1 percent increase in electricity consumption where the 20 percent increase learning rate case resulted in 4 percent decrease electricity consumption. These results are expected as increases and decreases in electrification forced manufactures to adopt other types of technologies. See Table 7-2 and Table 7-3 for these cost metrics.

7.2.2.4 Flat Off-Cycle and AC Efficiency

OC and AC efficiency technologies can provide fuel economy benefits in real-world vehicle operation. As discussed in TSD Chapter 3.8, our analysis considers manufacturers adopting OC and AC technologies as a part of their compliance strategies. We believe that these flexibilities represent an interim option for manufacturers as they explore future implementation into more advanced technologies. However, there could be cases where some manufacturers do not reach the maximum cap. The ‘flat’ OC and AC sensitivity case evaluates the scenario where no further improvements in OC and AC occur after MY 2021. The estimated credits for MY 2021 for each manufacturers’ fleet are used for MY 2022 and beyond for this sensitivity case.

The aggregate social cost and benefit results for this sensitivity case show a 7 percent increase in total costs and 5 percent increase in total benefits compared to the reference case. More specifically, gasoline consumption decreased by about 3 percent, electricity consumption decreased by about 8 percent, and both the regulatory cost and vehicle cost increased by about 7 percent. By removing the ability to meet the standards with OC and AC flexibilities, manufacturers are forced to adopt advanced technologies, such as electrification, at a quicker rate, which yields more benefits to consumers and positive externalities. Table 7-4 shows this occurring as there are small decreases in conventional technologies like IC engines and increases in electrified technologies in both the No-Action Alternative and Preferred Alternative.

7.2.2.5 Engine Technologies

We ran two sensitivity cases to further inform our decisions concerning constraints we apply to the application of engine technologies in the standard setting analysis. One case removed all constraints on application of the existing HCR engine technologies are. Another case constrained all further application of advanced engine technologies. These analyses provide insight into the potential boundaries of conventional engine improvements.

hcr_skip_limited – We removed all adoption constraints for the HCR0, high compression ratio engine, level 1 (HCR1) and high compression ratio engine, level 1 with DEAC (HCR1D) technologies.

HCR technology penetration increased by approximately 14.5 percent when we removed the constraints on application of the HCR technologies. This resulted in an increase in both societal costs and societal benefits, but ultimately a reduced net benefit, by 3.3 percent. The reduction in net benefits is a result of increases in vehicle cost outpacing the benefits of applying the additional HCR technology.

conv-tech-impr-limited – We disabled application of all advanced engine technologies during the simulation for vehicles that did not start with advanced technology.

As a result of the concerns expressed in the comments regarding the reduction in advanced engine technology investment, we included a sensitivity analysis with inputs assuming vehicle manufacturers would no longer deploy advanced engine technologies.[136] We designed the sensitivity analysis to simulate a potential technology path where manufacturers choose to stop applying additional ICE improvements and only invest in partial or full electrification technologies going forward. Our "no advanced engines" sensitivity analysis shows a modest increase in SHEV and PHEV technology adoption compared to the central analysis. This represents a modest increase in penetration of 1-4 percent of SHEVs and PHEVs, showing manufacturers could meet the standards without the adoption of additional advanced ICE technology. The "no advanced engine" technology pathway increases the estimated average vehicle costs by $23 over the reference analysis. The sensitivity run resulted in both lower societal costs (-2.4 percent) and lower societal benefits (-1.6 percent). However, the change in costs and benefits resulted in a slightly higher net benefit.

7.2.3 Effect of Economic Parameters

7.2.3.1 Oil Prices

One of the most significant sources of uncertainty in transportation market outcomes is the cost of fuel. Fuel costs affect the program net benefit calculation both in the year when new vehicles are produced, and in subsequent years when vehicles are used. In the central analysis, the rising price of fuel over time creates fuel savings (in dollars) above and beyond the anticipated savings at the time of purchase. Under the high fuel price case, this phenomenon is more pronounced.

Figure 7-4 presents the fuel price time series for the reference case and sensitivity cases alongside historical fuel price levels in 2018 dollars. The historical trend highlights the amount of price variability in past years. While future trends in prices are uncertain, this sensitivity analysis relies on three price projections: high- and low-price projections from AEO 2021 that rely on EIA assumptions about future oil price trajectories, and a price forecast from the IHS Markit (IHS) GI October 2021 forecast. Details of these price projections are available in Chapter 4.1.2 of the accompanying TSD. It is important to note that all of these estimates were made prior to the Russian invasion of Ukraine and thus do not account for any price effects of that conflict. In broad terms, the high, low, and reference price projections represent high, low, and moderate growth trends in fuel prices. The GI forecast differs from EIA's assumption of moderate growth and instead shows a pattern of retail gasoline price declines after a large

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[136] *See, e.g.*, Ford Motor Company, Docket No. NHTSA-2021-0053-1545-A1 at 1; Volkswagen Group of America, Docket No. NHTSA-2021-0053-1548-A1 at 21-22; Toyota Motor North America, Inc., Docket No. NHTSA-2021-0053-1568 at 2; Alliance for Automotive Innovation, Docket No. NHTSA-2021-0053-0021-A1 at 8.

increase above 2020 levels in 2021. The series approaches EIA's low oil price forecast value in 2050.

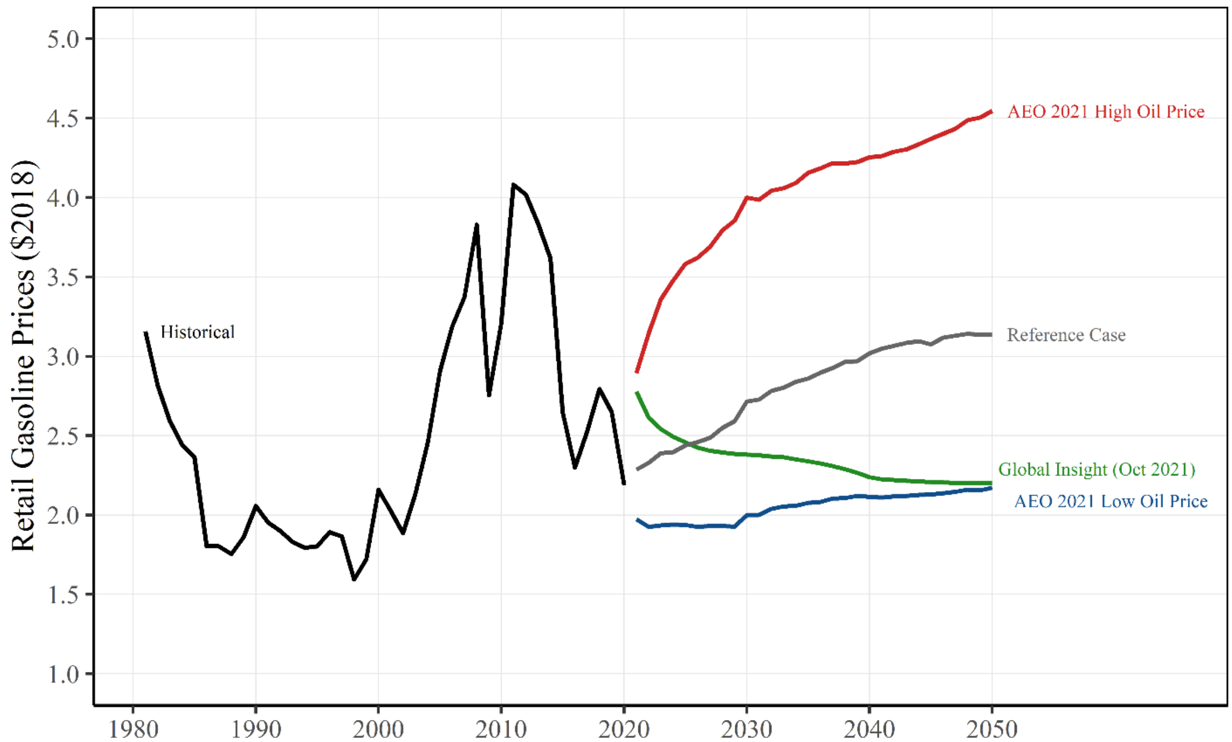

Figure 7-4 – Fuel Price Sensitivity Cases

In the case of increasing fuel prices—especially the rapid increase in the high oil price scenario—consumers foreseeably demand more fuel economy in the new vehicle market because each gallon of fuel saved during the 30-month payback period is worth more. As a result, more fuel-saving technology is applied in the baseline, and the number of gallons saved under the Preferred Alternative (as compared to the baseline) is muted – though each gallon saved is worth more than in the reference case. The opposite is true in the low oil price case. This can be seen in the average vehicle cost results of Table 7-3, where the difference in costs between the No-Action Alternative and Alternative 2.5 are smaller in the high oil price case than in the reference case (and vice versa for low oil prices). Average fuel savings are correspondingly higher. Lower costs and greater avoided fuel expenditure produce significantly higher total social benefits and lower total social costs. Together, the high oil price case results in net benefits of approximately $59 billion relative to the No-Action Alternative. Effects in the low oil price case become negative. In a low gasoline price setting, the stringencies of Alternative 2.5 are binding for more manufacturers compared to what would be happening in the baseline and require technology application with smaller fuel savings returns (on a dollar basis). This translates to a decrease in overall social benefits and a corresponding increase in costs. Net benefits decline by more than $30 billion relative to the baseline. The GI forecast leads to costs similar to those of the reference case, but lower social benefits. The GI price trajectory produces a scenario in which costs are high relative to the central case during the period of regulation and lower after.

On net, this reduces net benefits over the useful lives of vehicles produced prior to MY 2030 by approximately $25 billion, but over the longer term, annual benefits in costs (i.e., in each calendar year) would approach those occurring under the low oil price forecast in AEO 2021.

The results of these oil price sensitivities lead to a wide range of potential net benefit outcomes from the Preferred Alternative. This is the product of two important factors. First, the price of fuel is one of the most significant determinants of the value of avoided fuel consumption. Large differences in this metric play a key role in influencing total social benefits. Second, the value of these fuel savings is a direct input into the effective cost metric used to determine technology application. Alongside technology costs, it is a primary factor in determining total social costs. Further, the price series used in this sensitivity analysis (especially the EIA high and low oil price forecasts) represent extremes of potential future price points, with prices ranging from just over $2 per gallon to $4.50 per gallon in 2018 dollars. The GI case is much different from the EIA cases in that it represents a consistent decrease in prices. While not indicated in the figure above due to current events in Eastern Europe, the EIA's Annual Energy Outlook (AEO) updated in March 2022 forecasts higher oil prices from 2022 until 2030, compared to the High Oil Price sensitivity of AEO 2021. Further, the EIA's March 2022 Short Term Energy Outlook projects prices in the High Oil Price range for 2022 and 2023. It is worth emphasizing the challenge in forecasting future energy prices with certainty. Note, this short term outlook was completed days prior to the European Commission announcement of a plan to plan to wean Europe from imports of Russian oil "well before 2030." The effect of Europe's plan on gasoline prices in the United States is not known but would be implicated by the U.S. domestic demand for gasoline and whether domestic producers and refiners can provide an alternative supply to the European market. In evaluating the sensitivity of the model to these oil price cases, it is important to note as well that the high- and low-price cases are not symmetrical. There is a greater difference between the reference case and the high case, than the reference and low case. However, there is also no period in the historical series that represents *sustained* real prices as high as the high oil case beyond 2035.

7.2.3.2 Payback Period

New vehicle buyers have a variety of preferences for vehicle attributes (e.g., seating capacity, interior volume, drive type, performance, and fuel efficiency, among many others). The current analysis characterizes buyers' preference for fuel economy improvements by the number of years required to offset the initial technology investment with avoided fuel costs – the payback period. Like the 2012, 2016, and 2020 versions of the CAFE Model, the current version applies the same payback period across all regulatory alternatives. The central analysis uses a 30-month payback period to quantify the average preference for fuel economy improvements in the new vehicle market. To examine the effect of this payback period, the sensitivity cases include a range of alternative payback period lengths (24-, 36-, and 60-month scenarios) as well as one case that eliminated the payback period entirely. With a longer payback period, more costly, but effective, technologies and technologies that offer smaller marginal fuel efficiency improvements become more attractive options. Technologies with higher costs, but also higher effectiveness, can appear more attractive (to both manufacturers and consumers) if the period over which fuel savings is valued is longer. More effective technologies will likely have higher monthly savings but, with shorter assumed payback periods, there still may not be enough months to accumulate sufficient fuel savings to offset the higher initial cost.

Sensitivity cases that vary payback period lengths produce results consistent with expectations: average vehicle costs, lifetime fuel savings, social benefits, and social costs (relative to the baseline) all decrease when compared to reference case levels for scenarios with payback periods longer than 30 months. Longer payback periods mean manufacturers apply more "extra" technology (i.e., technology beyond that necessitated by CAFE and CO_2 standards) under less stringent regulatory alternatives than under more stringent regulatory alternatives, thus reducing the estimated incremental impacts, benefits, and costs of more stringent new standards. The opposite is true (i.e., these measures increase) for scenarios with payback periods that are shorter than the reference case. Net benefits move identically with the exception of the scenario that eliminates the payback period; in this scenario, net benefits decline relative to the central case. One caveat to this scenario is that technology penetration rates in the No-Action Alternative differ from those in the other payback period cases, especially with respect to rolling resistance, aerodynamic, and mass reduction technologies. As expected, eliminating the payback period produces less technology adoption (in both the No-Action Alternative and the regulatory alternative). Eliminating the payback period means assuming manufacturers will act as if buyers are not willing to pay anything at all for improved fuel economy, no matter how much they are paying for gasoline (or, relevant to PHEVs and BEVs, how little they are paying for electricity).

Each of these results should be interpreted keeping in mind an important limitation of any case that involves modification only to the payback period used to simulate decisions to apply technology: the current sales and scrappage modules do not respond to changes in this payback period assumption, but rather to separate payback assumption specified when running the model. For today's final rule, DOT staff have updated the CAFE Model to support independent control of both of these payback periods.

Beyond simply varying the payback period length used to simulate manufacturers' decisions to apply technology, NHTSA included two additional scenarios that are pertinent to consumer willingness to pay and technology investment: (1) a scenario in which fuel savings were valued at 30-months (as in the central case), but 70,000 miles is used as the basis for valuation in the sales and scrappage models (twice as long as the 35,000 miles in the central case representing approximately 5 years of *consumer* value for fuel economy improvements), and (2) a case that includes a very rough approximation of potential consumer effects that may result from potential forgone vehicle attribute improvements that exceed the reference case 30-month payback period, referenced as an "implicit opportunity cost."

The first of these assesses sensitivity to the fuel savings consumers take into account when making purchasing and scrappage decisions. If consumers are willing to pay for more fuel savings than assumed in the reference case, but manufacturers' decisions are as if fuel savings are valued as in the reference case, the increased fuel economy resulting from the rule will result in fleet turnover somewhat faster than in the reference case (and will slightly increase overall sales). Because manufacturer assessment of consumer willingness to pay matches that of the central case, technology application and hence vehicle offerings are minimally different, but consumers purchase more of these vehicles. Overall, this reduces total social costs by 6 percent and increases social benefits by 3 percent, increasing net social benefits relative to the central case by approximately $11.5 billion. NHTSA's NPRM included an extensive theoretical discussion of consumer valuation of fuel economy, including a detailed theoretical analysis of consumer choices between vehicle performance and fuel economy when buyers are constrained by limited budgets and manufacturers by fuel economy standards. This sensitivity is meant to exemplify some of the concepts identified there. For more details, see 86 FR 49723-31 (Sept. 3, 2021).

The second assumes buyers' current perceived reluctance to purchase higher-mpg models, rather than being due to various market failures, instead means they view the opportunity costs of the desirable features , if any, that manufacturers may trade off against fuel economy improvements (or the price premium they would face for purchasing a model that offers both higher mpg and their desired levels of other attributes) as at least equal to the savings in outlays for fuel beyond the payback period used to represent their willingness to pay for fuel economy.[137] The central case assumes that buyers are willing to pay for fuel economy improvements they expect to repay their higher initial costs within the first 30 months they own a new car or light truck of vehicle operation. The implicit opportunity cost sensitivity case assumes that if consumers are willing to forgo the additional fuel savings that would result from spending more to purchase models that employ additional fuel-saving technology and achieve still higher fuel economy, the value they derive from using the savings in technology costs for other purposes must equal or exceed those forgone fuel savings. NHTSA approximates this value as the discounted value of fuel savings over the first 72 months buyers will own new vehicles less the undiscounted value of fuel savings over the first 30 months, but the agency recognizes that this is a rough and indirect approximation and that both values are likely to vary among individual vehicle buyers. The logic underlying this measure is that if consumers do not value fuel savings beyond 30 months but standards require manufacturers to make improvements in fuel economy that take longer to repay their costs, manufacturers will make accompanying trade-offs to vehicles' other desirable attributes (e.g., interior space and comfort, carrying capacity, ride quality, performance) or increase prices recover their higher costs, and in either case buyers will regard the outcome as less desirable than any fuel savings they would realize after 30 months. Imposing these opportunity costs or further price increases on new car and light truck buyers thus represents an additional cost of adopting fuel economy standards that are more demanding than those prevailing under the No-Action Alternative. Because any trade-off in potential improvements to other attributes are not directly observable (they may have occurred in the future under prevailing standards, but under the maximum feasible standards may not), their value must be inferred indirectly and in aggregate rather than itemized and valued explicitly. Operationally, the CAFE Model includes an "implicit opportunity cost" component that is populated in this sensitivity analysis. In MY 2029, the implicit opportunity cost is approximately $400 per vehicle at a 3 percent discount rate. This value increases with increasing stringency. As this measure is not included in the central case, total social costs increase. This case increases total social costs $26 billion, approximately $10 billion more than net social benefits in the reference case.

However, these estimates do not include potential countervailing effects. If manufacturers do trade off fuel economy and other vehicle attributes, contrary to the assumption of performance neutrality used in calculating compliance costs, our estimates may overstate the actual compliance costs of the standards. The CAFE Model's assumptions about the adoption of technologies in response to the standards sometimes results in technologies that may

[137] The case is conceptually equivalent to the assumption—applied in the central analysis and discussed above in Chapter 5.4 and in Chapter 7.4 of the TSD—that the incremental safety risk associated with additional driving implies some otherwise-unaccounted-for corresponding incremental value of that driving.

simultaneously improve fuel economy and other vehicle performance features, but the benefits of any such improved vehicle performance under the standards have not been estimated. In addition, some potentially forgone attributes may be associated with various externalities, such as increased accident rates associated with acceleration, and these countervailing effects have not been estimated. Some vehicle attributes may resemble "positional goods" to a degree where consumers derive some utility from a rank order of desirability (e.g., having "best in class acceleration"). In such a case, it is unclear that more stringent CAFE standards will impact consumers' relative positions in consumption of such attributes. However, NHTSA does not have sufficient information to determine whether, and to what extent, consumers' utility is a function of positionality.

Ultimately, this sensitivity analysis is not sufficiently robust to include in a primary analysis.

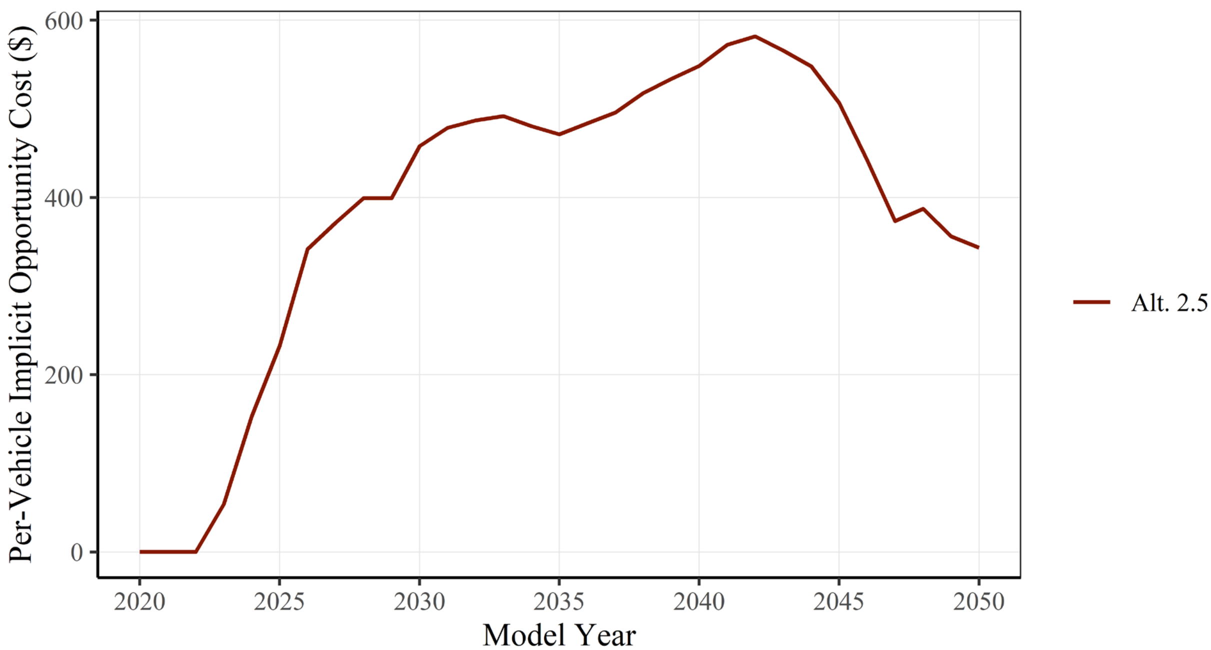

Figure 7-5 - Simulated Per-Vehicle Implicit Opportunity Cost (3 Percent Discount Rate)

7.2.3.3 Rebound Effect

The CAFE Model results are less sensitive to some parameters than others. As seen in Table 7-2, changing the rebound effect in either direction has a moderate impact on net benefits under Alternative 2.5. The central analysis uses a rebound effect of 10 percent, and the two sensitivity cases used assume 5 percent rebound and 15 percent rebound. The effect of these sensitivity cases on VMT for Alternative 2.5 relative to Alternative 0 is displayed in Figure 7-6.

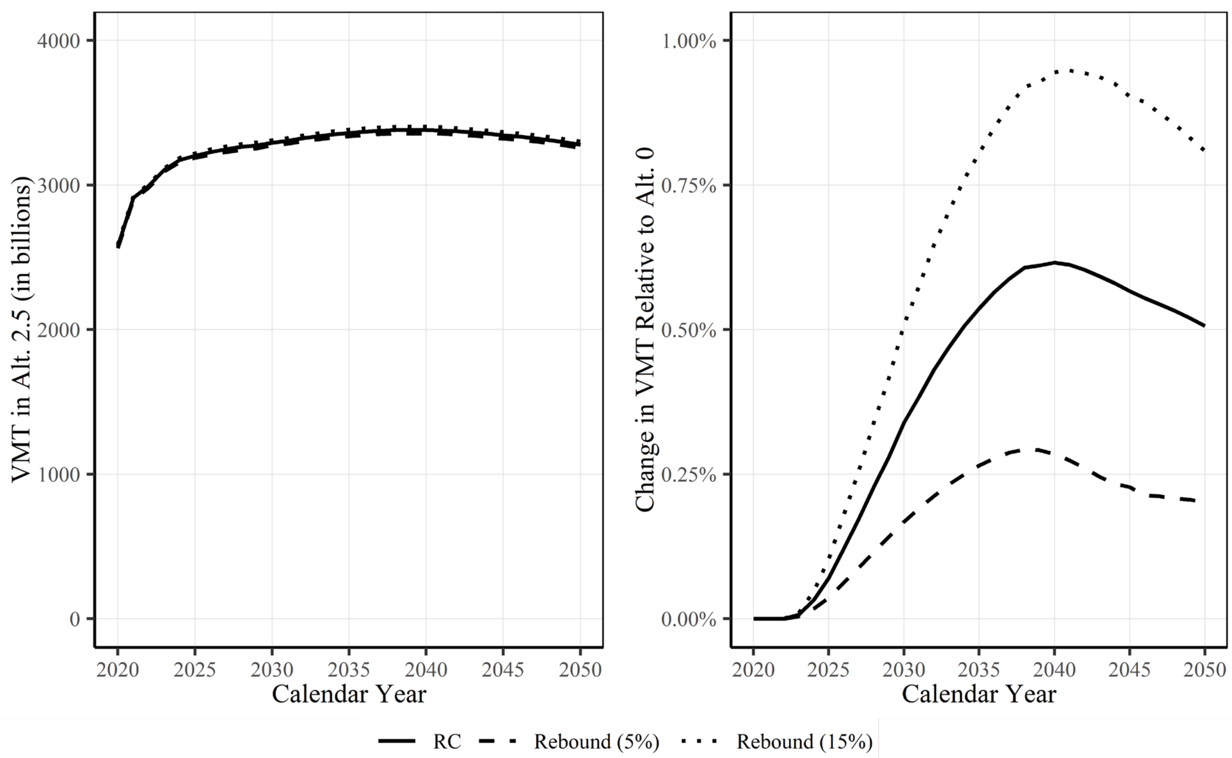

Figure 7-6 - Vehicle Miles Traveled in Alternative Rebound Cases

Using a 3 percent discount rate, assuming a rebound effect of 5 percent results in slightly lower costs and benefits (relative to the reference case), and an increase in net benefits, while assuming a rebound effect of 15 percent leads to higher cost and benefit values and a decrease in net benefits relative to the reference case. In both cases, benefits change by a magnitude of 3 percent, while costs change by a magnitude of 8 percent and net benefits change by a magnitude of 32 percent.

7.2.3.4 Sales and Scrappage Response

Sensitivity cases with adjusted sales and scrappage responses produce relatively small changes in costs and benefits. As shown in Table 7-2, we include three cases with different sales-scrappage responses. Two cases vary the price elasticity around the central case. The high elasticity case uses a price elasticity of -0.5 and the low elasticity case uses -0.1. Sales effects of Alternative 2.5 in each of these sensitivities are presented in Figure 7-7.

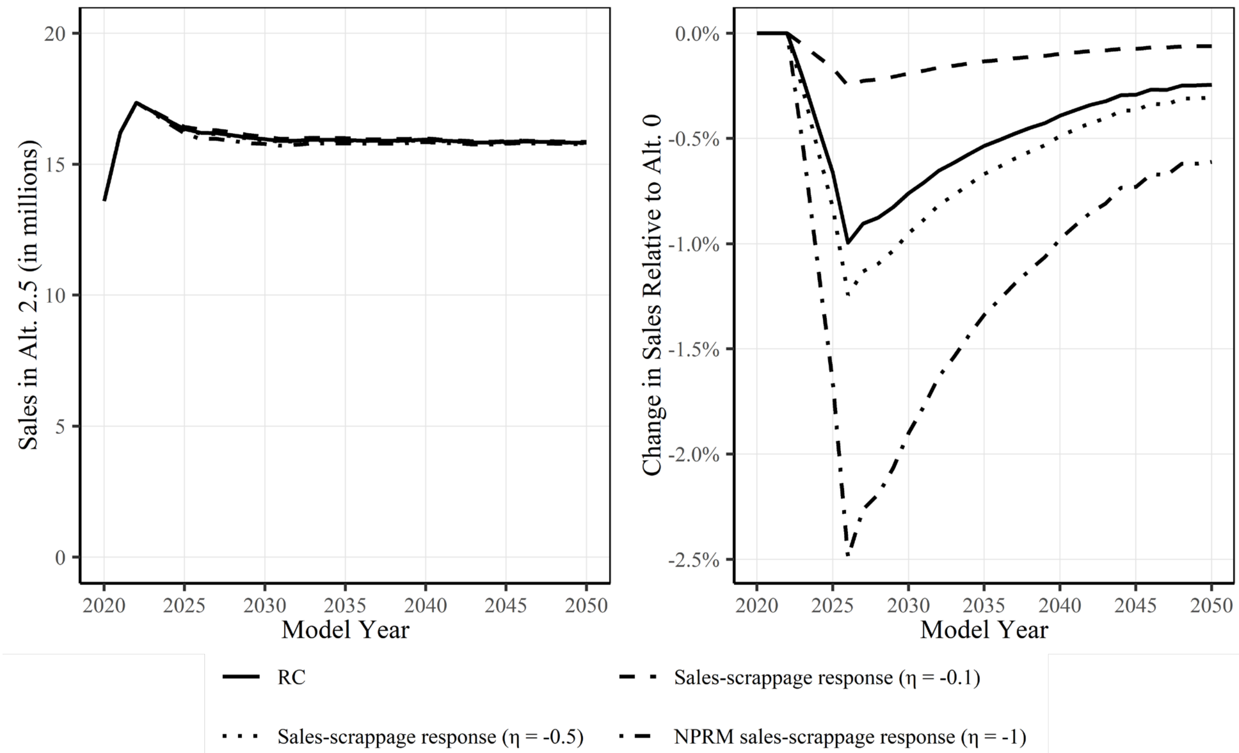

Figure 7-7 - Sales Effects of Alternative Price Elasticity Estimates

Readers should note the scale on the y-axis in the above picture. The high elasticity case increases costs by approximately 1 percent over the reference case and decreases benefits by approximately 1 percent. The low elasticity case reduces costs and increase benefits, changing each by approximately 2 percent.

As discussed in Section III.E.2 of the preamble, the assumed price elasticity in the central case is -0.4, a change from an elasticity of -1 in the NPRM. To examine effects of this adjustment, we also estimate a case using a price elasticity of -1. This adjustment causes single-digit percentage changes in costs and benefits: costs increase by 5 percent and benefits decline by 4 percent. Combined, this reduces net benefits by $12 billion at a 3 percent discount rate and net benefits remain positive at $4.3 billion.

7.2.3.5 Effect of Macroeconomic Growth

The CAFE Model relies on a set of macroeconomic assumptions related to Gross Domestic Product (GDP) growth, U.S. population, real disposable personal income, and consumer confidence to simulate the economic context in which CAFE regulations are implemented. These values affect the projected size of the new vehicle market, the rate at which the on-road fleet turns over, and the total demand for travel in light-duty vehicles. In this analysis, the reference case assumptions come from the IHS GI October 2021 Macroeconomic Outlook base case. Along with the case used in this rulemaking, IHS also produces "pessimistic" and "optimistic" estimates of the aforementioned macroeconomic parameters. The "Low GDP" and "High GDP" sensitivity cases in the tables and figures of Chapter 7.2.1 refer to our implementation of those two growth cases in the CAFE Model. In an attempt to vary only one input component at a time, these cases hold fuel prices fixed at the reference case level. Two additional cases include the corresponding fuel price series for gasoline and diesel.[138]

The lingering consequences of the COVID-19 pandemic have only increased the level of uncertainty that would typically be present in any projection of macroeconomic conditions that spans a period as long as the one covered by this analysis. In comparison to the net benefits for the reference case (see Table 7-2), the net benefits under the low GDP sensitivity case increase by 13 percent (using the 3 percent SC-GHG discount rate), costs decrease by 7 percent, and benefits decrease by 5 percent. Under the high GDP case, net benefits increase by 3 percent, costs increase by 5 percent, and benefits increase by 5 percent relative to the reference case. As both cases produce positive net benefits values similar to those of the reference case, this result should provide some measure of confidence that the estimated net benefits in the reference case are only somewhat sensitive to alternative growth assumptions about the U.S. economy.

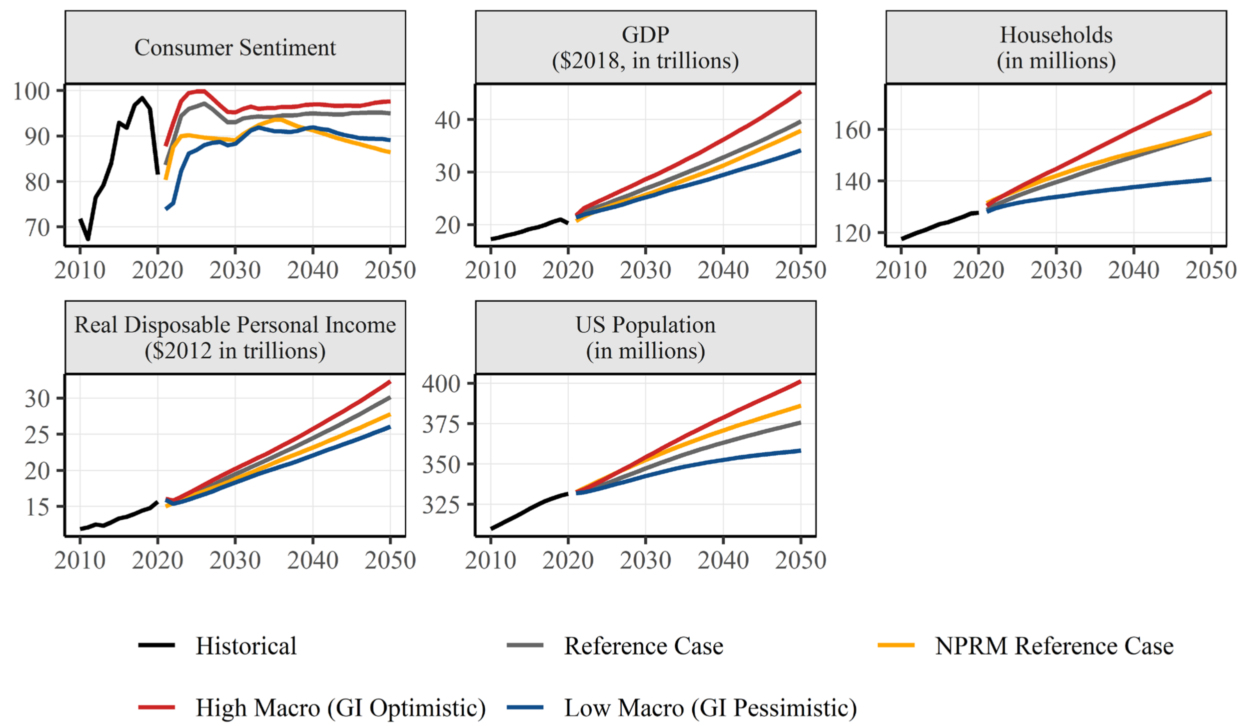

Figure 7-8 - Parameter Input Values for Macroeconomic Sensitivity Cases

The NPRM included macroeconomic forecasts from AEO 2021. As discussed in Section III.E.1 of the final rule preamble, the evolving macroeconomic consequences of the COVID-19 pandemic lead to a change to a more recent macroeconomic parameter set from IHS. To examine the effect of this change, NHTSA staff produced a sensitivity case based on the macroeconomic forecast used in the NPRM. The input values for this case along with the other

[138] Because the fuel prices are deviations from the IHS base gasoline price, these results are best compared to the Global Insight oil price scenario.

macroeconomic reference cases is presented in Figure 7-6. Compared to the central case, the NPRM macroeconomic assumptions lead to limited change in total social benefits and costs. Costs increase by 1 percent, benefits increase by 2 percent at a 3 percent discount rate, and corresponding net benefits increase by approximately $2 billon, or 13 percent.

7.2.3.6 Alternative Dynamic Fleet Share Formulation

Between the NPRM and this final rule, NHTSA staff explored alternative approaches to the CAFE Model's fleet share forecast methodology. Details of this investigation are included in a memo to this docket. The CAFE Model was modified to estimate effects using this alternative form. Results are included in the tables and figures of Chapter 7.2.1. This adjustment produces significant changes in benefits and costs: in a case that fixes the share of passenger cars (and hence light trucks) across alternatives, costs increase by 3 percent or $4 billion, and benefits increase by 7 percent or $10 billion; in a case that allows the share of passenger cars (and hence light trucks) to vary across alternatives, costs increase by 7 percent or $9.5 billion, and benefits increase by 33 percent or $48 billion.[139] The most obvious driver of this change is the difference in the estimated car and truck shares between the central case and the two alternative DFS cases. The alternative DFS model produces much lower passenger car shares, especially in the later analysis years. A fleet with a larger share of trucks—with lower fuel efficiencies on average—means the potential for higher marginal benefits from fuel efficiency standards. In the case where fleet mix is allowed to vary among alternatives, the alternative DFS produces higher shares of passenger cars with higher stringencies. Measures of benefits across alternatives in this case pick up technology effects of the policy as well as a mix-shift effect; the ratio of the two effects would vary with policy stringency.

7.2.4 Effect of Social and Environmental Parameters

7.2.4.1 Mass-Size Safety and Crash Avoidance

The two mass-size-safety sensitivity cases cause social costs to change by a magnitude of 7 percent, with positive net benefits in both cases. At a 3 percent discount rate, net benefits are $24.6 billion (lower-bound coefficient levels) and $8 billion (upper-bound coefficient values). These sensitivities produce fatality estimates that bound the central case, reducing fatality estimates by approximately 40 percent in the low case and increasing fatality estimates by 40 percent in the high case.

The crash avoidance effectiveness values are the least responsive out of all of the consumer and social parameters, as the two crash avoidance sensitivity cases show total social costs and benefits changing by less than 1 percent. Net benefits and fatality estimates see similarly small changes between cases.

[139] The choice to model both cases (fixed and variable across alternatives) is discussed in detail in the accompanying docket memo. In essence, because the alternative DFS does not include price as an explanatory variable, the extent to which a particular alternative affects car and truck market share is dictated by vehicle attributes (e.g., fuel efficiency) and does not account for differences in vehicle price (e.g., technology cost).

7.2.4.2 Low Renewables Cost (Clean Grid/Reduced Power Plant Emissions Case)

We created a clean grid sensitivity case to examine the effect of low renewable energy costs on the social costs, benefits, and net benefits of the rule. This sensitivity case is based on EIA's AEO 2021's low renewables cost case.[140] We incorporated these AEO values into the GREET Model's default national grid mix to view the effects on upstream emission factors. Changes to the upstream emission factors directly affect the emission inventories, pollutant costs, and health damages in the analysis. Overall, the results indicate that using the clean grid mix decreases social costs by 1 percent relative to the reference case (discounted at 3 percent) and increases net benefits by 2 percent, with no effect on social benefits. Figure 7-9 shows the difference in certain criteria pollutant emissions selected over CYs 2020-2050 for Alternative 2.5 in the clean grid case relative to the reference case. These upstream inventories diverge after 2030, demonstrating significantly lower emissions for the clean grid case.

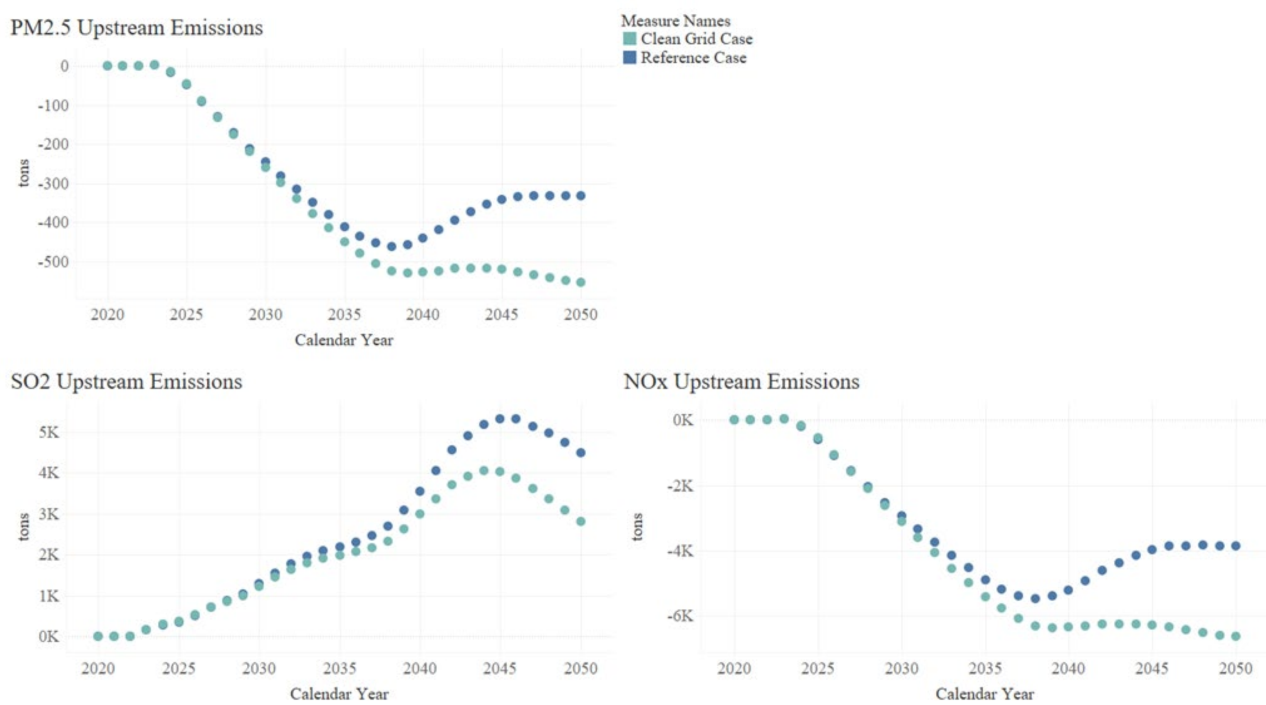

Figure 7-9 – Criteria Pollutant Emissions Under the Clean Grid Case and the Reference Case

7.2.4.3 Criteria Pollutant Health Damage Costs

Health damages related to criteria pollutant (NO_X, SO_X, $PM_{2.5}$) emissions are monetized in the CAFE analysis using benefit-per-ton (BPT) values from the latest available EPA sources. As discussed in TSD Chapter 5, several of the estimates in these papers are based on a study by

[140] *See* AEO 2021 Case Descriptions.
https://www.eia.gov/outlooks/archive/aeo21/assumptions/case_descriptions.php. (Accessed: March 28, 2022).

Krewski et al.[141] In this sensitivity case, we use values based on Lepeule et al[142] to examine how social benefits respond to changes in these estimates, under the Preferred Alternative. As seen in Table 7-1, using the Lepeule et al estimates leads to a 1 percent increase in social benefits, and an 11 percent increase in net benefits, with no effect on social costs. Reduced criteria pollutant emissions benefits were the only affected social benefits category, as this case changes only the monetized value for these benefits.

7.2.5 Effect of Policy-Related Parameters

7.2.5.1 No ZEV Program in Baseline

We modeled the California Air Resources Board (CARB)'s ZEV program in the baseline of the reference case, assuming that manufacturers would comply with those standards (see Chapter 2.3 of the TSD for further details of the ZEV modeling). As a sensitivity case, we removed the ZEV program from the baseline to examine its impact on social costs and benefits. Relative to the reference case, social benefits increase by 3 percent, costs increase by 2 percent, and net social benefits increase by 19 percent. Table 7-4 shows the impact of the No-ZEV case on technology penetration. For instance, the rates of SHEVs and PHEVs increase slightly in the No-ZEV case relative to the reference case, while the technology penetration rate of BEVs is slightly lower.

7.2.5.2 Fixed Nominal Fine Rate

EPCA allows manufacturers who do not achieve compliance with a CAFE standard in a given model year and who cannot apply credits sufficient to cover the compliance shortfall to pay civil penalties to the Federal Government. This sensitivity case represents the approach taken for the NPRM analysis. The approach taken for this final rule was updated to reflect new regulations. For discussion in the approach taken the final rule see TSD Chapter 2.2.2. Table 7-2, Table 7-3, and Table 7-4 show the results of the sensitivity case. This sensitivity reflects the slightly lower fine level that existed at the time of the NPRM. Overall, the impact of a slightly lower fine rate is small. There is an increase of 1 percent in social costs and a minimal increase in social benefits compared to reference case (which means the new higher rate has net benefits). The technology penetration simulations resulted in less than 3.7 percent increase electrification technology (PHEV and BEV) in MY 2029 compared to the reference case and this is indicative that in the reference case. On average, vehicle cost is $9 lower compared to the reference case.

7.2.5.3 Unadjusted MDPCS Stringency

NHTSA must set a minimum standard for domestically manufactured passenger cars, which is often referred to as the "MDPCS." Any time NHTSA establishes or changes a passenger car standard for a model year, the MDPCS must also be evaluated or re-evaluated and established accordingly. For the central analysis, we used an adjusted MDPCS based on cases that reflected historical difference between the MDPCS and actual MDPC performance. This sensitivity case

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141 Krewski D., M. Jerrett, R.T. Burnett, R. Ma, E. Hughes, Y. Shi, et al. 2009. Extended Follow-Up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality. HEI Research Report, 140, Health Effects Institute, Boston, MA.

142 Lepeule J, Laden F, Dockery D, Schwartz J. Chronic exposure to fine particles and mortality: an extended follow-up of the Harvard Six Cities study from 1974 to 2009. Environ Health Perspect. 2012 Jul;120(7):965-70.

does not adjust the value (92 percent) specified in 49 U.S.C. 32902(b)(4)(B). On average, the gasoline consumption, electricity consumption and vehicle price did not change between this sensitivity and the reference case. Similarly, the social costs and social benefits did not change for MDPCS and the reference case. Table 7-4 above did not show any notable change in technology penetration indicating that the preferred approach resulted in no changes in key metrics for this sensitivity case.

7.2.5.4 Constrained PHEV FE Compliance Values

As for the proposal and NPRM preceding today's notice and FRIA and notice, today's reference case assumes that, for each of MYs 2020-2050, manufacturers' compliance calculations would treat PHEVs as operating on electricity at estimated actual levels (ranging among MY 2020 PHEVs from about 30 percent of vehicle operation to about 80 percent). This sensitivity analysis case instead assumes that for MYs 2024-2026, these calculations would treat PHEVs as operating on gasoline only.

This sensitivity case results in minimal changes to total costs and benefits with total social costs increasing by one percent and total social benefits increasing by four percent. Net benefits increase by $4 billion. Effects in this case are small because the change alters PHEV technology penetration rates, which are low in the central case. In MY 2029, the PHEV technology penetration rate in Alt. 2.5 is 3.1 percent. This drops to 0.5 percent in this sensitivity case; instead of PHEVs, manufacturers rely on SHEV technology along with small increases in HCR and ADEAC. Higher levels of mass reduction are utilized as well, with more 15-percent mass reduction applied than in the central case (under Alternative 2.5 in MY 2029, 37 percent penetration rate in the constrained PHEV case, 32 percent in the central analysis).

7.2.6 Additional Sensitivity Results

Results of sensitivity analysis cases evaluated at a 7 percent social discount rate are presented in Table 7-5 and Table 7-6 below.

Table 7-5 – Summary of Social Costs and Benefits for Sensitivity Cases (MYs 1981-2029, Alt. 2.5, 7 Percent Discount Rate)

Sensitivity Case	Total Social Costs	Total Social Benefits				Net Social Benefits				% diff from RC (at 3%)		
		5%	3%	2.5%	3% @ 95th	5%	3%	2.5%	3% @ 95th	Costs	Benefits	Net benefits
RC	95.8	79.3	99.7	114.1	155.4	-16.5	3.9	18.3	59.6	-	-	-
EIS-RC	86.2	70.4	89.9	103.6	143.1	-15.8	3.7	17.4	56.8	-10%	-10%	-6%
MR5/6 skip (>100k)	95.8	79.3	99.7	114.1	155.4	-16.5	3.9	18.3	59.6	0%	0%	0%
MR5/6 skip (>2k)	90.0	79.6	100.1	114.4	155.8	-10.5	10.0	24.4	65.8	-6%	0%	154%
No MR5/6 skip	139.8	77.8	97.9	112.0	152.7	-62.0	-41.9	-27.8	12.8	46%	-2%	-1163%
2020 Final Rule MR5/6 costs	92.3	79.5	100.0	114.3	155.7	-12.8	7.7	22.0	63.4	-4%	0%	94%
One-year redesign cadence	80.5	87.4	108.0	122.6	164.4	6.8	27.5	42.0	83.8	-16%	8%	598%
Battery direct costs (-20%)	99.5	87.4	109.9	125.6	171.1	-12.1	10.3	26.1	71.6	4%	10%	162%
Battery direct costs (+20%)	102.3	79.1	98.9	112.7	152.6	-23.2	-3.5	10.4	50.2	7%	-1%	-188%
Battery learning rate (-20%)	100.7	79.6	100.0	114.3	155.5	-21.1	-0.7	13.6	54.8	5%	0%	-118%
Battery learning rate (+20%)	92.1	79.0	99.3	113.5	154.5	-13.1	7.2	21.4	62.4	-4%	0%	82%
Flat AC/OC	102.5	83.8	105.0	119.8	162.6	-18.7	2.5	17.3	60.1	7%	5%	-37%
Limited HCR skip	109.1	83.8	106.1	121.7	166.7	-25.3	-3.0	12.6	57.6	14%	6%	-176%

Sensitivity Case	Total Social Costs	Total Social Benefits				Net Social Benefits				% diff from RC (at 3%)		
		5%	3%	2.5%	3% @ 95th	5%	3%	2.5%	3% @ 95th	Costs	Benefits	Net benefits
Limited conventional tech. improvement	93.3	78.1	98.1	112.2	152.7	-15.2	4.8	18.9	59.4	-3%	-2%	23%
Oil price (EIA AEO 2021 low)	104.0	67.3	90.8	107.2	154.7	-36.7	-13.2	3.2	50.7	9%	-9%	-435%
Oil price (Global Insight)	91.4	62.9	82.1	95.5	134.3	-28.6	-9.4	4.1	42.8	-5%	-18%	-338%
Oil price (EIA AEO 2021 high)	83.1	96.8	113.7	125.5	159.7	13.7	30.6	42.4	76.6	-13%	14%	674%
No payback period	101.1	81.8	104.2	119.9	165.3	-19.3	3.1	18.9	64.2	5%	4%	-21%
24-month payback period	100.7	85.5	107.6	123.1	167.8	-15.2	6.9	22.4	67.1	5%	8%	75%
36-month payback period	91.3	73.4	92.4	105.7	144.1	-17.9	1.1	14.4	52.7	-5%	-7%	-73%
60-month payback period	79.8	65.8	81.9	93.3	126.0	-14.0	2.1	13.5	46.2	-17%	-18%	-46%
30-month fuel-savings value (70k miles)	91.6	81.4	102.4	117.1	159.5	-10.2	10.8	25.5	68.0	-4%	3%	174%
Implicit opportunity cost	113.6	79.3	99.7	114.1	155.4	-34.2	-13.8	0.5	41.8	19%	0%	-450%

Sensitivity Case	Total Social Costs	Total Social Benefits				Net Social Benefits				% diff from RC (at 3%)		
		5%	3%	2.5%	3% @ 95th	5%	3%	2.5%	3% @ 95th	Costs	Benefits	Net benefits
Rebound (5%)	89.7	76.3	97.2	111.9	154.2	-13.5	7.5	22.2	64.5	-6%	-3%	90%
Rebound (15%)	101.9	82.3	102.3	116.2	156.5	-19.5	0.4	14.4	54.7	6%	3%	-90%
Sales-scrappage response (η = -0.1)	93.7	81.0	101.8	116.3	158.3	-12.7	8.1	22.7	64.7	-2%	2%	106%
Sales-scrappage response (η = -0.5)	96.6	78.8	99.1	113.3	154.4	-17.8	2.5	16.8	57.8	1%	-1%	-36%
NPRM sales-scrappage response (η = -1)	100.4	76.0	95.8	109.7	149.6	-24.3	-4.6	9.3	49.2	5%	-4%	-216%
Low GDP	88.5	74.9	94.4	108.1	147.7	-13.6	6.0	19.7	59.2	-8%	-5%	51%
High GDP	101.1	83.5	104.9	119.9	163.3	-17.6	3.8	18.9	62.2	6%	5%	-3%
Low GDP (+ fuel prices)	84.2	63.9	82.1	94.9	131.6	-20.3	-2.1	10.7	47.4	-12%	-18%	-153%
High GDP (+ fuel prices)	103.2	68.3	90.6	106.2	151.1	-34.8	-12.6	3.0	47.9	8%	-9%	-419%
NPRM macro forecast	96.4	80.9	101.7	116.4	158.6	-15.6	5.3	20.0	62.2	1%	2%	35%
Alt. DFS model (fixed)	99.3	84.7	106.9	122.4	167.2	-14.6	7.6	23.1	67.9	4%	7%	93%
Alt. DFS model (varying)	104.4	104.9	132.7	152.1	208.2	0.5	28.2	47.7	103.8	9%	33%	616%

Sensitivity Case	Total Social Costs	Total Social Benefits				Net Social Benefits				% diff from RC (at 3%)		
		5%	3%	2.5%	3% @ 95th	5%	3%	2.5%	3% @ 95th	Costs	Benefits	Net benefits
Mass-size-safety (low)	90.5	79.1	99.5	113.8	155.2	-11.4	9.0	23.3	64.6	-5%	0%	128%
Mass-size-safety (high)	101.0	79.5	100.0	114.3	155.6	-21.5	-1.1	13.3	54.6	5%	0%	-127%
Crash avoidance (low effectiveness)	95.7	79.2	99.6	114.0	155.3	-16.5	3.9	18.2	59.6	0%	0%	-1%
Crash avoidance (high effectiveness)	95.9	79.4	99.8	114.2	155.5	-16.5	4.0	18.3	59.6	0%	0%	1%
Reduced power plant emissions	95.1	78.7	99.3	113.7	155.4	-16.5	4.2	18.6	60.3	-1%	0%	5%
Lepeule criteria pollutant BPT estimates	95.8	80.3	100.7	115.0	156.3	-15.5	4.9	19.2	60.5	0%	1%	24%
No ZEV mandates	96.4	82.1	103.1	117.8	160.2	-14.3	6.7	21.4	63.9	1%	3%	71%
Fixed nominal fine rate	96.8	79.7	100.1	114.4	155.8	-17.2	3.3	17.6	59.0	1%	0%	-17%
Unadjusted MDPCS stringency	95.8	79.3	99.7	114.1	155.4	-16.5	3.9	18.3	59.6	0%	0%	0%

Sensitivity Case	Total Social Costs	Total Social Benefits				Net Social Benefits				% diff from RC (at 3%)		
		5%	3%	2.5%	3% @ 95th	5%	3%	2.5%	3% @ 95th	Costs	Benefits	Net benefits
EPCA constraints throughout MYs 2023-2029	113.0	89.6	111.4	126.7	170.9	-23.3	-1.5	13.8	57.9	18%	12%	-138%
No response of domestic crude production	95.8	79.3	99.8	114.1	155.4	-16.5	4.0	18.3	59.6	0%	0%	0%
Constrained PHEV FE compliance values	96.4	82.7	103.4	117.9	159.6	-13.7	7.0	21.4	63.2	1%	4%	77%

Table 7-6 – Summary of Selected Model Metrics for Sensitivity Cases (MYs 1981-2029, Alt. 2.5, 7 Percent Discount Rate)

Sensitivity Case	Gasoline consumption (billion gallons)	Electricity consumption (TWh)	CO_2 emissions (MMT)	Fatalities	Fleet avg curb weight (MY 2029, lbs)	Regulatory cost (MY 2029, $/vehicle)	Vehicle cost (MY 2029, $/vehicle)	Retail fuel outlay (MY 2029, $/vehicle)
RC	-60	179	-607	1,335	-32.9	1,087	1,256	-1,070
EIS-RC	-59	236	-580	1,143	-30.7	999	1,156	-1,025
MR5/6 skip (>100k)	-60	179	-607	1,335	-32.9	1,087	1,256	-1,070
MR5/6 skip (>2k)	-60	181	-608	1,251	-31.8	1,021	1,181	-1,073
No MR5/6 skip	-59	176	-598	2,000	-42.6	1,767	2,038	-1,042
2020 Final Rule MR5/6 costs	-60	180	-608	1,297	-32.9	1,046	1,210	-1,073
One-year redesign cadence	-57	41	-616	1,356	-19.6	971	1,128	-1,282
Battery direct costs (-20%)	-67	215	-668	1,295	-35.5	1,041	1,204	-1,170
Battery direct costs (+20%)	-58	169	-585	1,608	-50.2	1,195	1,384	-1,058
Battery learning rate (-20%)	-60	180	-605	1,543	-43.5	1,156	1,337	-1,076
Battery learning rate (+20%)	-60	172	-602	1,240	-30.0	1,045	1,207	-1,059
Flat AC/OC	-62	165	-629	1,466	-35.8	1,160	1,341	-1,087
Limited HCR skip	-67	227	-662	1,406	-34.2	1,153	1,333	-1,116
Limited conventional tech. improvement	-60	203	-596	1,307	-36.0	1,106	1,279	-1,035
Oil price (EIA AEO 2021 low)	-68	179	-697	1,768	-45.3	1,191	1,380	-919
Oil price (Global Insight)	-57	183	-570	1,503	-32.7	1,049	1,212	-854
Oil price (EIA AEO 2021 high)	-51	175	-502	876	-31.3	958	1,104	-1,285

Sensitivity Case	Gasoline consumption (billion gallons)	Electricity consumption (TWh)	CO_2 emissions (MMT)	Fatalities	Fleet avg curb weight (MY 2029, lbs)	Regulatory cost (MY 2029, $/vehicle)	Vehicle cost (MY 2029, $/vehicle)	Retail fuel outlay (MY 2029, $/vehicle)
No payback period	-70	298	-668	1,424	-34.2	1,158	1,340	-1,150
24-month payback period	-66	221	-657	1,392	-42.0	1,152	1,333	-1,203
36-month payback period	-56	170	-564	1,279	-30.2	1,051	1,214	-1,001
60-month payback period	-46	90	-480	1,113	-31.2	928	1,073	-847
30-month fuel-savings value (70k miles)	-62	179	-623	803	-32.9	1,087	1,255	-1,089
Implicit opportunity cost	-60	179	-607	1,335	-32.9	1,087	1,593	-1,070
Rebound (5%)	-62	179	-622	1,037	-32.9	1,087	1,256	-1,104
Rebound (15%)	-59	179	-592	1,632	-32.9	1,087	1,256	-1,037
Sales-scrappage response (η = -0.1)	-61	181	-616	984	-32.9	1,088	1,255	-1,110
Sales-scrappage response (η = -0.5)	-60	178	-604	1,452	-32.9	1,087	1,257	-1,055
NPRM sales-scrappage response (η = -1)	-59	176	-588	2,042	-32.9	1,087	1,261	-989
Low GDP	-58	182	-582	1,319	-32.3	1,090	1,260	-1,129
High GDP	-63	187	-637	1,347	-27.9	1,087	1,256	-1,062
Low GDP (+ fuel prices)	-54	167	-542	1,430	-34.4	1,049	1,210	-977
High GDP (+ fuel prices)	-65	194	-660	1,665	-33.7	1,106	1,278	-850
NPRM macro forecast	-62	185	-620	1,378	-33.8	1,088	1,258	-1,107
Alt. DFS model (fixed)	-65	198	-659	1,307	-50.7	1,127	1,281	-1,192

Sensitivity Case	Gasoline consumption (billion gallons)	Electricity consumption (TWh)	CO_2 emissions (MMT)	Fatalities	Fleet avg curb weight (MY 2029, lbs)	Regulatory cost (MY 2029, $/vehicle)	Vehicle cost (MY 2029, $/vehicle)	Retail fuel outlay (MY 2029, $/vehicle)
Alt. DFS model (varying)	-81	214	-826	989	-112.5	1,113	1,173	-1,455
Mass-size-safety (low)	-60	179	-607	780	-32.9	1,087	1,256	-1,070
Mass-size-safety (high)	-60	179	-607	1,886	-32.9	1,087	1,256	-1,070
Crash avoidance (low effectiveness)	-60	179	-607	1,333	-32.9	1,087	1,256	-1,070
Crash avoidance (high effectiveness)	-60	179	-607	1,335	-32.9	1,087	1,256	-1,070
Reduced power plant emissions	-60	187	-612	1,304	-33.1	1,088	1,257	-1,066
Lepeule criteria pollutant BPT estimates	-60	179	-607	1,335	-32.9	1,087	1,256	-1,070
No ZEV mandates	-61	168	-623	1,438	-52.0	1,133	1,312	-1,140
Fixed nominal fine rate	-60	177	-607	1,345	-32.1	1,078	1,247	-1,060
Unadjusted MDPCS stringency	-60	179	-607	1,335	-32.9	1,087	1,256	-1,070
EPCA constraints throughout MYs 2023-2029	-64	166	-649	1,538	-37.2	1,264	1,461	-1,132
No response of domestic crude production	-60	179	-607	1,335	-32.9	1,087	1,256	-1,070
Constrained PHEV FE compliance values	-59	103	-613	1,455	-39.4	1,072	1,240	-1,092