Final Regulatory Impact Analysis

Corporate Average Fuel Economy Standards for Passenger Cars and Light Trucks for Model Years 2027 and Beyond and Fuel Efficiency Standards for Heavy-Duty Pickup Trucks and Vans for Model Years 2030 and Beyond

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

NHTSA

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Table of Acronyms and Abbreviations

Abbreviation	Term
AC	Air Conditioning
ACC	Advanced Clean Cars
ACT	Advanced Clean Trucks
AFV	Alternative Fuel Vehicle
AMPC	Advanced Manufacturing Production Credit
AT	Automatic transmissions
AWD	All-Wheel Drive
BEV	Battery Electric Vehicle
BISG	Belt-Integrated Starter Generator
BMW	BMW of North America, LLC
BTU	British Thermal Unit
BTW	Brake & Tire Wear
CAFE	Corporate Average Fuel Economy
CARB	California Air Resources Board
CH_4	Methane
CI	Compression Ignition
CNG	Compressed Natural Gas Engine
CO_2	Carbon Dioxide
COVID	Coronavirus disease of 2019
CVC	Clean Vehicle Tax Credit
CVT	Continuously Variable Transmission
CY	Calendar Year
DCT	Dual-Clutch Transmission
DEAC	Cylinder Deactivation
DMC	Direct Manufacturing Costs
DOE	U.S. Department of Energy
DOHC	Dual Overhead Cam
DOT	U.S. Department of Transportation
DPC	Domestic Passenger Car
DR	Discount Rate
EIA	U.S. Energy Information Administration
EIS	Environmental Impact Statement
EISA	Energy Independence and Security Act of 2007
EPA	Environmental Protection Agency
EPCA	Energy Policy and Conservation Act of 1975
EV	Electric Vehicle

Abbreviation	Term
FCEV	Fuel Cell Electric Vehicle
FCF	Fuel Content Factor
FCIV	Fuel Consumption Improvement Value
FCV	Fuel Cell Vehicle
FE	Fuel Economy
FHWA	Federal Highway Administration
FP	Fuel Price
FR	Federal Register
FWD	Front-Wheel Drive
GCWR	Gross Combined Weight Rating
GDP	Gross Domestic Product
GGE	Gasoline Gallon Equivalent
GHG	Greenhouse Gas
GI	Global Insight
GM	General Motors
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
GVWR	Gross Vehicle Weight Rating
GWP	Global Warming Potential
HCR	High Compression Ratio
HD	Heavy-Duty
HDPUV	Heavy-Duty Pickups and Vans
HTF	Highway Trust Fund
IC	Internal Combustion
ICE	Internal Combustion Engine
IFR	Interim Final Rule
IPC	Imported Passenger Car
IRA	Inflation Reduction Act
IWG	Interagency Working Group
LD	Light-Duty
LDT	Light-Duty Trucks
LDV	Light-Duty Vehicle
LFP	Lithium Iron Phosphate
LT	Light Trucks
MDPCS	Minimum Domestic Passenger Car Standard
MMT	Million Metric Tons
MOVES	Motor Vehicle Emission Simulator
MPG	Miles Per Gallon
MR	Mass Reduction

Abbreviation	Term
MSRP	Manufacturer Suggested Retail Price
MY	Model Year
NAS	National Academy of Sciences
NASEM	National Academies of Sciences, Engineering, and Medicine
NEMS	National Energy Modeling System
NEPA	National Environmental Policy Act
NHTSA	National Highway Traffic Safety Administration
NMC	Nickel Manganese Cobalt
NO_X	Nitrogen Oxide
NPRM	Notice of Proposed Rulemaking
NREL	National Renewable Energy Laboratory
OMB	Office of Management and Budget
OPEC	Organization of the Petroleum Exporting Countries
PC	Passenger Car
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
PRIA	Preliminary Regulatory Impact Analysis
RC	Reference Case
RIA	Regulatory Impact Analysis
ROLL	Tire Rolling Resistance
SC	Social Cost
SHEV	Strong Hybrid Electric Vehicle
SI	Spark Ignition
SO2	Sulfur Dioxide
SOHC	Single Overhead Camshaft
SO_X	Sulfur Oxide
SS12V	Stop-Start 12V Hybrid Electric Vehicle
SUV	Sport Utility Vehicle
TCO	Total Cost of Ownership
TS&D	Fuel Transportation, Storage, and Distribution
TSD	Technical Support Document
TWh	Terawatt-hours
UNFCCC	United Nations Framework Convention on Climate Change
USD	US Dollars
VCR	Variable Compression Ratio Engine

Abbreviation	Term
VMT	Vehicle Miles Traveled
VSL	Value of a Statistical Life
VTG	Variable Turbo Geometry
VTGE	Variable Turbo Geometry (Electric)
VVL	Variable Valve Lift
VWA	Volkswagen Group of America
WF	Work Factor
ZEV	Zero Emission Vehicle

1. Executive Summary

Pursuant to Executive Order 12866 and Executive Order 13563, the National Highway Traffic Safety Administration (NHTSA) has prepared this Final Regulatory Impact Analysis (FRIA) to assess the potential and anticipated consequences of final and alternative Corporate Average Fuel Economy (CAFE) standards for passenger cars (PCs) and light trucks (LTs) for model years (MYs) 2027-2031, and fuel efficiency standards for heavy-duty pickup trucks and vans (HDPUVs) for MYs 2030-2035. Regulatory analysis is a tool used to anticipate and evaluate likely consequences of rules by providing a formal way of organizing and presenting the key effects, positive and negative, of the various alternatives that are considered in developing regulations. The goal of this FRIA is to consolidate evidence and inform decision-makers of the potential consequences of choosing among the considered regulatory paths.

This assessment examines the costs and benefits of the final and alternative CAFE standards for passenger cars and light trucks for MYs 2027 through 2031, and final and alternative HDPUV standards levels for HDPUVs for MYs 2030 through 2035. The final rule is issued under the agency's statutory authority codified at 49 U.S.C. 32902. The MY 2032 standards set forth and discussed for passenger cars and light trucks are "augural," in that they fall beyond the statutory 5-model-year period set out for CAFE standards in 49 U.S.C. 32902, and thus represent what the agency *would* propose, based on the information currently before us, but which will not be finalized as part of this final rule. This assessment examines the costs and benefits of setting fuel economy standards for passenger cars and light trucks and fuel efficiency standards for HDPUVs that change at a variety of different rates during those model years.[1] It includes a discussion of the technologies that can improve fuel economy/efficiency, as well as an 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.[2] Estimating impacts also involves considering consumers' responses to standards – for example, whether and how changes in vehicle prices as a result of changes in CAFE or HDPUV standards could affect sales of new and used vehicles.

The Energy Independence and Security Act of 2007 (EISA) requires NHTSA to set attribute-based CAFE standards that are based on a mathematical function for passenger cars and light trucks and gives NHTSA discretion to set attribute-based standards based on a mathematical function for HDPUVs. For passenger cars and light trucks, the mathematical function or "curve" representing the standards is a constrained linear function that provides a separate fuel economy target for each vehicle footprint. There are separate curves for cars and for trucks. Vehicle footprint has been used as the relevant attribute for passenger car and light truck curves since MY 2011. For HDPUVs, the mathematical functions representing the standards are unconstrained linear curves. The curves provide a separate fuel consumption target for each vehicle based on a "work factor" (WF) which is a function of payload and towing capabilities. NHTSA sets separate standards for "compression ignition" (CI) (i.e., diesel) HDPUVs and "spark ignition" (i.e., gasoline) HDPUVs. WF has been used as the relevant attribute for all HDPUV curves since MY 2014. Generally, the more of the attribute a vehicle has, the less numerically stringent the corresponding fuel economy/efficiency target. With attribute-based standards, the burden of compliance is theoretically distributed across all vehicles and across all manufacturers. Under all of the regulatory alternatives, the standards would eventually become more stringent, relative to the MY 2026 standards for passenger cars and light trucks and the MY 2027 standards for HDPUVs. That said, each manufacturer is subject to individualized compliance obligations for passenger cars, light trucks, and HDPUVs, in each model year, based on the vehicles it produces.

We constructed an analysis fleet representing the entire MY 2022 passenger car and light truck fleet and the MY 2022 HDPUV fleet in detail as a starting point to evaluate the costs and benefits of the final rule, against which we simulate manufacturers' year-by-year response through MY 2050[3] to standards defining each

[1] Throughout this FRIA, cost and benefit analyses are presented for individual model years as well as the cumulative total for all model years through 2031 for passenger cars and light trucks, although some physical effects are presented on a calendar year basis instead, as appropriate. Only calander year cumulative effects for on-the road vehicles for year 2022 through 2050 are presented for HDPUVs. Additional results that include the proposed augural year are presented in FRIA Chapter 8.

[2] 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 Environmental Impact Statement (EIS) accompanying the final rule.

[3] As in prior analyses, the analysis for this final rule exercises the CAFE Model using inputs that extend the explicit compliance simulation through MY 2050 – many years beyond the last year for which we are issuing 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 time frame.

regulatory alternative. The analysis fleet is comprised of the best information available as of August of 2022 regarding the MY 2022 fleet for passenger cars and light trucks and the MY 2022 fleet for HDPUVs. For each of 3,527 specific vehicle model/configurations, the analysis contains information such as production volumes, fuel economy/efficiency ratings, dimensions, curb weight and gross vehicle weight rating (GVWR), engine characteristics, transmission characteristics, and other key engineering information. For the No-Action alternatives, we used the CAFE Model[4] to simulate manufacturers' year-by-year application of technology that improves fuel economy/efficiency, assuming that even in the absence of new CAFE standards, manufacturers would respond to reference baselines consisting of the CAFE standards finalized in 2022 and the HDPUV standards finalized in 2016, with and without California's Zero Emission Vehicle (ZEV) program (termed the "reference baseline" and "No ZEV alternative baseline" or "alternative baseline", respectively), U.S. Environmental Protection Agency (EPA)'s fleetwide greenhouse gas (GHG) standards finalized in 2021 for passenger cars and light trucks and those finalized in 2016 for HDPUVs, and buyers' willingness to pay for a portion of the fuel savings expected to occur over vehicles' lifetimes. The reference baseline and the alternative baseline also includes the effects of changes in the CAFE compliance calculations, such as changes to the Petroleum Equivalency Factor (PEF), and changes to the Off-Cycle and Air Conditioning efficiency programs.

NHTSA is finalizing CAFE standards that will increase at 2 percent per year for passenger cars during MYs 2027-2031, and for light trucks, standards that will not increase beyond the MY 2026 standards in MYs 2027-2028, thereafter increasing at 2 percent per year for MYs 2029-2031. The final HDPUV standards will increase at 10 percent per year during MYs 2030-2032, and then increase at 8 percent for MYs 2033-2035. The regulatory alternatives representing these final stringency increases are called "PC2LT002" for passenger cars and light trucks, and "HDPUV108" for HDPUVs. These standards are also referred to throughout the rulemaking documents as the "preferred alternative" or "final standards." NHTSA has concluded these levels of increase are maximum feasible in those model years for those vehicle fleets, under the statutory factors established by the Energy Policy and Conservation Act of 1975 (EPCA) and EISA. Although NHTSA and EPA took separate actions in this round of rulemaking for a variety of reasons, NHTSA sought to coordinate its final rule with EPA's to the greatest extent possible given our statutory and programmatic differences.

While NHTSA's and EPA's final rules differ in certain respects, the fact that differences exist is not new in this final rule. Some parts of the programs are harmonized, and others differ, often due to statute. Since NHTSA and EPA began regulating concurrently under President Obama, programmatic differences have meant that manufacturers have had (and will have) to plan their compliance strategies considering both the NHTSA standards and the EPA standards and ensure that they comply with both. Auto manufacturers are sophisticated companies accustomed to operating under multiple regulatory regimes simultaneously (both within the United States and beyond), and we remain confident that they will achieve that goal. For purposes of the FRIA, we have only attempted to report costs and benefits attributable to the NHTSA CAFE and HDPUV final standards, and not also EPA's final standards. We refer readers to EPA's documents for more information about their final rule and its estimated effects,[5] and note (as in the NHTSA rulemakings that have been in effect 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 and HDPUV standards.[6] EPCA requires that CAFE standards be set separately for passenger cars and light trucks[7] at the "maximum feasible average fuel economy level that the Secretary decides the manufacturers can achieve in that model year,"[8] based on the agency's consideration of four statutory factors: technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy.[9] EPCA does not define these terms or specify what weight to give each factor in balancing them. Instead, such considerations are left within the discretion of the Secretary of Transportation (delegated to NHTSA) based on current information. Accordingly, NHTSA interprets these factors and determines the appropriate weighting that leads to the

[4] FInal CAFE Model Documentation for 2024 FRM is on NHTSA Website
[5] 88 FR 29184 (May 5, 2023).
[6] See preamble Section V.A. for a complete discussion of the EPCA and EISA constraints placed on NHTSA's analysis and rulemaking.
[7] 49 U.S.C. 32902(b)(1). EPCA uses the terms "passenger automobile" and "non-passenger automobile" while NHTSA uses the regulatory terms "passenger car" and "light truck," but they are intended interchangeably.
[8] 49 U.S.C. 32902(a).
[9] 49 U.S.C. 32902(f).

maximum feasible standards given the circumstances present at the time of promulgating each CAFE standard rulemaking. Similarly, HDPUV standards must be set at the level that “achieve[s] the maximum feasible improvement,” and in determining that level, NHTSA must consider whether standards are “appropriate, cost-effective, and technologically feasible.” As for PC and Light Truck (LT) CAFE standards, EPCA/EISA does not define these terms or specify what weight to give each factor in balancing them, so this is left to NHTSA’s discretion, and NHTSA interprets the factors and determines the appropriate weighting based on the information currently before us. Always in making these determinations, NHTSA remains mindful that EPCA’s overarching purpose is energy conservation.

As stated above, NHTSA is setting new standards for PCs and LTs that the agency concludes would represent maximum feasible CAFE standards for MYs 2027-2031 and setting forth augural PC and LT standards for MY 2032. NHTSA is also setting new standards for HDPUVs that the agency concludes would represent maximum feasible HDPUV standards for MYs 2030-2035. While the actual standards are footprint-based target curves, for PCs and LTs, and work-factor-based target curves, for HDPUVs, NHTSA currently estimates that the final standards would require, on an average industry fleet-wide basis, roughly 65 mpg for PCs in MY 2031, 45 mpg for LTs in MY 2031, and 2.9 gallons per 100 miles for HDPUVs in MY 2035.

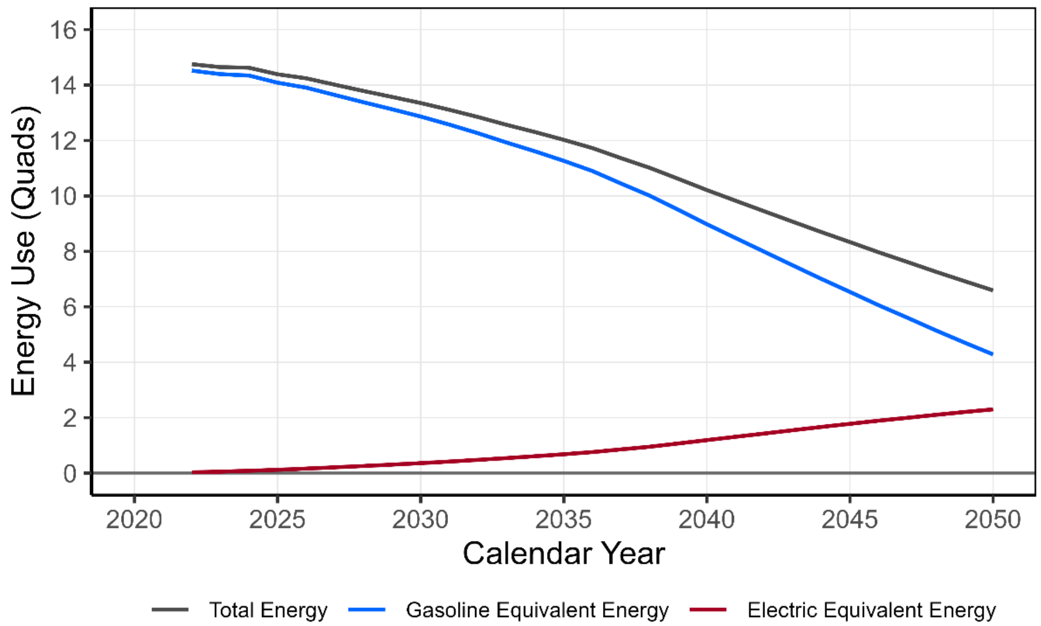
Because NHTSA is establishing final PC/LT standards for MYs 2027-2031, and because of various other analytical changes and updates, the estimated effects for the final rule are slightly different from those estimated for the proposal. NHTSA estimates that the final rule stringency increases in the PC/LT fleet would reduce gasoline consumption through calendar year (CY) 2050 by approximately 64 billion gallons relative to reductions in the reference baseline No-Action Alternative or 116 billion gallons relative to the No ZEV alternative baseline No-Action alternative.[10] That said, it should be noted that under the reference baseline No-Action fuel consumption was estimated at 2,578 billion gallons by CY 2050, and under the No ZEV alternative baseline No-Action fuel consumption was estimated at 2,665 billion gallons by CY 2050, the PC2LT002 alternative modeled against the reference baseline resulted in 2,514 billion gallons of fuel burned by CY 2050 and the PC2LT002 alternative modeled against the No ZEV alternative baseline resulted in 2,549 billion gallons of fuel burned by CY 2050. This context is given to show while the reduction in fuel use versus the baseline is almost twice that for the alternative baseline analysis, the absolute amount of fuel predicted to be used once the CAFE standards apply only differs by 1.4 percent. Under the same conditions, NHTSA also estimates an increase in electricity consumption of approximately 333 terawatt-hours (TWh) over the reference baseline No-Action, and approximately 493 terawatt-hours over the No ZEV alterative baseline No-Action, with the absolute electricity consumption differing by 7.8 percent once the CAFE standard is applied over either baseline.[11] This increase in electricity consumption, 333 terawatt-hours, represents 4.2 percent of overall energy consumed in the reference baseline No-Action Alternative. The additional electricity use shown in NHTSA’s analysis is attributed to an increase in the number of plug-in hybrid electric vehicles (PHEVs); PHEV fuel economy is only considered in charge-sustaining (i.e., gasoline-only) mode in the compliance analysis, but electricity consumption is computed for the effects analysis. In the HDPUV fleet, gasoline consumption declines by approximately 5.6 billion gallons and electricity consumption increases by 56 TWh through CY 2050. The change in electricity consumption is 5.4 percent of overall energy consumed in the HDPUV No-Action Alternative and is the result of increases in PHEV and Battery Electric Vehicle (BEV) adoption. For simplicity, projected regulatory impacts presented in this document use the reference baseline unless otherwise stated.)

Overall, for the reference baseline fleet consumption of electricity is inversely related to the consumption of gasoline, and other liquid fuels,[12] for the overall predicted future vehicle fleet. Figure 1-1 shows the translation of gasoline to equivalent British Thermal Units (BTUs) of energy and compares the reduction of gasoline energy to the increase in electrical energy, also converted to equivalent BTUs, over time for the CAFE fleet. This comparison shows the increase of electrical energy is significantly less than the reduction in liquid fuel energy burned. Electrical energy use increase in the reference baseline fleet represents about 16% of the total gasoline energy use reduction in the reference baseline fleet, across the years shown in Figure

[10] For comparison, the U.S. consumed about 135.06 billion gallons of finished motor gasoline in 2022. U.S. Energy Information Administration (EIA), Frequently Asked Questions, “How much gasoline does the United States consume?”, *available at* https://www.eia.gov/tools/faqs/faq.php?id=23&t=10 (last accessed Mar. 7, 2023).
[11] For comparison, the U.S. consumed about 4.07 trillion kilowatts (kWh) of electricity in 2022. EIA, “Electricity Explained; Use of electricity.” *Available at* https://www.eia.gov/energyexplained/electricity/use-of-electricity.php. (last accessed Mar. 7, 2023).
[12] Other liquid fuels include E85, Diesel and CNG. In the light duty fleet analysis these fuels represented a very small percentage of the overall energy used and were not shown in the figures. In the HDPUV fleet analysis only diesel was shown in addition to gasoline.

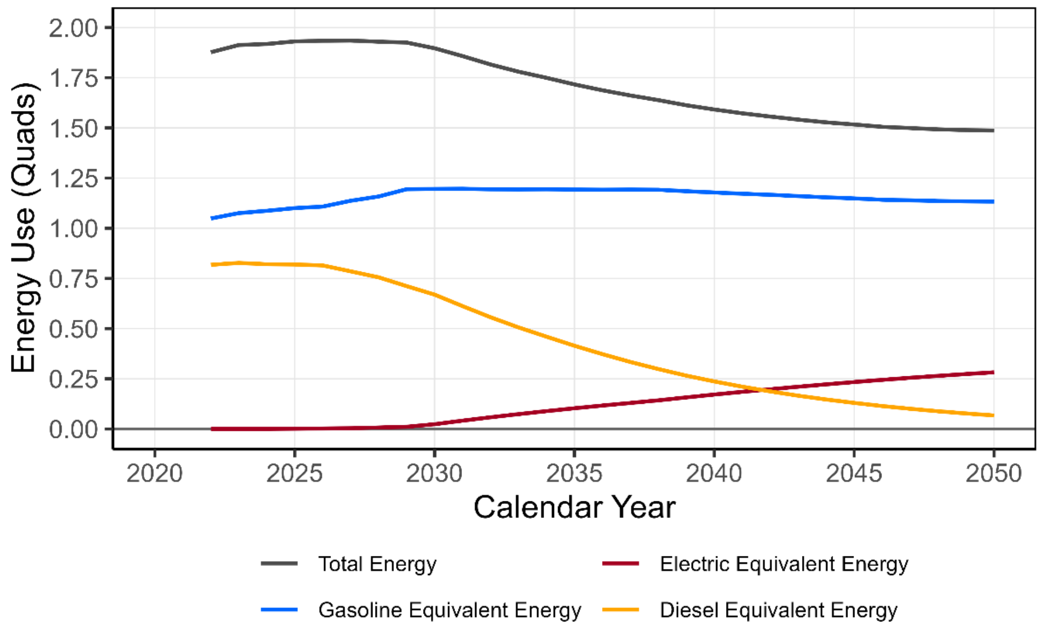
1-1. The difference in energy reduced and energy gained, by the overall fleet, is likely caused by the continued increase in efficiency of combustion-based technologies, including hybridization, as well as the introduction of BEVs into fleet.[13] The efficiency level of vehicles that use electricity as one of their fuel types is typically significantly higher in their conversion of stored energy to locomotion. A similar behavior is observed for the HDPUV fleet, see Figure 1-2. For reference in the figures below, 1 Quad is equivalent to 10^{15} BTUs.

Figure 1-1: Total Energy Use by the CAFE Fleet for the No-Action Alternative



[13] The BEVs introduced into the baseline fleet are a result of other standards and regulations that are not part of this rule making, but considered in our baseline fleet, see TSD Chapter 2.

Figure 1-2: Total Energy Use by the HDPUV Fleet for the No-Action Alternative



The effect of the final standards is also shown in Figure 1-3 and demonstrates a further reduction in gasoline energy use in comparison to the No-Action Alternative. The final HDPUV standards also shows a further reduction in gasoline and diesel energy used in that fleet, see Figure 1-4. As compared to the figures above, these two figures show the reduction in total gasoline and diesel reduction which the main purpose of the CAFE and HDPUV Fuel Efficiency program.

Figure 1-3: Additional Decrease in Gasoline Energy Used by the CAFE Fleet Due to the Final Standards

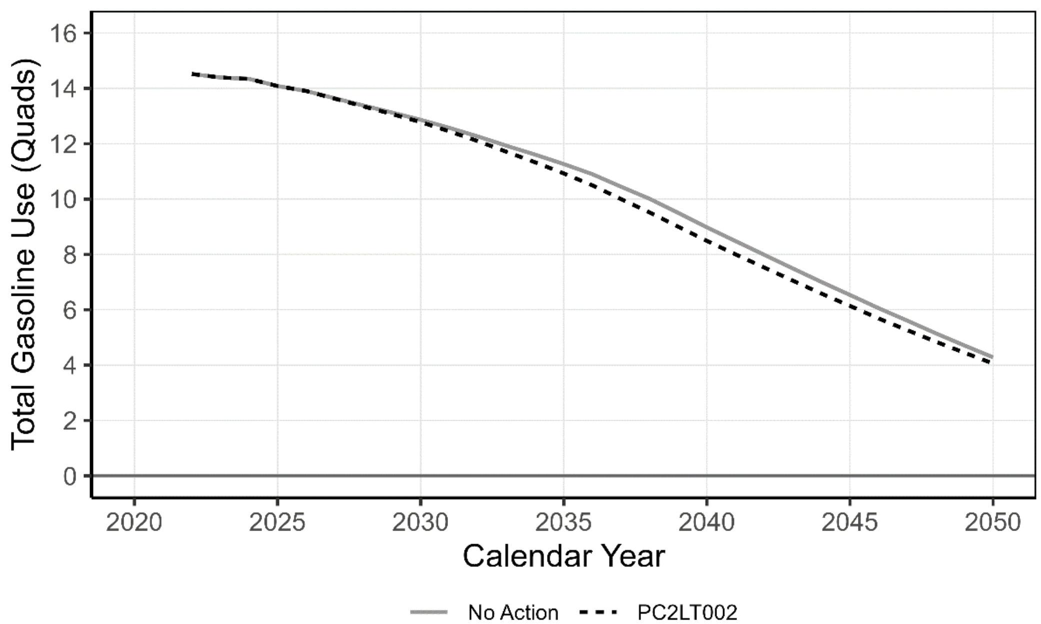
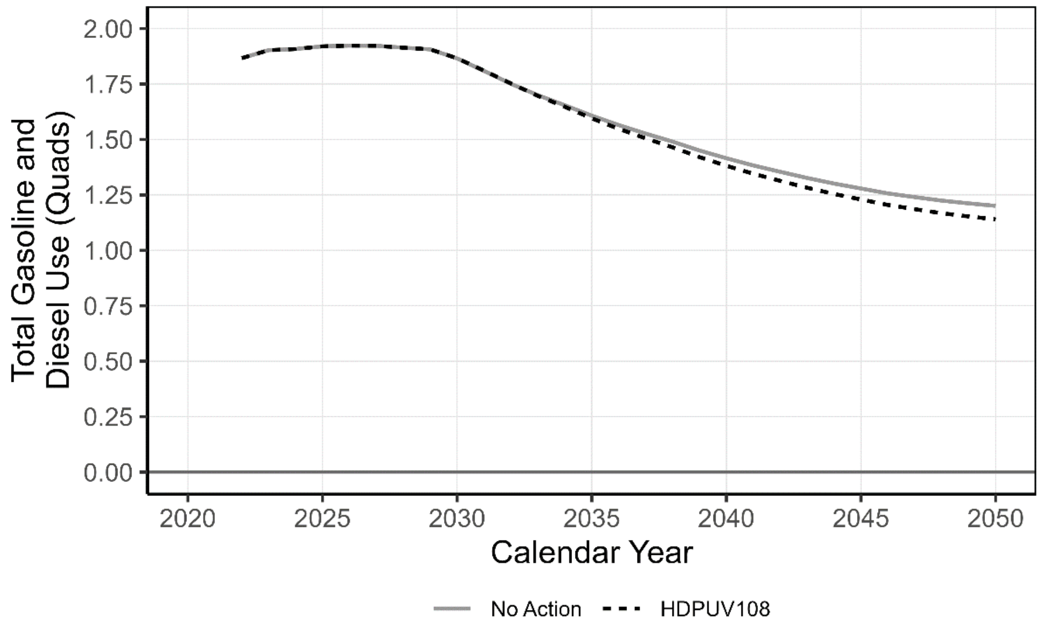


Figure 1-4: Additional Decrease in Gasoline and Diesel Energy Used by the HDPUV Fleet Due to the Final Standards



Accounting for emissions from both vehicle fleets and upstream energy sector processes (e.g., petroleum refining and electricity generation), NHTSA estimates that the final standards would reduce GHG emissions as shown in Table 1-1.

Table 1-1: Predicted GHG Change Caused by the Final Rule Standards Relative to the Reference Baseline No-Action Alternative for PC/LT CAFE and HDPUV FE Final Standards, CY 2022-2050

	Carbon Dioxide (CO_2) (mmt)	Methane (CH_4) (mmt)	Nitrous Oxide (N_2O) (tmt)
Passenger Cars and Light Trucks	-659	-0.825	-23.5
HDPUVs	-55	-0.065	-3.0

Similarly, to the savings in gasoline discussed above, the final standards save nearly twice the carbon dioxide (CO_2) when compared to the alternative baseline No-Action alternative. There is a predicted reduction of 1,207 mmt of Carbon Dioxide relative to the alternative No-Action case for CY 2022-2050. However, there is only a 1 percent difference between the absolute CO_2 produced when CAFE standards are applied.

Relative reductions in CO_2 for the final standards and each of the considered alternatives for CAFE and for HDPUV are shown in Figure 1-5 and Figure 1-6:

Figure 1-5: Annual CO_2 Emissions Projected as a Function of CAFE Stringencies

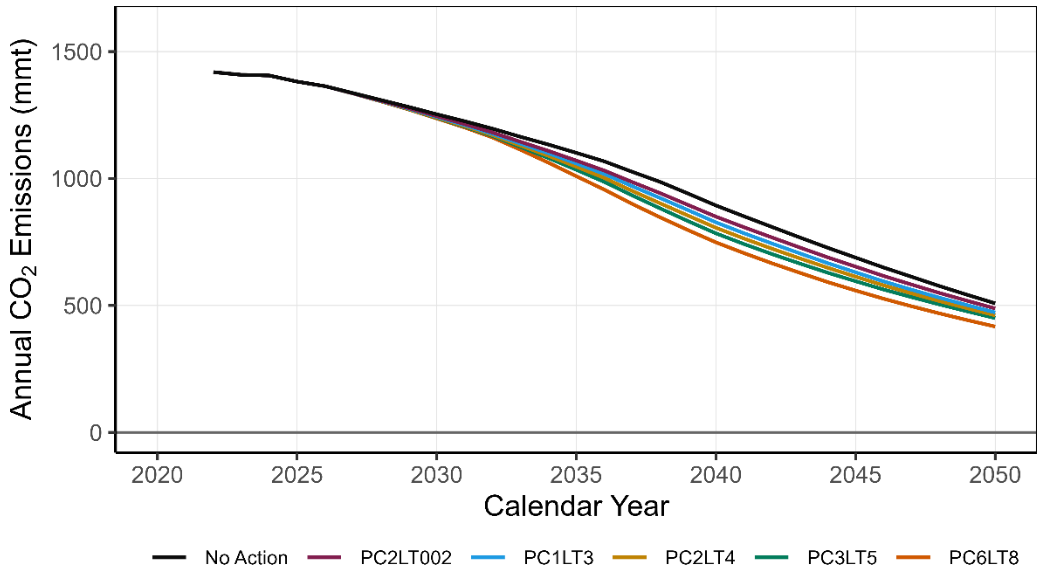
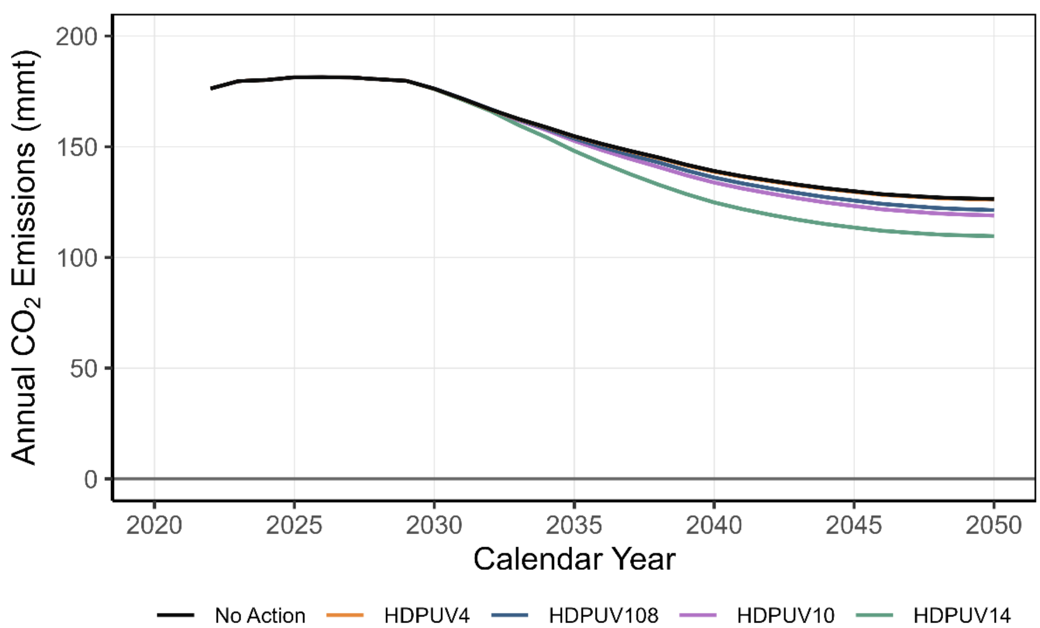


Figure 1-6: Annual CO_2 Emissions Projected as a Function of HDPUV Stringencies



For PCs and LTs, NHTSA projects that under these final standards, required technology costs summed over the entire fleet could increase by $18 billion over the No-Action alternative through MY 2031, and civil penalty payments summed across the entire industry would average about $0.36 billion per year over the 5 years,[14] although the standards are performance-based and manufacturers are always free to choose their own compliance path (which can include civil penalty payments, but need not). 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 PCs and LTs would increase by roughly $392 in MY 2031, on average,

[14] For context, the combined profits for Stellantis, GM and Ford was approximately $143 billion over the last 5 years, averaging $28.6 billion per year. See: https://www.epi.org/blog/uaw-automakers-negotiations/.

as compared to if the MY 2026 standards in the reference baseline were retained; but concurrently, fuel savings for those vehicles would increase, by roughly $639, on average, so that consumers would see an overall net benefit in savings.[15] If the No ZEV alternative baseline is considered we estimate that the per-vehicle costs paid by U.S. consumers for new PCs and LTs would increase by roughly $661 in MY 2031, on average. However, the absolute difference in increased per vehicle costs for MY 2031 vehicles fall within 3% for each baseline analysis considered, on average, after the application of the CAFE standards.

Overall total discounted benefits attributable to the final PC and LT standards over the lifetime of vehicles through MY 2031 for the reference baseline analysis are $35.2 billion at a 3 percent discount rate (2.0% percent discount rate for the social cost of GHGs (SC-GHG)) and $30.8 billion at a 7 percent discount rate (2.0% percent discount rate for SC-GHG).[16] It is important to stress that these estimates could change – sometimes dramatically – with different assumptions and are, likely, conservative. For example, if estimates of future fuel prices are too low, corresponding input revisions could significantly increase net benefits. For the No ZEV alternative baseline, overall total discounted benefits attributable to the final PC and LT standards over the lifetime of vehicles through MY 2031 are $44.9 billion at a 3 percent discount rate (2.0% percent discount rate for the social cost of GHGs (SC-GHG)) and $39.8 billion at a 7 percent discount rate (2.0% percent discount rate for SC-GHG)

For HDPUVs, NHTSA projects that under these final standards, required technology costs summed over the entire fleet could increase by $59 million over the No-Action alternative through MY 2038. If those costs are passed on to consumers as average increases in MSRP, we estimate that per-vehicle costs paid by U.S. consumers for new HDPUVs would increase by roughly $226, on average, as compared to if the Phase 2 standards were retained; but concurrently, fuel savings for those vehicles would increase, by roughly $716, on average.[17] Overall total discounted benefits attributable to the final HDPUV standards for the fleet through CY 2050 are $13.62 billion at a 3 percent discount rate (2.0% percent discount rate for SC-GHG) and $11.8 billion at a 7 percent discount rate (2.0% percent discount rate for SC-GHG). As above, these estimates could change with different assumptions. The rows in the tables below represent the different regulatory alternatives considered for PCs and LTs, in Table 1-2 and Table 1-3, and HDPUVs in Table 1-4. The numbers in each column heading represent the rate of increase, year over year, in stringency that the standards would represent – so, for example, PC1LT3 refers to the regulatory alternative in which PC standard stringency would increase at 1 percent year over year, and LT standard stringency would increase at 3 percent year over year. "DR" is an abbreviation for "discount rate."

The results of this analysis are set forth in the rest of this document.

Table 1-2: Estimated Monetized Costs and Benefits – Passenger Cars and Light Trucks – Model Year Perspective, $2021 billions, 2% SC-GHG Discount Rate

	Total			Annualized		
	Monetized Benefits	Monetized Costs	Monetized Net Benefits	Monetized Benefits	Monetized Costs	Monetized Net Benefits
3% Discount Rate						
PC2LT002 (Final Std.)	59.7	24.5	35.2	2.34	0.96	1.38
PC1LT3	85.8	31.8	54.0	3.37	1.25	2.12
PC2LT4	107.2	47.1	60.1	4.20	1.85	2.36
PC3LT5	117.8	60.1	57.7	4.62	2.36	2.26
PC6LT8	136.3	80.8	55.8	5.36	3.17	2.19

[15] The value of lifetime fuel savings assumes a discount rate of 3 percent.
[16] Climate benefits are based on changes (reductions) in CO_2, CH_4, and N_2O emissions and are calculated using three different estimates of the SCC, SC-CH_4, and SC-N_2O. Each estimate assumes a different discount rate (1.5 percent, 2 percent, and 2.5 percent). We emphasize the value of cosnidering the benefits using all three estimates. For simplicity, most tabels throughout this analysis pair the 3 percent and 7 percent social discount rates of non-GHG related effects with a 2 percent discount rate for the social cost of GHGs. For comparison to NPRM values, Chapter 9 includes results using the various discount rates and draft interim estimated SC-GHGs from the IWG.
[17] The value of lifetime fuel savings assumes a discount rate of 3 percent.

	Total			Annualized		
	Monetized Benefits	Monetized Costs	Monetized Net Benefits	Monetized Benefits	Monetized Costs	Monetized Net Benefits
7% Discount Rate						
PC2LT002 (Final Std.)	47.0	16.2	30.8	3.41	1.18	2.23
PC1LT3	66.8	21.0	45.8	4.85	1.53	3.32
PC2LT4	83.1	31.0	52.1	6.04	2.26	3.78
PC3LT5	91.3	39.4	51.9	6.63	2.86	3.77
PC6LT8	105.4	53.8	51.6	7.66	3.91	3.75

Table 1-3: Estimated Monetized Costs and Benefits – Passenger Cars and Light Trucks – Calendar Year Perspective, $2021 billions, 2% SC-GHG Discount Rate

	Total			Annualized		
	Monetized Benefits	Monetized Costs	Monetized Net Benefits	Monetized Benefits	Monetized Costs	Monetized Net Benefits
3% Discount Rate						
PC2LT002 (Final Std.)	236.9	76.8	160.1	12.35	4.00	8.34
PC1LT3	362.2	115.3	247.0	18.88	6.01	12.87
PC2LT4	473.0	175.8	297.1	24.65	9.16	15.49
PC3LT5	577.9	243.4	334.4	30.11	12.69	17.43
PC6LT8	787.5	352.9	434.6	41.04	18.39	22.65
7% Discount Rate						
PC2LT002 (Final Std.)	182.4	43.6	138.8	14.86	3.55	11.30
PC1LT3	277.4	63.4	214.1	22.60	5.16	17.43
PC2LT4	362.1	96.3	265.8	29.49	7.84	21.65
PC3LT5	442.7	131.9	310.7	36.06	10.75	25.31
PC6LT8	602.5	190.4	412.1	49.07	15.51	33.56

Table 1-4: Estimated Monetized Costs and Benefits – HDPUVs – Calendar Year Perspective, $2021 billions, 2% SC-GHG Discount Rate

	Total			Annualized		
	Monetized Benefits	Monetized Costs	Monetized Net Benefits	Monetized Benefits	Monetized Costs	Monetized Net Benefits
3% Discount Rate						
HDPUV4	1.1	0.2	0.9	0.06	0.01	0.05
HDPUV108 (Final Std.)	17.0	3.4	13.6	0.89	0.18	0.71
HDPUV10	27.8	5.6	22.2	1.45	0.29	1.16
HDPUV14	68.9	13.8	55.2	3.59	0.72	2.87
7% Discount Rate						

	Total			Annualized		
	Monetized Benefits	Monetized Costs	Monetized Net Benefits	Monetized Benefits	Monetized Costs	Monetized Net Benefits
HDPUV4	1.0	0.1	0.9	0.08	0.01	0.07
HDPUV108 (Final Std.)	13.4	1.6	11.8	1.09	0.13	0.96
HDPUV10	22.0	2.7	19.4	1.79	0.22	1.58
HDPUV14	56.0	6.7	49.3	4.56	0.55	4.01

2. The Need for CAFE and HDPUV Regulations

NHTSA is required by statute to set CAFE and HDPUV standards and does not have the discretion not to do so.[18] 49 U.S.C. 32902(a) and (b) direct the Secretary of Transportation (by delegation, NHTSA) to prescribe by regulation average fuel economy standards for passenger cars and LTs at least 18 months before the beginning of each model year, and to establish those standards at the maximum feasible average fuel economy level that the Secretary decides the manufacturers can achieve in that model year.

For HDPUV standards, while NHTSA interprets its standards to continue in perpetuity, NHTSA is still obligated by 49 U.S.C. 32902(k) to set standards designed to achieve the maximum feasible improvement in fuel economy, subject to the regulatory lead-time and stability requirements. If NHTSA determines that more stringent standards than those established previously would be the maximum feasible, NHTSA interprets 32902(k) as requiring the agency to set standards at that level.

The overarching purpose of EPCA/EISA, and of CAFE/HDPUV regulations, is energy conservation. Energy conservation is important to our nation because it can save consumers money; it can reduce our dependence on potentially hostile foreign nations and actors, because we need to consume fewer energy resources that they supply to us; and it can help reduce pollution associated with energy consumption, which can mitigate climate change and its negative health and environmental impacts as well as exposure to harmful conventional air pollutants. This FRIA, as well as the accompanying preamble and Technical Support Document (TSD), discuss these effects at length, as well as the possible market failure(s) that inform the need for regulation.

2.1. Market Failure

Executive Order 12866 states that in determining whether regulation is justified, "Each agency shall identify the problem that it intends to address (including, where applicable, the failures of private markets or public institutions that warrant new agency action) as well as assess the significance of that problem." As the preceding chapter explains, NHTSA is required by law to regulate fuel economy, but there are also market failures that can be mitigated or exacerbated by changing fuel economy standards. This chapter summarizes the various energy security, environmental, safety, and consumer-related market failures that may motivate or be affected by changes in fuel economy and fuel efficiency standards.

2.1.1. Energy Security Market Failure

U.S. consumption and imports of petroleum products have three potential effects on the domestic economy that are often referred to as “energy security externalities,” and increases in their magnitude are sometimes cited as possible social costs of increased U.S. demand for petroleum.[19] Insofar as these represent genuine externalities that result from vehicle buyers’ choices of inadequate or ”sub-optimal” levels of fuel economy and impose significant uncompensated costs as a result, raising fuel economy and efficiency standards improve overall economic welfare by reducing their prevalence. First, increases in global petroleum prices that result from higher U.S. gasoline demand will cause a transfer of revenue from consumers of petroleum products to oil producers worldwide, because consumers throughout the world – not just those in the U.S. – are ultimately subject to the higher global prices for petroleum and refined products that result. With competitive markets, this transfer is simply a shift of resources that produces no change in global economic output or welfare. But because individual consumers of petroleum products are unlikely to consider the financial drain that higher prices impose on the U.S. economy when making their consumption choices, the transfer is sometimes

[18] This chapter of the FRIA describes the need for regulation, per Section 1(a) of Executive Order 12866 and Section 5 of OMB Circular A-4.
[19] See Brown, S. and Huntington, H, 2013. Assessing the U.S. Oil Security Premium. *Energy Economics.* Vol. 38: pp. 118-127. Available at: https://doi.org/10.1016/j.eneco.2013.03.010. (Accessed: Feb. 15, 2024).

described as an external cost of increased U.S. petroleum consumption.[20] To the degree that global suppliers like Organization of the Petroleum Exporting Countries (OPEC) and Russia exercise market power, oil prices will be above their level in a competitive market, and will generate a loss in potential Gross Domestic Product (GDP).[21] In the presence of such market power, increases in U.S. gasoline demand can in theory drive prices further above competitive levels and increase the opportunity for suppliers to engage in monopolistic behavior, thus exacerbating this loss. To the extent this actually occurs, reducing domestic fuel demand by raising standards can reduce the financial drain that fuel purchases impose on the U.S. economy, and also mitigate losses in potential U.S. GDP.

Increased U.S. consumption of refined products such as gasoline can also expose domestic users of other petroleum products – whose consumption would be unrelated to changes in CAFE or fuel efficiency standards – to added economic risks by increasing the consequences of sudden changes in their prices or interruptions in their supply and the disruptions those can cause. Because users of petroleum products are unlikely to consider any effect their own consumption has on other economic actors' exposure to oil supply shocks, the expected economic cost of that increased risk is often cited as another external cost of increased U.S. petroleum consumption that higher CAFE and fuel efficiency standards can reduce. Finally, some analysts argue that growing domestic demand for imported petroleum may also require increased U.S. military spending to secure the nation's supplies of imported oil, although the nation's recently achieved self-sufficiency in petroleum supply might mitigate this impact. Because any increase in the cost of military activities necessary to enable additional petroleum imports would not be reflected in the price paid at the gas pump, this effect is often asserted to be a third category of external costs from U.S. petroleum consumption that imposing higher standards could potentially reduce.[22]

Each of these three effects (and their associated costs) is likely to decline incrementally as a consequence of the reduction in U.S. petroleum consumption that the agency estimates would result from the increases in CAFE and fuel efficiency standards this Final Rule establishes. TSD Chapter 6.2.4 discusses in detail the mechanisms that would reduce these externalities and the agency's methods for estimating the economic benefits that would result.

2.1.2. Environmental Market Failures

The burning of fossil fuels and associated emission of CO_2, methane (CH_4), and nitrous oxide (GHGs) is a textbook example of an externality -- a failure of private markets that occurs when an economic transaction generates uncompensated costs on or provides benefits (the former, in the case we analyze) to parties who are not involved in those transactions.[23] Emitting GHGs creates a global externality, because GHGs emitted in one country mix uniformly in the earth's atmosphere with similar gases emitted by sources located in others, and ultimately impose damages on all nations by trapping heat in the earth's atmosphere. This inhibits heat from radiating back into space as it normally would, thereby causing the earth's climate to warm. Because GHGs degrade slowly and tend to accumulate in the earth's atmosphere, the economic damages associated with a warming climate increase as their atmospheric concentrations increase. Because some GHGs emitted today can remain in the atmosphere for hundreds of years, burning fossil fuels today not only imposes uncompensated costs on others around the globe today, but also imposes uncompensated damages

[20] The key distinction between petroleum and most othe commodities that the U.S. imports is that because the nation accounts for such a large share of global petroleum consumption, increased U.S. demand for petroleum exaggerates the change in the financial flow beyond the addiitonal outlay to purchase addiitonal oil supplies, because it raises the price of all *current* purchases as well. The United States became a net exporter of oil on a weekly basis several times in late 2019, and EIA's subsequent analyses continue to project that it will do so on a sustained, long-term basis after 2020; see EIA. 2023. AEO Table 11. Petroleum and Other Liquids Supply and Disposition. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=11-AEO2023&cases=ref2022&sourcekey=0 (Accessed: Feb. 27, 2024). As the United States has approached self-sufficiency in petroleum production, this transfer of revenue has increasingly been from U.S. consumers of refined petroleum products to U.S. petroleum producers, so any price increase that results from increased domestic petroleum demand not only leaves welfare unaffected, but even ceases to be a financial burden on the U.S. economy. In fact, as the United States has become a net petroleum exporter (AEO 2022 projects the nation to be a net exporter of petroleum and other liquids through 2050), the transfer from global consumers to petroleum producers created by higher world oil prices provides a net financial benefit to the U.S. economy. Uncertainty about the nation's long-term import-export balance makes it difficult to project precisely how this situation might change in response to changes in U.S. domestic consumption of petroleum products, but the important point is that changes in revenue flows resulting from variation in global petroleum prices are not a measure of economic costs or benefits that can be attributed to policies that affect petroleum demand.
[21] Greene, D. 2010. Measuring Energy Security: Can the United States Achieve Oil Independence? *Energy Policy*. Vol. 38: pp. 1614-21. Available at: https://www.sciencedirect.com/science/article/pii/S0301421509000755. (Accessed: Feb. 14, 2024).
[22] See Delucchi, M. and Murphy, J. 2008. US Military Expenditures to Protect the Use of Persian Gulf Oil for Motor Vehicles. *Energy Policy*. Vol. 36(6): pp. 2253-64. Available at: https://doi.org/10.1016/j.enpol.2008.03.006. (Accessed: Feb. 22, 2024).
[23] Hanley, N. et al. 2007. Environmental Economics in Theory and Practice. 2nd ed. Red Globe Press London: London, UK. Chapter 3, "Market Failure".Available at: https://www.bloomsbury.com/us/environmental-economics-9780333971376. (Accessed: Feb. 22, 2024).

on future generations. Raising U.S. fuel economy and fuel efficiency standards can reduce the current flow of GHGs into the atmosphere and thus reduce the climate-related damages their accumulation causes.

Abating climate-related damages is generally viewed as a global public good, because the benefits it produces can be extended to additional nations at no cost and it is impossible to exclude individuals from experiencing them.[24] In other words, there exists no market that would compensate a driver who chooses a vehicle that emits less GHGs for the benefits that driver creates for present and future generations.

The scientific evidence that burning fossil fuels is causing the earth to warm is abundant. The greenhouse effect is a natural process whereby certain gases in the atmosphere, called GHGs, trap and absorb heat from the sun, which warms the Earth's surface and helps to maintain a habitable temperature on Earth. GHGs include water vapor, CO_2, CH_4, and nitrous oxide (N_2O). The increase in atmospheric concentrations of these GHGs due to human activities, primarily the burning of fossil fuels, land-use changes, and agriculture, is causing the planet to warm. The scientific evidence for this is based on a wide range of observations and analyses, including measurements of atmospheric concentrations of GHGs, surface and satellite measurements of temperature, and changes in ocean heat content, sea level, and other indicators of climate change. These observations show that the Earth's temperature has increased by about 1.1°C since the pre-industrial era, and that this warming is unequivocally due to human activities.[25]

Criteria pollutants emitted by light-duty (LD) vehicles also exemplify an externality because their associated costs and consequences are borne by society at large, rather than the vehicle owners and manufacturers themselves. These pollutants, including particulate matter, nitrogen oxides, and sulfur oxides contribute to air pollution, and the U.S. population's exposure to higher pollutant concentrations adversely affects public health.[26] As vehicle owners and manufacturers do not directly incur the costs of the environmental and health damages caused by these emissions, they have little incentive to reduce them, but regulating fuel economy can reduce the external damages that fuel refineries' and vehicles' emissions of these pollutants cause.

2.1.3. External Safety Risks

The "rebound effect" is a measure of the additional driving that vehicle users may choose to do when the cost of driving declines. More stringent standards reduce vehicles' operating costs per mile, and in response some consumers may choose to drive more. Although this doesn't represent a market failure, it may produce economic consequences that drivers do not fully internalize. This additional driving increases drivers' and their passengers' exposure to the safety risks associated with auto travel, and this added exposure ultimately translates into more frequent fatalities and injuries. Because fuel economy standards merely make driving less costly and do not require drivers to drive more miles, NHTSA believes that a large fraction of the private safety risks associated with additional driving must be offset by benefits to those drivers from the additional travel. Although the actual fraction of crash risks that drivers "internalize" is unknown, we suspect that drivers are more likely to internalize the potential consequences of serious crashes than of minor ones, and that some drivers may not completely internalize the consequences of injuries to occupants of other vehicles involved in potential crashes, or to pedestrians. However, legal consequences from crash liability, both criminal and civil, should also act as a caution for drivers considering added crash risk exposure. The rebound effect is discussed in greater detail in TSD Chapter 4.3, while the extent of the external safety risk of rebound miles is discussed in TSD Chapter 7.5.

2.1.4. Consumer-Related and Supply-Side Market Failures

How potential buyers value fuel savings from purchasing new cars, LTs, and HDPUV models that offer higher fuel efficiency is a central issue in identifying the need for, and assessing the benefits and costs of fuel economy regulations. If buyers fully valued the savings in fuel costs that result from driving vehicles that offer

[24] Nordhaus, W. 2013. Chapter 16 – Integrated Economic and Climate Modeling. *Handbook of Computable General Equilibrium Modeling*. Vol. 1: pp. 1069-131. Available at: https://www.sciencedirect.com/science/article/abs/pii/B978044459568300016X. (Accessed: Feb. 22, 2024).
[24] Note that NHTSA does not attempt to estimate these spillover effects on other nations' GHG emissions.
[25] Intergovernmental Panel on Climate Change (IPCC). 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: New York, NY. Available at: https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/. (Accessed: Feb. 22, 2024).
[25] Allcott, H., and Greenstone, M. 2012. Is There an Energy Efficiency Gap? *Journal of Economic Persepectives.* Vol. 26 (1): pp. 3-28. Available at: https://www.aeaweb.org/articles?id=10.1257/jep.26.1.3. (Accessed: Feb. 22, 2024).
[26] See TSD section 6.2.2 for more information on the public health impacts of this Final Rule.

higher fuel economy or fuel efficiency (and in the absence of other market failures), manufacturers would presumably supply all improvements in those features that buyers valued highly enough to be willing to pay prices that repaid producers' costs for making them. Vehicle prices would then fully reflect *both* the costs of equipping vehicles with additional fuel saving technology and the future cost savings consumers would realize from owning—and potentially re-selling—more fuel-efficient models.

In this situation, imposing fuel economy and fuel efficiency requirements above this market-determined level would necessarily impose net losses on vehicle buyers, who would already have considered the resulting potential savings in their purchasing decisions and concluded that they did not justify paying higher prices to compensate for producers' increased costs. In this case, raising standards could not provide net benefits to buyers themselves, and could only provide social benefits by reducing the costs of externalities that buyers impose on others but do not recognize. If consumers instead systematically undervalue future fuel savings when choosing among competing vehicle models in the absence of market failures, establishing more stringent CAFE or fuel efficiency standards will lead manufacturers to make improvements in fuel economy that buyers might not initially choose, but would ultimately improve consumer welfare.[27] Note that NHTSA's assumption that consumers are willing to pay for fuel-economy technology that pays for itself within 30 months or less, together with the assumed consumer discount rates of 3 and 7 percent, typically produce results consistent with undervaluation. That is to say, NHTSA's analyses typically show discounted fuel savings in excess of technology costs.

The potential for car buyers to voluntarily forego improvements in fuel economy that offer savings exceeding their initial higher purchasing costs is one example of what is often termed the "energy efficiency gap." The appearance of such a gap between the level of energy efficiency that would minimize consumers' overall costs – including both up-front purchase prices and recurring energy outlays over products' lifetimes –and what they actually purchase is frequently based on comparisons of engineering-based estimates of initial costs for providing higher energy efficiency to the present value of the resulting savings in future energy costs.

There has long been an active debate about whether such a gap actually exists, and why it might arise. Manufacturers have consistently told the agency that new vehicle buyers will pay for 2-3 years of anticipated fuel savings before price increases reflecting the cost of improving fuel economy begin to affect sales. Of course, it is also possible that manufacturers are incorrect in their assumptions. As NHTSA discusses in this section, published economic literature provides support for assumptions ranging from full valuation to substantial undervaluation of vehicles' lifetime energy savings.[28]

Conventional economic theory predicts that in the absence of market failures, informed individuals will purchase more energy-efficient products when the discounted savings in future energy costs they offer promise to offset their higher initial cost, including the opportunity costs of any sacrifices (or postponements) in potential improvements in products' other features that manufacturers would have made had standards not been raised. Thus the additional costs of purchasing and using more energy-efficient products can include more than just the cost of the technology necessary to improve their efficiency; they can also include losses in the utility that vehicles provide to their buyers if manufacturers make tradeoffs in vehicles' other desirable features in their efforts to improve fuel efficiency.

In the context of vehicles, whether the anticipated value of fuel savings outweighs the added cost of purchasing a model offering higher fuel economy or fuel efficiency will depend on how much buyers expect to drive, their expectations about future fuel prices, the discount rates buyers apply to future expenses, the expected effect of a vehicle's higher fuel economy or fuel efficiency on its resale value, and whether more efficient models offer equivalent attributes such as performance, safety, carrying capacity, reliability, ride quality, or other characteristics Economists have identified numerous ways the decision making of both consumers and firms can deviate from standard models of rational consumer behavior and competitive firms when their choices involve such uncertainty.[29] The future value of purchasing a model that offers higher fuel

[27] For more information about how NHTSA models consumer valuation of fuel economy in purchase decisions, please see Chapter 4 of the FRIA.
[28] OMB Circular A-4 (2023) specifically highlights modeling behavior distortions (along with market or institutional distortions) as a standard starting point for conducting BCA for regulatory actions. Addressing behavioral biases is mentioned as a common need for regulation, and the circular further categorizes behavioral biases into two categories: limitations on information processing and decision-making biases, both of which are addressed in this section.
[29] Dellavigna, S. 2009. Psychology and Economics: Evidence from the Field. *Journal of Economic Literature.* Vol. 47(2): pp. 315-72. Available at: https://www.jstor.org/stable/27739926. (Accessed: Feb. 22, 2024).

economy is uncertain for several reasons: the mileage any particular consumer experiences when driving a particular vehicle will generally differ from that shown on fuel economy labels, potential buyers may be uncertain about how much they will actually drive a new vehicle, and future fuel prices are difficult to predict.[30]

Some recent research indicates that typical consumers' behavior often departs from what the standard economic model of utility-maximizing choices would predict,[31] and the explanations for why it appears to do so could account for buyers' undervaluing fuel economy. These include valuing potential losses more than identical potential gains when facing a choice with uncertain outcomes("loss aversion"), behavior consistent with discount factors that decrease over time ("hyperbolic" discounting), a preference for certain over uncertain outcomes, and inattention to further complexity once a choice is deemed "good enough" (or "satisficing").[32] [33] A variety of factors could also inhibit buyers in an unregulated market from purchasing higher levels of fuel efficiency even when those would deliver net economic savings, including informational asymmetries among consumers, dealerships, and manufacturers; market power of manufacturers; and conflicting incentives between vehicle purchasers and drivers, such as with fleet vehicle purchases and use. The recent academic literature has suggested each of the above factors could contribute to the observed energy efficiency gap in the vehicle market.[34][35]

Published empirical studies have not arrived at a consensus about consumers' willingness-to-pay for greater fuel economy, or whether it implies that they correctly value the appropriately discounted value of expected fuel savings from purchasing a model with higher fuel economy. Many studies have relied on car buyers' purchasing behavior to estimate their willingness-to-pay for future fuel savings; a common such approach has been to use "discrete choice" models that relate individual buyers' choices among competing vehicles to their purchase prices, fuel economy, and other attributes (such as performance, carrying capacity, and reliability), and to infer buyers' valuation of higher fuel economy from the relative importance of purchase prices and fuel economy those models imply.[36] Because a vehicle's price is often correlated with its other attributes (both measured and unobserved), analysts have often resorted to instrumental variables or other approaches to address endogeneity and other resulting concerns.[37] Empirical estimates using these approaches span a wide range, extending from substantial undervaluation of fuel savings to significant overvaluation, thus making it difficult to identify a consensus estimate of the value consumers place on fuel economy.[38]

Given the variation in estimated willing-to-pay for fuel economy, it is worth directly considering the implications for welfare CAFE fuel economy standards have in each of these scenarios. If fuel economy is relatively

[30] Greene, D.L., 2011. Uncertainty, Loss Aversion and Markets for Energy Efficiency. Energy Economics. Vol. 33(4): pp. 608-16. Available at: https://EconPapers.repec.org/RePEc:eee:eneeco:v:33:y:2011:i:4:p:608-616. (Accessed: Feb. 22, 2024); Hamilton, J. 2009. Understanding Crude Oil Prices. *The Energy Journal*. Vol. 30(2): pp. 179-206. Available at: https://www.nber.org/system/files/working_papers/w14492/w14492.pdf. (Accessed: Feb. 22, 2024).; Greene, D. et al. 2017. What is the Evidence Concerning the Gap Between On-road and EPA Fuel Economy Ratings? *Transport Policy*. Vol. 53: pp. 146-60. Available at: https://doi.org/10.1016/j.tranpol.2016.10.002. (Accessed: Feb. 22, 2024).

[31] Stango, V. and Zinman, J. 2020. We Are All Behavioral, More or Less: A Taxonomy of Consumer Decision-Making. NBER Working Paper 28138, National Bureau of Economic Research, Cambridge, MA. Available at: https://www.nber.org/papers/w28138. (Accessed: Feb. 22, 2024).Based on nationally representative panel data, the study concludes that the typical U.S. consumer exhibits 10 "behavioral biases".

[32] Leard, B. 2018. Consumer Inattention and the Demand for Vehicle Fuel Cost Savings. *Journal of Choice Modeling*. Vol. 29: pp. 1-16. Available at: https://doi.org/10.1016/j.jocm.2018.08.002. (Accessed: Feb. 22, 2024); Heutel, G. 2019. Prospect Theory and Energy Efficiency. *Journal of Environmental Economics and Management.* Vol. 96: pp. 236-54. Available at: https://doi.org/10.1016/j.jeem.2019.06.005. (Accessed: Feb. 22, 2024); Greene, D.L. et al. 2013. Survey Evidence on the Willingness of U.S. Consumers to Pay for Automotive Fuel Economy. *Energy Policy*. Vol. 61: pp. 1539-50. Available at: https://doi.org/10.1016/j.enpol.2013.05.050. (Accessed: Feb. 22, 2024.

[33] Kahneman, D. 2011. Thinking Fast and Slow. Farrar, Straus and Giroux: New York, New York. Available at: https://us.macmillan.com/books/9780374533557/thinkingfastandslow. (Accessed: Feb. 22, 2024).

[34] Academic literature on these market failures is collected and summarized by Rothschild, R. & J. Schwartz. 2021. Tune Up: Fixing Market Failures to Cut Fuel Costs and Pollution from Cars and Trucks. Institute for Policy Integrity Report. Available at: https://www.jstor.org/stable/resrep45792. (Accessed: Feb. 22, 2024).

[35] Academic literature on these market failures is collected and summarized by Rothschild, R. & J. Schwartz. 2021. Tune Up: Fixing Market Failures to Cut Fuel Costs and Pollution from Cars and Trucks. Institute for Policy Integrity Report. Available at: https://www.jstor.org/stable/resrep45792. (Accessed: Feb. 22, 2024).

[36] In a typical vehicle choice model, the ratio of estimated coefficients on fuel economy — or more commonly, fuel cost per mile driven — and purchase price is used to infer the dollar value buyers attach to slightly higher fuel economy.

[37] Berry, S. et al. 1995. Automobile Prices in Market Equilibrium. ***Econometrica***. Vol. 63(4):pp. 841–90. Available at: https://www.jstor.org/stable/2171802. (Accessed: Feb. 22, 2024).

[38] For detailed reviews of these cross-sectional studies see See Greene, D.L., et al. 2018. Consumer Willingness to Pay for Vehicle Attributes: What Do We Know? *Transportation Research Part A Policy Practice*. Vol. 118: pp. 258-79. Available at: https://pubmed.ncbi.nlm.nih.gov/30505075/. (Accessed: Feb. 22, 2024);Greene et al. (2018), Helfand, G., and Wolverton, A. 2011. Evaluation the Consumer Response to the Fuel Economy: A Review of the Literature. *International Review of Environmental and Resource Economics*. Vol. 5: pp. 103-46. Available at: https://www.researchgate.net/publication/260035383_Evaluating_the_Consumer_Response_to_Fuel_Economy_A_Review_of_the_Literature. (Accessed: Feb. 22, 2024).Helfand and Wolverton (2011); and Greene, D. 2010. Measuring Energy Security: Can the United States Achieve Oil Independence? *Energy Policy*. Vol. 38: pp. 1614-21. Available at: https://www.sciencedirect.com/science/article/pii/S0301421509000755. (Accessed: Feb. 22, 2024); and Greene (2010) for detailed reviews of these cross- sectional studies.

undervalued, then consistent with the “energy efficiency gap” literature welfare-improving policy options would include minimum efficiency standards. By the same notion, if consumers have more accurate valuations of fuel economy, then fuel economy standards would not correct private investment inefficiencies. Furthermore, it is possible that there is a distribution of valuations of fuel economy that are concurrently present in the population, such that fuel economy standards could have simultaneously positive or negative effects depending on the consumer.

More recent research has criticized these studies for a variety of technical concerns. Some have questioned the power of the statistical instruments they use,[39] while others have observed that coefficients estimated using complex statistical methods can be sensitive to the optimization algorithm and initial values specified.[40] Collinearity (i.e., high correlations) among vehicle attributes—most notably among fuel economy, performance or power, and vehicle size—and between vehicles’ measured and unobserved features also raises questions about the reliability and interpretation of estimated coefficients, since they may conflate the value of fuel economy with other attributes (Sallee et al., 2016; Busse et al., 2013; Allcott & Wozny, 2014; Allcott & Greenstone, 2012; Helfand & Wolverton, 2011).[41]

To overcome the shortcomings of past analyses, more recent studies rely on changes in prices between repeated sales of individual vehicle models and very large samples to improve their reliability in identifying the association between vehicles’ prices and their fuel economy (Sallee et al. 2016; Allcott & Wozny, 2014; Busse et al., 2013; Leard et al., 2023).[42] Results from these studies are reported in Table 2-1. Although they differ in certain details, each of these analyses relates changes over time in individual models’ selling prices to fluctuations in fuel prices and differences in their fuel economy – which combine to change their remaining lifetime fuel costs and presumably their market value, while controlling for increases in their age and accumulated use between subsequent sales, since those affect their market value by shortening their expected remaining lifetimes.

Because a vehicle’s projected future fuel costs are a function of both its fuel economy and expected gasoline prices, changes in fuel prices have varying effects on the remaining lifetime fuel costs and thus the market values of vehicles with different fuel economy. Comparing changes in individual models’ actual selling prices to those that would be expected if their buyers fully valued the impact of changing fuel prices on future fuel costs can reveal the fraction of changes in their lifetime fuel costs that is reflected in their selling prices (Allcott & Wozny, 2014). Using very large samples of sales allows these studies to define vehicle models at an extremely disaggregate level, which enables their authors to isolate differences in their fuel economy from other attributes (including those that are difficult to observe or measure) that affect their sale prices.[43]

[39] Allcott, H., and Greenstone, M. 2012. Is There an Energy Efficiency Gap? *Journal of Economic Perspectives.* Vol. 26 (1): pp. 3–28. Available at: https://www.aeaweb.org/articles?id=10.1257/jep.26.1.3. (Accessed: Feb. 22, 2024).
[40] Metaxoglou, K., and Knittel, C.R. 2014. Estimation of Random-Coefficient Demand Models: Two Empiricists’ Perspective. *Review of Economics and Statistics*. Vol. 96(1): pp. 34-59. Available at: https://dspace.mit.edu/handle/1721.1/87587. (Accessed: Feb. 22, 2024).
[41] Sallee, J. et al. 2016. Do Consumers Recognize the Value of Fuel Economy? Evidence from Used Car Prices and Gasoline Price Fluctuations. *Journal of Public Economics*. Vol. 135(2016): pp. 61-73. Available at: https://www.nber.org/papers/w21441. (Accessed: Feb. 22, 2024); Busse, M. et al. 2013. Are Consumers Myopic? Evidence from New andUsed Car Purchases. *American Economic Review*. Vol. 103(1): pp. 220–56. Available at: https://dspace.mit.edu/handle/1721.1/87769. (Accessed: Feb. 22, 2024); Allcott, H., Wozny, N. 2014. Gasoline Prices, Fuel Economy and the Energy Paradox. *The Review of Economics and Statistics*. Vol. XCVI(5). Available at: https://direct.mit.edu/rest/article-abstract/96/5/779/58196/Gasoline-Prices-Fuel-Economy-and-the-Energy?redirectedFrom=fulltext. (Accessed: Feb. 22, 2024); Allcott, H., Greenstone, M. 2012. Is There an Energy Efficiency Gap? *Journal of Economic Perspectives*. Vol. 26 (1): pp. 3–28. Available at: https://www.aeaweb.org/articles?id=10.1257/jep.26.1.3. (Accessed: Feb. 22, 2024).
[42] Leard, B. et al. 2023. How Much Do Consumers Value Fuel Economy and Performance? Evidence from Technology Adoption. *The Review of Economics and Statistics*. Vol. 105(1): pp. 158-74. Available at: https://doi.org/10.1162/rest_a_01045. (Accessed: Feb. 22, 2024).
[43] These studies rely on individual vehicle transaction data from dealer sales and wholesale auctions, which includes actual sale prices and allows their authors to define vehicle models at a highly disaggregated level. For instance, Allcott and Wozny (2014) differentiate vehicles by manufacturer, model or nameplate, trim level, body type, fuel economy, engine displacement, number of cylinders, and “generation” (a group of successive ps during which a model’s design remains largely unchanged). All three studies include transactions only through mid- 2008 to limit the effect of the recession on vehicle prices. To ensure that the vehicle choice set consists of true substitutes, Allcott and Wozny (2014) define the choice set as all gasoline-fueled light-duty cars, trucks, SUVs, and minivans that are less than 25 years old (i.e., they exclude vehicles where the substitution elasticity is expected to be small). Sallee et al. (2016) exclude diesels, hybrids, and used vehicles with less than 10,000 or more than 100,000 miles.

Table 2-1: Percent of Future Fuels Costs Internalized in Used Vehicle Purchase Price Using Current Gasoline Prices to Reflect Expectations (for Base Case Assumptions)

Authors (Pub. Date)	Discount rate			
	3%	5%	6%	10%
Busse et al. (2013)*	54%-87%	60%-96%	62%-100%	73%-117%
Allcott and Wozny (2014)	48%		55%	65%
Sallee et al. (2016)		101%		142%
Leard et al (2023)		69.1%		90.4%

*Notes: The ranges in the estimates from Busse et al. (2013) depend on which quartiles of the fuel economy distribution are compared, so this table presents the full quartile comparison range. The central estimate of this value reported in Leard et al. (2023) is 53.6% using a discount rate of 1.3%. The authors report values using several alternative discount rates in their online appendix.[44]

These studies point to a somewhat narrower range of estimates than suggested by previous research; more importantly, they consistently suggest that, at least at higher discount rates, buyers value a large proportion—and perhaps even all—of the future savings that models with higher fuel economy offer.[45] Because they rely on estimates of fuel costs over vehicles' expected remaining lifetimes, these studies' estimates of how buyers value fuel economy are sensitive to how they measure differences among individual models' fuel economy (and the assumption that vehicles' fuel economy does not deteriorate over their lifetimes) and how they estimate vehicles' remaining "life expectancy," as well as to their assumptions about buyers' discount rates and expectations for future gasoline prices. Anderson et al. (2013)[46] found evidence that consumers expect future gasoline prices to resemble current prices, and the agency uses this assumption to compare the findings of the studies and examine how they vary with the discount rates buyers are assumed to apply to future fuel savings.[47]

For discount rates of five to six percent, the Busse et al. (2013) results imply that variation among vehicles' prices reflects 60 to 100 percent of differences in their future fuel costs. Allcott and Wozny (2014) found that consumers incorporate 55 percent of future fuel costs into vehicle purchase decisions if they are assumed to discount future costs at six percent and their expectations for future gasoline prices reflect prevailing prices at the time of their purchases. With that same expectation about future fuel prices, these authors report that consumers would fully value fuel costs only if they apply discount rates of 24 percent or higher. Sallee et al. (2016) begin with the perspective that buyers fully internalize future fuel costs into vehicles' purchase prices and cannot reliably reject that hypothesis; their base specification actually suggests that changes in vehicle prices incorporate slightly *more* than 100 percent of changes in future fuel costs. Leard et al. (2023) uses instrumental variables to account for endogeneity between fuel costs and performance of vehicles and reports a central value of 53.6 percent assuming a real discount rate of 1.3 percent; these results imply full valuation of fuel costs at discount rates above 12 percent.

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[44] See: Leard, B., Linn, J., and Zhou, Y.C. Appendix for "How Much Do Consumers Value Fuel Economy and Performance? Evidence from Technology Adoption." Available: https://direct.mit.edu/rest/article-abstract/105/1/158/100976/How-Much-Do-Consumers-Value-Fuel-Economy-and (Accessed: Feb. 22, 2024).

[45] Much earlier, Killian and Sims (2006) and Sawhill (2010) developed similar longitudinal approaches to examine consumer valuation of fuel economy, although they used average sale values or list prices instead of actual transaction prices for specific vehicles. Since these studies remain unpublished, their empirical results are subject to change, and they are excluded from this discussion. See Kilian, Lutz, and Eric R. Sims, The Effects of Real Gasoline Prices on Automobile Demand: A Structural Analysis Using Micro Data, University of Michigan, April 18, 2006; and James W. Sawhill, Three Essays on Strategic Considerations for Product Development, University of California, Berkeley, 2010.

[46] Anderson, S. T., Kellogg, R. and Sallee, J. M., 2013. What do consumers believe about future gasoline prices?, *Journal of Environmental Economics and Management*. Elsevier. Vol. 66(3). Pages 383-403. Available at: https://ideas.repec.org/a/eee/jeeman/v66y2013i3p383-403.html. (Accessed: Mar. 7, 2024).

[47] Each of the studies makes slightly different assumptions about appropriate discount rates. Sallee et al. (2016) use five percent in their base specification, while Allcott and Wozny (2014) rely on six percent. As some authors note, a five to six percent discount rate is consistent with current interest rates on car loans, but they also acknowledge that borrowing rates could be higher in some cases, which could be used to justify higher discount rates. Rather than assuming a specific discount rate, Busse et al. (2013) directly estimate implicit discount rates at which future fuel costs would be fully internalized; they find discount rates of six to 21 percent for used cars and one to 13 percent for new cars at assumed demand elasticities ranging from -2 to -3. Their estimates can be translated into the percent of fuel costs internalized by consumers, assuming a particular discount rate. To make these results more directly comparable to the other two studies, we assume a range of discount rates and uses the authors' spreadsheet tool to translate their results into the percent of fuel costs internalized into the purchase price at each rate. Because Busse et al. (2013) estimate the effects of future fuel costs on vehicle prices separately by fuel economy quartile, these results depend on which quartiles of the fuel economy distribution are compared; our summary shows results using the full range of quartile comparisons.

The studies also explore the sensitivity of the results to other parameters that could influence their results. Busse et al. (2013) and Allcott and Wozny (2014) find that assuming lower annual vehicle use or survival probabilities (which imply that vehicles will not last as long) moves their estimates closer to full valuation, an unsurprising result because both reduce the changes in expected future fuel costs caused by fuel price fluctuations. Allcott and Wozny's (2014) base results rely on an instrumental variables estimator that groups miles-per-gallon (MPG) into two quantiles to mitigate potential attenuation bias due to measurement error in fuel economy, and they find that greater disaggregation of the MPG groups implies greater undervaluation. These authors' estimates using gasoline price forecasts that mirror oil futures markets are closer to full valuation, because the petroleum market apparently expected prices to fall during this period, and this expectation reduces the discounted value of all vehicles' expected remaining lifetime fuel costs. Busse et al. (2013) allow gasoline prices to vary across local markets in their main specification; using national average gasoline prices, an approach more directly comparable to the other studies, results in estimates that are closer to or above full valuation. Sallee et al. (2016) find modest undervaluation by vehicle fleet operators or manufacturers making large- scale purchases, compared to buyers purchasing vehicles at retail dealers (i.e., 70 to 86 percent).

Since they rely predominantly on changes in vehicles' prices between repeat sales, most of the valuation estimates reported in these studies apply directly to buyers of used vehicles. Only Busse et al. (2013) and Leard (2023) examine new vehicle sales. Busse (2013) find that consumers value between 75 to 133 percent of future fuel costs for new vehicles, higher levels than they estimate for used vehicles, while Leard (2023) finds results suggesting lower consumer valuation of fuel cost savings using a different approach and dataset. When the latter authors apply their methodology to the dataset used in Busse (2013), they obtain similar results, yet when they apply the methodology of Busse (2013) to their own dataset, they find undervaluation comparable to their own baseline results, suggesting both results are sensitive to the sample period rather than methodology. Allcott and Wozny (2014) examine how their estimates vary by vehicle age and find that fluctuations in purchase prices of younger vehicles imply that buyers whose fuel price expectations mirror the petroleum futures market value a much higher fraction of future fuel costs: 93 percent for one- to three-year-old vehicles, compared to their estimate of 76 percent for all used vehicles assuming the same price expectation.[48] Accounting for differences in their data and estimation procedures, the studies described here suggest that car buyers who use discount rates of five to six percent value at least half—and perhaps all—of the savings in future fuel costs they expect from choosing models that offer higher fuel economy.

Based on a meta-analysis of the literature from 1995-2015 that included most of the papers discussed above, Greene et al. (2018) concluded that economic literature from that period did not support a consensus estimate of consumers' willingness to pay for fuel economy, although it clearly ruled out the possibility of zero valuation. The National Academies of Sciences, Engineering, and Medicine (NASEM, 2021) fuel economy committee agreed, observing that, "Many papers found undervaluation, and many have found full or even overvaluation. Both earlier studies and more recent ones have found undervaluation. Studies using both methodologies (discrete choice or otherwise) have found undervaluation." (NASEM, 2021, p. 11-351). More recently, Gillingham et al. (2021) analyzed the effects of changes in fuel economy *ratings* of 1.6 million vehicles on their purchase prices and concluded that if those correctly predicted their actual on-road fuel economy, consumers appeared willing to pay only 16-39 cents per dollar of fuel savings, assuming they discounted future fuel costs an annual rate of 4 percent.[49]

NHTSA also examined whether the heterogeneity in consumer response was different for commercial HDPUVs. Even if commercial operators are profit-maximizing buyers of fuel economy, that assumption does not necessarily mean that commercial operators are willing to pay $1 for every future $1 of fuel savings. Tight profit margins, skepticism about the claimed on-road performance benefits of energy saving technologies, and the differing incentives faced by fleet owners and truck drivers all could act to limit the value that fleet managers place upon potential fuel savings, according to a report from the International Energy Agency.[50]

[48] Allcott and Wozny (2014) and Sallee et al. (2016) also find that future fuel costs for older vehicles are substantially undervalued (26-30 percent). The pattern of Allcott and Wozny's results for different vehicle ages is similar when they use retail transaction prices (adjusted for customer cash rebates and trade-in values) instead of wholesale auction prices, although the degree of valuation falls substantially in all age cohorts with the smaller, retail price based sample.

[49] Gillingham, K. et al. 2021. Consumer Myopia in Vehicle Purchases: Evidence from a Natural Experiment. *American Economic Journal: Economic Policy*. Vol. 13(3): pp. 207–38. Available at: https://www.nber.org/papers/w25845. (Accessed: Feb. 22, 2024).

[50] International Energy Agency. 2017. The Future of Trucks: Implications for Energy and the Environment. Second Edition. Available at: https://www.iea.org/reports/the-future-of-trucks. (Accessed: Feb. 22, 2024).

Smaller fleet operators are reportedly less willing to adopt new cost saving technologies due to more limited financial resources, and greater risk aversion.[51] In the heavy-duty commercial vehicle realm, the required payback period reported by truck buyers ranged from 6 to 36 months for small fleets (1-20 vehicles), and up to 18-48 months for larger fleets.[52] The average payback period for fleet operators in the HDPUV market could be influenced by the share of the market made up by larger operators, and consumer preferences for fuel efficiency could change over time based on new information, innovation, and changing prices (e.g. fuel prices).

NHTSA examined several sources of information to ascertain the composition of consumers in the HDPUV market. The agency analyzed data from a 2018 draft Advanced Clean Trucks (ACT) Market Segment Analysis, prepared by the Truck and Engine Manufacturers Association (EMA) for the California Air Resources Board (CARB), and found that commercial users represented just under half of new vehicle sales in the HDPUV market.[53] While there is thus some evidence to conclude that buyers in this market are on average more likely to be fleet operators than in the light duty market, there is significant uncertainty about the extent of this difference. For this final rule, the agency's assumption about HDPUV buyers' willingness to pay for improved fuel economy thus mirrors its assumption about the behavior of light-duty vehicle buyers, but also includes sensitivity cases that vary this assumption.

The above discussion highlights the complexity of these issues, and indeed, of human behavior when it comes to vehicle purchasing decisions and thus ultimate fleet fuel economy/efficiency. If the energy efficiency gap is caused by a market failure, then, without the intervention of fuel economy standards, the levels of fuel economy in the United States would be suboptimal. While NHTSA is bound by statute to regulate and to set maximum feasible standards for passenger cars, light trucks, and HDPUVs, one effect of regulating may be to address the market failures described above.

[51] Birky, A. et al. 2017. Electrification Beyond Light Duty: Class 2b-3 Commercial Vehicles. Final Report. No. ORNL/TM-2017/744. Energy and Transportation Science Division. Oak Ridge National Laboratory. (ORNL). pp 1-47. Available at: https://info.ornl.gov/sites/publications/Files/Pub106416.pdf. (Accessed: Feb. 9, 2024).
[52] Schoettle, B et al. 2016. A Survey of Fuel Economy and Fuel Usage by Heavy-Duty Truck Fleets. Report No. SWT-2016-12. Available at: https://www.semanticscholar.org/paper/A-Survey-of-Fuel-Economy-and-Fuel-Usage-by-Truck-Schoettle-Sivak/28838cfa69923f0f7d63e83e7dd2ff1deef1d445. (Accessed: Feb. 22, 2024).
[53] For this analysis personal use pickup trucks were considered to be the only non-commercial vehicle sale classification. These vehicles represented 50.7 percent of the overall market. This report was presented at the December 4, 2018 Public Workshop on Advanced Clean Trucks. Data can be accessed at: https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks/act-meetings-workshops.

3. Baseline and Alternatives Considered

Agencies typically consider regulatory alternatives in rulemaking analyses as a way of evaluating the comparative effects of different potential ways of accomplishing their desired goal, which in this case is the statutory mandate to set maximum feasible standards. The National Environmental Policy Act (NEPA) requires agencies to compare the potential environmental impacts of their regulatory actions to those of a reasonable range of alternatives.[54] E.O. 12866 and E.O. 13563, as well as Office of Management and Budget (OMB) Circular A-4, also encourage agencies to evaluate regulatory alternatives in their rulemaking analyses. 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.

CAFE Model Files Referenced in this Chapter

Below is a list of CAFE Model Files referenced in this chapter. See TSD Chapter 2.1.9 Where to Find the Internal NHTSA Files? for a full list of files referenced in this document and their respective file locations.

- Market Data Input File
- Scenario Input File

Alternatives analysis begins with a "No-Action" Alternative, typically described as what would occur in the absence of any regulatory action by the agency – in other words, the reference baseline. OMB Circular A-4 states that "the choice of an appropriate baseline may require consideration of a wide range of potential factors, including:

- evolution of markets;
- changes in regulations promulgated by the agency or other government entities;
- other external factors affecting markets;
- the degree of compliance by regulated entities with other regulations; and
- the scale and number of entities or individuals that will be subject to, or experience the benefits or costs of, the regulation."[55]

For PCs and LTs, this final rule includes the No-Action alternative and five "action alternatives;" for HDPUVs, this final rule includes the No-Action alternative and four action alternatives. The final standards may, in places, be referred to as the "Preferred Alternative(s)," which is NEPA parlance, but NHTSA intends "final standards" and "Preferred Alternative(s)" to be used interchangeably for purposes of this document.

The different action alternatives are defined in terms of percent-changes in stringency from year to year, but they differ slightly between PCs and LTs on the one hand, and HDPUVs on the other. For PCs and LTs, readers should recognize that those year-over-year changes in stringency are *not* measured in terms of mile per gallon differences (as in, 1 percent more stringent than 30 MPG in one year equals 30.3 MPG in the following year), but rather in terms of shifts in the *footprint functions* that form the basis of the *actual* CAFE standards (as in, on a gallon per mile basis, the CAFE standards change by a given percentage from one model year to the next).

For PCs, consistent with prior rulemakings, NHTSA is defining final fuel economy targets as shown in Equation 3-1.

Equation 3-1: Passenger Car Fuel Economy Footprint Target Curve

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

[54] 40 CFR 1502.14.

[55] Office of Management and Budget. 2023. Circular A-4. General Issues, 4. Developing an Analytic Baseline. Washington, D.C. Pages 1 – 93. Available at: https://www.whitehouse.gov/wp-content/uploads/2023/11/CircularA-4.pdf. (Accessed: Apr. 26, 2024).

Where:

$TARGET_{FE}$ is the fuel economy target (in mpg) applicable to a specific vehicle model type with a unique footprint combination,

a is a minimum fuel economy target (in mpg),

b is a maximum fuel economy target (in mpg),

c is the slope (in gallons per mile per square foot, or gpm per square foot), of a line relating fuel consumption (the inverse of fuel economy) to footprint, and

d is an intercept (in gpm) of the same line.

Here, MIN and MAX are functions that take the minimum and maximum values, respectively, of the set of included values. For example, MIN[40, 35] = 35 and MAX(40, 25) = 40, such that MIN[MAX(40, 25), 35] = 35.

The resultant functional form is reflected in graphs displaying the PC target function in each MY for each regulatory alternative in preamble Sections IV.B.1 and IV.B.3.

For LTs, also consistent with prior rulemakings, NHTSA is defining fuel economy targets as shown in Equation 3-2.

Equation 3-2: Light Truck Fuel Economy Footprint Target Curve

$$TARGET_{FE} = MAX\left(\frac{1}{MIN\left[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}\right]}, \frac{1}{MIN\left[MAX\left(g \times FOOTPRINT + h, \frac{1}{e}\right), \frac{1}{f}\right]}\right)$$

Where:

$TARGET_{FE}$ is the fuel economy target (in mpg) applicable to a specific vehicle model type with a unique footprint combination,

a, b, c, and d are as for PCs, but taking values specific to LTs,

e is a second minimum fuel economy target (in mpg),

f is a second maximum fuel economy target (in mpg),

g is the slope (in gpm per square foot) of a second line relating fuel consumption (the inverse of fuel economy) to footprint), and

h is an intercept (in gpm) of the same second line.

NHTSA is defining HDPUV fuel efficiency targets as shown in Equation 3-3:

Equation 3-3: HDPUV Fuel Efficiency Work Factor Target Curve

Sub configuration Target Standard (gallons per 100 miles)=[c x (WF)]+d

Where:

c is the slope of the gasoline, compressed natural gas engine (CNG), Strong Hybrid, and PHEV work factor target curve in gal/100 mile per WF

For diesel engines, BEVs and FCEVs, c will be replaced with e

d is the gasoline, CNG, Strong Hybrid, and PHEV minimum fuel consumption work factor target curve value in gal/100 mile

For diesel engines, BEVs and FCEVs, d will be replaced with f

WF=Work Factor=[0.75× (Payload Capacity+Xwd)]+[0.25 × Towing Capacity]

Where:

Xwd = 4wd adjustment = 500 lbs. if the vehicle group is equipped with 4wd and all-wheel drive (AWD), otherwise equals 0 lbs. for 2wd

Payload Capacity = GVWR (lbs.) – Curb Weight (lbs.) (for each vehicle group)

Towing Capacity = GCWR (lbs.) – GVWR (lbs.) (for each vehicle group)

In a departure from recent CAFE rulemaking trends, for this final rule, we have applied individual rates of increase to the PC and the LT fleets in different MYs. Rather than have both fleets increase their respective standards at the same rate, PC standards will increase at a steady rate year over year, while LT standards will not increase for a few years before beginning to rise again at the PC rate. Several action alternatives evaluated for this final rule have PC fleet rates-of-increase of fuel economy that are different from the rates-of-increase of fuel economy for the LT fleet. NHTSA has discretion, by law, to set CAFE standards that increase at different rates for cars and trucks, because NHTSA must set maximum feasible CAFE standards separately for cars and trucks.[56]

For HDPUVs, the different action alternatives are also defined in terms of percent-increases in stringency from year to year, but in terms of fuel consumption reductions rather than fuel economy increases, so that increasing stringency appears to result in standards going *down* (representing a direct reduction in fuel consumed) over time rather than *up*. Also, unlike for the PC and LT standards, because HDPUV standards are in the fuel consumption space, year-over-year percent changes do actually represent gallon/mile differences across the work-factor range. Under each action alternative for HDPUVs, the stringency changes are the same, or a slightly different percentage in the case of the preferred alternative, rates in each model year in the rulemaking time frame. One action alternative is less stringent than the Preferred Alternative for HDPUVs, and two action alternatives are more stringent.[57]

Table 3-1: Regulatory Alternatives Under Consideration for MYs 2027-2031 Passenger Cars and Light Trucks

Name of Alternative	Passenger Car Stringency Increases, Year-Over-Year	Light Truck Stringency Increases, Year-Over-Year
No Action Alternative	n/a	n/a
Alternative PC2LT002 (Final Standards)	2%	0% for MYs 2027-2028 2% for MYs 2029-2031
Alternative PC1LT3	1%	3%
Alternative PC2LT4	2%	4%
Alternative PC3LT5	3%	5%
Alternative PC6LT8	6%	8%

Table 3-2: Regulatory Alternatives Under Consideration for MYs 2030-2035 HDPUVs

Name of Alternative	HDPUV Stringency Increases, Year-Over-Year
No Action Alternative	n/a
Alternative HDPUV4	4%
Alternative HDPUV108 (Final Standards)	10% for MYs 2030-2032 8% for MYs 2033-2035

[56] See, e.g., the 2012 final rule establishing CAFE standards for MYs 2017 and beyond, in which rates of stringency increase for passenger cars and LTs were different. 77 FR 62623, 62638-39 (Oct. 15, 2012).
[57] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively. See Final TSD Chapter 1.2.1 for a complete discussion about the WF curve functions and how they are calculated.

Alternative HDPUV10	10%
Alternative HDPUV14	14%

A variety of factors will be at play simultaneously as manufacturers seek to comply with the eventual standards that NHTSA promulgates. Foreseeably, NHTSA, EPA, and CARB will all be regulating simultaneously; manufacturers will be responding to those regulations as well as to anticipated shifts in market demand during the rulemaking time frame (both due to cost/price changes for different types of vehicles over time, fuel price changes, and the recently-passed tax credits for BEVs and PHEVs). Many costs and benefits that will accrue as a result of manufacturer actions during the rulemaking time frame will be occurring for reasons other than CAFE standards, and NHTSA believes it is important to try to reflect many of those factors in order to present an accurate picture of the effects of different potential CAFE and HDPUV standards to decision-makers and to the public.

The following chapters define each regulatory alternative, including the No-Action Alternative, for each program, and explain their derivation.

3.1. Reference Baseline/No-Action Alternative

As with the 2022 final rule analysis, our No-Action Alternative (i.e., the reference baseline) is nuanced. In this analysis, the No-Action Alternative assumes:

- The existing (through MY 2026) national CAFE and GHG standards are met, and that the CAFE and GHG standards for MY 2026 finalized in 2022 continue in perpetuity.[58]
- Manufacturers who committed to the California Framework Agreements met their contractual obligations for MY 2022.
- The HDPUV MY 2027 standards finalized in the NHTSA/EPA Phase 2 program continue in perpetuity.
- Manufacturers will comply with the Advanced Clean Cars I and Advanced Clean Trucks (ACT) program that California and other states intend to implement through 2035.[59]
- Manufacturers will, regardless of the existence or non-existence of a legal requirement, produce additional electric vehicles consistent with the levels that would be required under the ZEV/Advanced Clean Cars II program if it were to be granted a Clean Air Act preemption waiver.[60]
- Manufacturers will make production decisions in response to estimated market demand for fuel economy or fuel efficiency, considering estimated fuel prices, estimated product development cadence, the estimated availability, applicability, cost, and effectiveness of fuel-saving technologies, and available tax credits.

NHTSA continues to believe that to properly estimate fuel economies/efficiencies (and achieved CO_2 emissions) in the No-Action Alternative, it is necessary to simulate all these legal requirements and other influences affecting automakers and vehicle design simultaneously. Consequently, the CAFE Model evaluates each requirement in each model year, for each manufacturer/fleet. Differences among fleets and compliance provisions often creates over-compliance in one program, even if a manufacturer is able to exactly comply (or under-comply) in the other program. This is similar to how manufacturers approach the question of concurrent compliance in the real world – when faced with multiple regulatory programs, the most cost-effective path may be to focus efforts on meeting one or two sets of requirements, even if that results in “more effort” than would be necessary for another set of requirements, in order to ensure that all regulatory obligations are met. We elaborate on those model capabilities below. Generally speaking, the model treats each manufacturer as applying the following logic when making technology decisions, both for simulating PC and LT compliance, and HDPUV compliance, with a given regulatory alternative:

1. What do I need to carry over from last year?

[58] NHTSA recognizes that before this final rule was published, EPA published new final GHG standards for MYs 2027 and beyond; however, those standards were not included in the reference baseline analysis, as the agencies developed their respective standards for MYs 2027 and beyond jointly.
[59] Additional discussion of how NHTSA modeled the ZEV programs is located in TSD Chapter 2.5.1.
[60] Additional discussion of how NHTSA modeled this voluntary ZEV deployment is located in TSD Chapter 2.5.1.

2. What should I apply more widely in order to continue sharing (of, e.g., engines) across different vehicle models?
3. What new BEVs do I need to build in order to satisfy the various ZEV programs and voluntary electric vehicle deployment consistent with ACC II?
4. What further technology, if any, could I apply that would enable buyers to recoup additional costs within 30 months after buying new vehicles?
5. What additional technology, if any, should I apply to respond to potential new CAFE and CO_2 standards for PCs and LT, or HDPUV standards?

Additionally, within the context of 4 and 5, the CAFE Model may consider, as appropriate, the applicability of recently-passed tax credits for battery-based vehicle technologies, which improve the attractiveness of those technologies to consumers and thus the model's likelihood of choosing them as part of a compliance solution. The model can also apply over-compliance credits if applicable and not legally prohibited. The CAFE Model simulates all of these simultaneously. As mentioned above, this means that when manufacturers make production decisions in response to actions or influences other than CAFE or HDPUV standards, those costs and benefits are not attributable to possible future CAFE or HDPUV standards. One consequence, in turn, is that the effects of the final rule appear less cost-beneficial than they would otherwise, but NHTSA believes that this is appropriate in order to give the decision-maker the clearest possible understanding of the effects of the decision being made, as opposed to the effects of many things that will be occurring simultaneously.

Existing NHTSA standards during the rulemaking time frame are modeled as follows:

To account for the existing MY 2026 PC and LT standards, the No-Action Alternative includes the following coefficients defining those standards, which (for purposes of this analysis) are assumed to persist without change in subsequent model years:

Table 3-3: Passenger Car CAFE Target Function Coefficients for No-Action Alternative[61]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	66.95	66.95	66.95	66.95	66.95	66.95
b (mpg)	50.09	50.09	50.09	50.09	50.09	50.09
c (gpm per s.f.)	0.00033512	0.00033512	0.00033512	0.00033512	0.00033512	0.00033512
d (gpm)	0.001196	0.001196	0.001196	0.001196	0.001196	0.001196

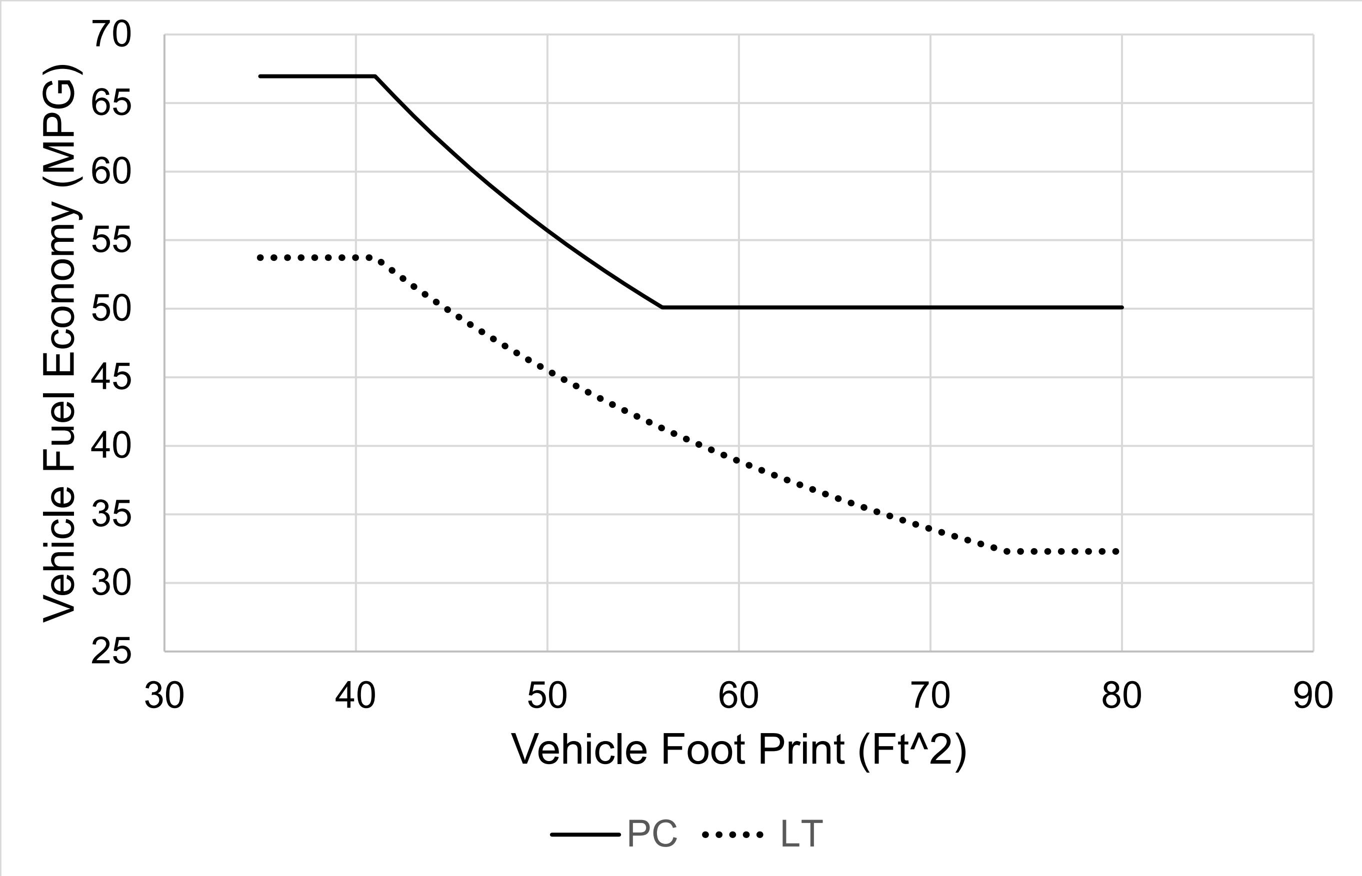
Table 3-4: Light Truck CAFE Target Function Coefficients for No-Action Alternative[62]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	53.73	53.73	53.73	53.73	53.73	53.73
b (mpg)	32.30	32.30	32.30	32.30	32.30	32.30
c (gpm per s.f.)	0.00037418	0.00037418	0.00037418	0.00037418	0.00037418	0.00037418
d (gpm)	0.00327158	0.00327158	0.00327158	0.00327158	0.00327158	0.00327158

These coefficients are used to create the graphic below, where the x-axis represents vehicle footprint and the y-axis represents fuel economy, showing that in "CAFE space," targets are higher in fuel economy for smaller footprint vehicles and lower for larger footprint vehicles:

[61] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.
[62] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.

Figure 3-1: No-Action Alternative, Passenger Car and Light Truck Fuel Economy, Target Curves



Note: There is no model year associated with the No-Action Alternative in this figure because the same curve would apply in all relevant model years.

Additionally, EPCA, as amended by EISA, requires that any manufacturer's domestically-manufactured PC fleet must meet the greater of either 27.5 mpg on average, or 92 percent of the average fuel economy projected by the Secretary for the combined domestic and non-domestic passenger automobile fleets manufactured for sale in the United States by all manufacturers in the model year. NHTSA retains the 1.9 percent offset to the Minimum Domestic Passenger Car Standard (MDPCS), first used in the 2020 final rule, to account for recent projection errors as part of estimating the total PC fleet fuel economy, and used in rulemakings since.[63,64] The projection shall be published in the Federal Register when the standard for that model year is promulgated in accordance with 49 U.S.C. 32902(b).[65,66] For purposes of the No-Action Alternative, the MDPCS is as it was established in the 2022

Table 3-5: No-Action Alternative – Minimum Domestic Passenger Car Standard (MPG)

2027	2028	2029	2030	2031	2032 (augural)
53.5	53.5	53.5	53.5	53.5	53.5

To account for the existing HDPUV standards finalized in the Phase 2 rule, the No-Action Alternative for HDPUVs includes the following coefficients defining those standards, which (for purposes of this analysis) are assumed to persist without change in subsequent model years. The four-wheel drive coefficient is maintained

[63] Preamble Section V.A.2 (titled "Separate Standards for Passenger Cars, Light Trucks, and Heavy-Duty Pickups and Vans, and Minimum Standards for Domestic Passenger Cars") discusses the basis for the offset.
[64] 87 FR 25710 (May 2, 2022).
[65] 49 U.S.C. 32902(b)(4).
[66] The offset will be applied to the final regulation numbers, but was not used in this analysis. The values for the MDPCS for the final rule alternatives are nonadjusted values.

at 500 (coefficient 'a') and the weighting multiplier coefficient is maintained at 0.75 (coefficient 'b'). The compression ignition (CI) and spark ignition (SI) coefficients are in the tables below:

Table 3-6: HDPUV CI Vehicle Fuel Efficiency Target Function Coefficients for No-Action Alternative[67]

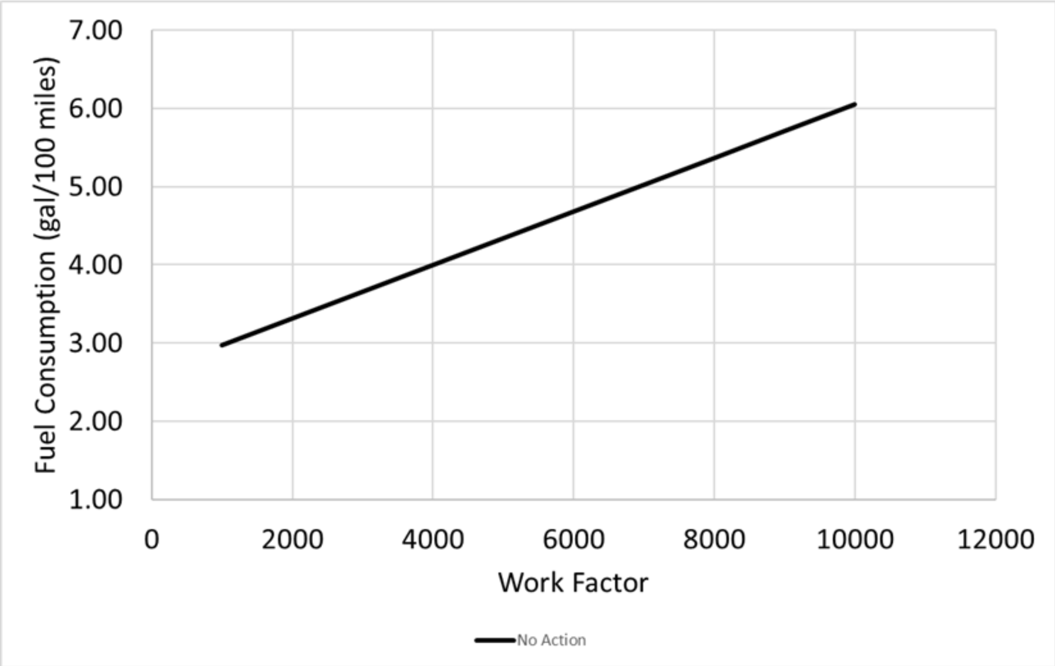
	2030	2031	2032	2033	2034	2035
e (gal/100 miles per WF)	0.00034180	0.00034180	0.00034180	0.00034180	0.00034180	0.00034180
f (gal/100 miles per WF)	2.633	2.633	2.633	2.633	2.633	2.633

Table 3-7: HDPUV SI Vehicle Fuel Efficiency Target Function Coefficients for No-Action Alternative[68]

	2030	2031	2032	2033	2034	2035
c (gal/100 miles per WF)	0.00041520	0.00041520	0.00041520	0.00041520	0.00041520	0.00041520
d (gal/100 miles per WF)	3.196	3.196	3.196	3.196	3.196	3.196

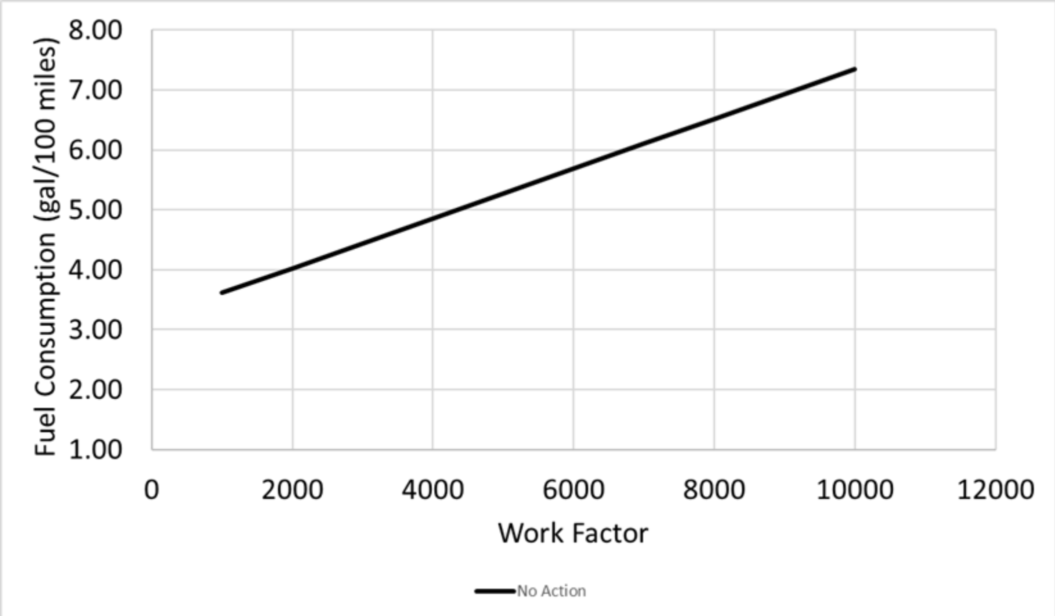
These equations are represented graphically below:

Figure 3-2: No-Action Alternative, HDPUV – CI Vehicles, Target Curves



[67] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.
[68] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.

Figure 3-3: No-Action Alternative, HDPUV – SI Vehicles, Target Curves



As the reference baseline scenario, the No-Action Alternative also includes the following other actions that NHTSA believes will occur in the absence of further regulatory action by NHTSA:

To account for the 2016 Phase 2 national GHG emissions standards, the No-Action Alternative for HDPUVs includes the following coefficients defining the GHG standards set by EPA in 2016 for MY 2026, which (for purposes of this analysis) are assumed to persist without change in subsequent model years:

Table 3-8: Passenger Car CO_2 Target Function Coefficients for No-Action Alternative

	2027	2028	2029	2030	2031	2032
a (g/mi)	114.3	114.3	114.3	114.3	114.3	114.3
b (g/mi)	160.9	160.9	160.9	160.9	160.9	160.9
c (g/mi per s.f.)	3.11	3.11	3.11	3.11	3.11	3.11
d (g/mi)	-13.10	-13.10	-13.10	-13.10	-13.10	-13.10
e (s.f.)	41.0	41.0	41.0	41.0	41.0	41.0
f (s.f.)	56.0	56.0	56.0	56.0	56.0	56.0

Table 3-9: Light Truck CO_2 Target Function Coefficients for No-Action Alternative

	2027	2028	2029	2030	2031	2032
a (g/mi)	141.8	141.8	141.8	141.8	141.8	141.8
b (g/mi)	254.4	254.4	254.4	254.4	254.4	254.4
c (g/mi per s.f.)	3.41	3.41	3.41	3.41	3.41	3.41
d (g/mi)	1.90	1.90	1.90	1.90	1.90	1.90
e (s.f.)	41.0	41.0	41.0	41.0	41.0	41.0
f (s.f.)	74.0	74.0	74.0	74.0	74.0	74.0

Coefficients *a*, *b*, *c*, *d*, *e*, and *f* define the existing MY 2026 federal CO_2 standards for HDPUVs, respectively, in Table 3-8 and Table 3-9 above. Analogous to coefficients defining fuel economy (FE) standards, coefficients *a* and *b* specify minimum and maximum CO_2 targets in each model year. Coefficients *c* and *d* specify the slope and intercept of the linear portion of the CO_2 target function, and coefficients *e* and *f* bound the region within which CO_2 targets are defined by this linear form.

To account for the NHTSA/EPA Phase 2 national GHG emission standards, the No-Action Alternative for HDPUVs include the following coefficients defining the WF-based standards set by EPA for MY 2027 and beyond. The four-wheel drive coefficient is maintained at 500 (coefficient 'a') and the weighting multiplier coefficient is maintained at 0.75 (coefficient 'b'). The CI and SI coefficients are in the tables below:

Table 3-10: HDPUV CI Vehicle CO_2 Target Function Coefficients for No-Action Alternative

	2027 and Later
e	0.0348
f	268

Table 3-11: HDPUV SI CO_2 Vehicle Target Function Coefficients for No-Action Alternative

	2027 and Later
c	0.0369
d	284

Coefficients *c, d, e*, and *f* define the existing MY 2027 and beyond CO_2 standards from the Phase 2 final rule for HDPUVs, in Table 3-10 and Table 3-11 above. The coefficients define a linear work-factor based function with c and d representing gasoline, CNG vehicles, strong hybrid electric vehicle (SHEVs) and PHEVs and *e* and *f* representing diesels, BEVS and Fuel Cell Electric Vehicles (FCEV). For this rule, this is identical to the NHTSA's fuel efficiency standards No-Action alternative.

The No-Action Alternative also includes NHTSA's estimates of ways that each manufacturer could introduce new PHEVs and BEVs in response to state ZEV programs (ACC I and ACT) and deploy additional ZEV voluntarily, consistent with manufacturer commitments. Vehicle manufacturers told NHTSA, in CBI conversations regarding planned vehicle product and technology investments, that they are complying with and plan to comply in the future with ZEV programs regardless of whether they are legally binding. These conversations were later confirmed by manufacturers' public announcements, which are discussed in more detail in preamble Section IV. To account for the ZEV programs and the additional non-regulatory deployment, for which NHTSA is using ACC II as a proxy, NHTSA has included in the main provisions of the ACC and ACT programs in the CAFE Models' analysis of compliance pathways. Incorporating these programs into the model includes converting vehicles that have been identified as potential ZEV candidates into BEVs so that a manufacturer's fleet is consistent with the calculated ZEV credit requirements. The two programs have different requirements per model year, so they are modeled separately in the CAFE analysis. Chapter 2.5.1 in the TSD discusses, in detail, how NHTSA developed these estimates.

The No-Action Alternative also includes NHTSA's estimates of ways that manufacturers would respond to recently-passed tax credits for battery-based vehicle technologies. NHTSA explicitly models portions of three provisions of the Inflation Reduction Act (IRA) when simulating the behavior of manufacturers and consumers. The first is the Advanced Manufacturing Production Tax Credit (AMPC). The AMPC also includes a credit for the production of applicable critical minerals. This provision of the IRA provides a $35 per kWh tax credit for manufacturers of battery cells and an additional $10 per kWh for manufacturers of battery modules (all applicable to manufacture in the United States).[69] The majority of these credits phase out from 2030 to 2032. The agency also jointly modeled the Clean Vehicle Tax Credit (CVC),[70] which provides up to $7,500 toward

[69] 26 U.S.C. 45X. If a manufacturer produces a battery module without battery cells, they are eligible to claim up to $45 per kWh for the battery module. The provision includes other provisions related to vehicles such as a credit equal to 10 percent of the manufacturing cost of electrode active materials, and another 10 percent for the manufacturing cost of critical minerals. We are not modeling these credits directly because of how we estimate battery costs and to avoid the potential to double count the tax credits if they are included into other analyses that feed into our inputs.
[70] 26 U.S.C. 30D.

the purchase of clean vehicles.[71] The AMPC and CVC provide tax credits for light-duty and HDPUV PHEVs, BEVS, and FCVs. Chapter 2.5.2 in the TSD discusses, in detail, how NHTSA has modeled these tax credits.

The No-Action Alternative for the PC, LT, and HDPUV fleets also includes NHTSA's assumption, for purposes of compliance simulations, that manufacturers will add fuel economy- or fuel efficiency-improving technology voluntarily, if the value of future undiscounted fuel savings fully offsets the cost of the technology within 30 months. This assumption is often called the "30-month payback" assumption, and NHTSA has used it for many years and in many CAFE rulemakings.[72] It is used to represent consumer demand for fuel economy. It can be a source of apparent "over-compliance" in the No-Action Alternative, especially when technology is estimated to be extremely cost-effective, as occurs later in the analysis time frame when learning has significant effects on some technology costs.

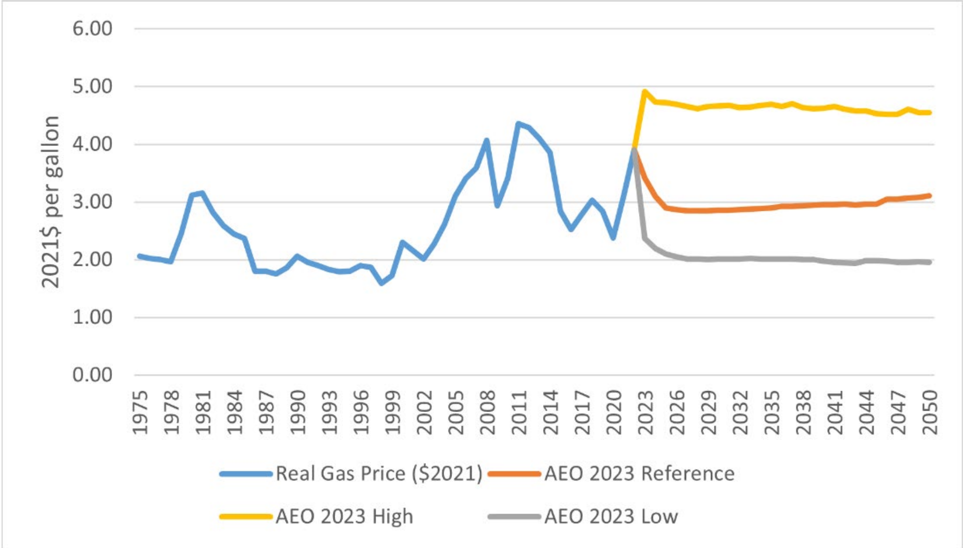
NHTSA has determined that manufacturers do at times improve fuel economy even in the absence of new standards, for several reasons. First, overcompliance is not uncommon in the historical data, both in the absence of new standards, and with new standards – NHTSA's analysis in the 2022 TSD included CAFE compliance data showing that from 2004-2017, while not *all* manufacturers consistently over-complied, a number did. Of the manufacturers who did over-comply, some did so by 20 percent or more, in some fleets, over multiple model years.[73] Ordinary market forces can produce significant increases in fuel economy, either because of consumer demand or because of technological advances.

Second, manufacturers have consistently told NHTSA that they do make fuel economy improvements where the cost can be fully recovered in the first 2-3 years of ownership. The 2015 National Academy of Sciences (NAS) report discussed this assumption explicitly, stating: "There is also empirical evidence supporting loss aversion as a possible cause of the energy paradox. Greene (2011) showed that if consumers accurately perceived the upfront cost of fuel economy improvements and the uncertainty of fuel economy estimates, the future price of fuel, and other factors affecting the present value of fuel savings, the loss-averse consumers among them would appear to act as if they had very high discount rates or required payback periods of about 3 years."[74] Furthermore, the 2020 NAS HD report states: "The committee has heard from manufacturers and purchasers that they look for 1.5- to 2-year paybacks or, in other cases, for a payback period that is half the expected ownership period of the first owner of the vehicle."[75] Naturally, there are heterogenous preferences for vehicle attributes in the marketplace, – at the same time that we are observing record sales of electrified vehicles, we are also seeing sustained demand for pickup trucks with higher payloads and towing capacity. This analysis, like all the CAFE analyses preceding it, uses an average value to represent these preferences for the CAFE fleet and the HDPUV fleet. The analysis balances the risks of estimating too low of a payback period, which would preclude most technologies from consideration regardless of potential cost reductions due to learning, against the risk of allowing too high of a payback period, which would allow an unrealistic cost increase from technology addition in the reference baseline fleet.

Third, as in previous CAFE analyses, our fuel price projections assume sustained increases in real fuel prices over the course of the rule (and beyond).[76] As readers are certainly aware, fuel prices have changed over time – sometimes quickly, sometimes slowly, generally upward:

[71] There are vehicle price and consumer income limitations on the CVC as well. Congressional Research Service. 2022. Tax Provisions in the Inflation Reduction Act of 2022 (H.R. 5376). Available at: https://crsreports.congress.gov/product/pdf/R/R47202/6. (Accessed: May 31, 2023).
[72] Even though NHTSA uses the 30-month payback assumption to assess how much technology manufacturers would add voluntarily in the absence of new standards, the benefit-cost analysis accounts for the full lifetime fuel savings that would accrue to vehicles affected by the final standards.
[73] See 2022 TSD, at 68.
[74] National Research Council. 2015. Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-Duty Vehicles. Washington, DC: The National Academies Press. p. 31. Available at: https://doi.org/10.17226/21744. (Accessed: Feb. 7, 2024). (hereinafter "2015 NAS report").
[75] National Academies of Sciences, Engineering, and Medicine. 2020. Reducing Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two: Final Report. Washington, DC: The National Academies Press. p. 296. Available at: https://doi.org/10.17226/25542. (Accessed: Feb. 7, 2024).
[76] Fuel Prices and other inputs are provided in TSD Chapter 2 and Chapter 3.

Figure 3-4: Real Fuel Prices Over Time



In the 1990s, when fuel prices were historically low (as shown above), manufacturers did not tend to improve their fuel economy, in part because there simply was very little consumer demand for improved fuel economy and CAFE standards remained flat. In subsequent decades, when fuel prices were higher, many manufacturers have exceeded their standards in multiple fleets, and for multiple years. Our current fuel price projections look more like the last two decades, where prices have been more volatile, but also closer to $3/gallon on average. In recent years, when fuel prices have generally declined on average and CAFE standards have continued to increase, fewer manufacturers have exceeded their standards. However, our compliance data shows that at least some manufacturers do improve their fuel economy if fuel prices are high enough, even if they are not able to respond perfectly to fluctuations precisely when they happen. This highlights the importance of fuel price assumptions both in the analysis and in the real world on the future of fuel economy improvements.

3.2. Alternative Baseline/No-Action Alternative

In addition to the reference baseline for the passenger car and light truck fleet analysis, NHTSA considered an alternative baseline analysis. This alternative baseline analysis for the passenger car and light truck fleets was performed to provide a greater level of insight into the possibilities of a changing baseline landscape. The Alternative Baseline analysis is not meant to be a replacement for the reference analysis, but a secondary review of the NHTSA analysis with all of the assumptions from the reference baseline held (see Paragraph 3.1 above), except for the assumption of compliance with CARB ZEV policies and voluntary manufacturer deployment of electric vehicles consistent with ACC II. The alternative baseline does not assume manufacturers will consider or preemptively react to any of the California light duty ZEV policies or voluntarily deploy additional electric vehicles consistent with the ACC II program (as currently submitted to EPA) during any of the model years simulated in the analysis. Results relative to this alternative baseline are shown in Chapter 8.2.7 below.

3.3. Action Alternatives for Passenger Cars, Light Trucks, and HDPUVs

In addition to the No-Action Alternatives, NHTSA has considered five “action” alternatives for PCs and LTs and four action alternatives for HDPUVs, each of which is more stringent than the No-Action Alternative during the rulemaking time frame. These action alternatives are specified below and demonstrate different possible approaches to balancing the statutory factors applicable for PCs, LT, and HDPUVs. Section V of the preamble discusses in more detail how the different alternatives reflect different possible balancing approaches.

3.3.1. Alternative PC2LT002 – Final Standards

Alternative PC2LT002 would increase CAFE stringency by 2 percent per year, year over year for MYs 2027-2032 for PCs, and no increase from MY 2027 through MY 2028 and 2 percent per year, year over year for MYs 2029-2032 for LTs.

Table 3-12: Passenger Car CAFE Target Function Coefficients for Alternative PC2LT002

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	68.32	69.71	71.14	72.59	74.07	75.58
b (mpg)	51.12	52.16	53.22	54.31	55.42	56.55
c (gpm per s.f.)	0.00032841	0.00032184	0.00031541	0.00030910	0.00030292	0.00029686
d (gpm)	0.00117220	0.00114876	0.00112579	0.00110327	0.00108120	0.00105958

Table 3-13: Light Truck CAFE Target Function Coefficients for Alternative PC2LT002

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	53.73	53.73	54.82	55.94	57.08	58.25
b (mpg)	32.30	32.30	32.96	33.63	34.32	35.02
c (gpm per s.f.)	0.00037418	0.00037418	0.00036670	0.00035936	0.00035218	0.00034513
d (gpm)	0.00327158	0.00327158	0.00320615	0.00314202	0.00307918	0.00301760

Table 3-14: Alternative PC2LT002 – Minimum Domestic Passenger Car Standard (MPG)

2027	2028	2029	2030	2031	2032 (augural)
55.2	56.3	57.5	58.6	59.8	61.1

3.3.2. Alternative PC1LT3

Alternative PC1LT3 would increase CAFE stringency by 1 percent per year, year over year, for MYs 2027-2032 for PCs, and by 3 percent per year, year over year, for MYs 2027-2032 for LTs.

Table 3-15: Passenger Car CAFE Target Function Coefficients for Alternative PC1LT3[77]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	67.63	68.31	69.00	69.70	70.40	71.11
b (mpg)	50.60	51.11	51.63	52.15	52.68	53.21
c (gpm per s.f.)	0.00033176	0.00032845	0.00032516	0.00032191	0.00031869	0.00031550
d (gpm)	0.00118417	0.00117232	0.00116060	0.00114900	0.00113751	0.00112613

Table 3-16: Light Truck CAFE Target Function Coefficients for Alternative PC1LT3[78]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	55.39	57.10	58.87	60.69	62.56	64.50
b (mpg)	33.30	34.33	35.39	36.48	37.61	38.78
c (gpm per s.f.)	0.00036296	0.00035207	0.00034151	0.00033126	0.00032132	0.00031168

[77] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.
[78] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.

d (gpm)	0.00317343	0.00307823	0.00298588	0.00289630	0.00280941	0.00272513

These coefficients create equations that are represented graphically in Chapter 1.4 of the TSD.

Under this alternative, the MDPCS would be as follows:

Table 3-17: Alternative PC1LT3 – Minimum Domestic Passenger Car Standard (MPG)

2027	2028	2029	2030	2031	2032 (augural)
54.6	55.2	55.7	56.3	56.9	57.4

3.3.3. Alternative PC2LT4

Alternative PC2LT4 would increase CAFE stringency by 2 percent per year, year over year, for MYs 2027-2032 for PCs, and by 4 percent per year, year over year, for MYs 2027-2032 for LTs.

Table 3-18: Passenger Car CAFE Target Function Coefficients for Alternative PC2LT4[79]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	68.32	69.71	71.14	72.59	74.07	75.58
b (mpg)	51.12	52.16	53.22	54.31	55.42	56.55
c (gpm per s.f.)	0.00032841	0.00032184	0.00031541	0.00030910	0.00030292	0.00029686
d (gpm)	0.00117220	0.00114876	0.00112579	0.00110327	0.00108120	0.00105958

Table 3-19: Light Truck CAFE Target Function Coefficients for Alternative PC2LT4[80]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	55.96	58.30	60.73	63.26	65.89	68.64
b (mpg)	33.64	35.05	36.51	38.03	39.61	41.26
c (gpm per s.f.)	0.00035921	0.00034485	0.00033105	0.00031781	0.00030510	0.00029289
d (gpm)	0.00314071	0.00301509	0.00289448	0.00277870	0.00266755	0.00256085

These coefficients create equations that are represented graphically in Chapter 1.4 of the TSD. Under this alternative, the MDPCS would be as follows:

Table 3-20: Alternative PC2LT4 – Minimum Domestic Passenger Car Standard (MPG)

2027	2028	2029	2030	2031	2032 (augural)
55.2	56.3	57.5	58.6	59.8	61.1

3.3.4. Alternative PC3LT5

Alternative PC3LT5 would increase CAFE stringency by 3 percent per year, year over year, for MYs 2027-2032 for PCs, and by 5 percent per year, year over year, for MYs 2027-2032 for LTs.

[79] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.
[80] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.

Table 3-21: Passenger Car CAFE Target Function Coefficients for Alternative PC3LT5[81]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	69.02	71.16	73.36	75.63	77.97	80.38
b (mpg)	51.64	53.24	54.89	56.58	58.33	60.14
c (gpm per s.f.)	0.00032506	0.00031531	0.00030585	0.00029668	0.00028777	0.00027914
d (gpm)	0.00116024	0.00112544	0.00109167	0.00105892	0.00102716	0.00099634

Table 3-22: Light Truck CAFE Target Function Coefficients for Alternative PC3LT5[82]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	56.55	59.53	62.66	65.96	69.43	73.09
b (mpg)	34.00	35.79	37.67	39.65	41.74	43.94
c (gpm per s.f.)	0.00035547	0.00033770	0.00032081	0.00030477	0.00028954	0.00027506
d (gpm)	0.00310800	0.00295260	0.00280497	0.00266472	0.00253148	0.00240491

These coefficients create equations that are represented graphically in Chapter 1.4 of the TSD.

Under this alternative, the MDPCS would be as follows:

Table 3-23: Alternative PC3LT5 – Minimum Domestic Passenger Car Standard (MPG)

2027	2028	2029	2030	2031	2032 (augural)
55.8	57.5	59.3	61.1	63.0	64.9

3.3.5. Alternative PC6LT8

Alternative PC6LT8 would increase CAFE stringency by 6 percent per year, year over year, for MYs 2027-2032 for PCs, and by 8 percent per year, year over year, for MYs 2027-2032 for LTs.

Table 3-24: Passenger Car CAFE Target Function Coefficients for Alternative PC6LT8[83]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	71.23	75.77	80.61	85.75	91.23	97.05
b (mpg)	53.29	56.69	60.31	64.16	68.26	72.61
c (gpm per s.f.)	0.00031501	0.00029611	0.00027834	0.00026164	0.00024594	0.00023119
d (gpm)	0.00112436	0.00105690	0.00099348	0.00093388	0.00087784	0.00082517

Table 3-25: Light Truck CAFE Target Function Coefficients for Alternative PC6LT8[84]

	2027	2028	2029	2030	2031	2032 (augural)
a (mpg)	58.40	63.48	69.00	74.99	81.52	88.60
b (mpg)	35.11	38.16	41.48	45.09	49.01	53.27

[81] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.
[82] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.
[83] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.
[84] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.

c (gpm per s.f.)	0.00034425	0.00031671	0.00029137	0.00026806	0.00024662	0.00022689
d (gpm)	0.00300985	0.00276906	0.00254754	0.00234373	0.00215624	0.00198374

These coefficients create equations that are represented graphically in Chapter 1.4 of the TSD.

Under this alternative, the MDPCS would be as follows:

Table 3-26: Alternative PC6LT8 – Minimum Domestic Passenger Car Standard (MPG)

2027	2028	2029	2030	2031	2032 (augural)
57.5	61.2	65.1	69.3	73.7	78.4

3.3.6. Alternative HDPUV4

Alternative HDPUV4 would increase HDPUV standard stringency by 4 percent per year for MYs 2030-2035 for HDPUVs. The four-wheel drive coefficient is maintained at 500 (coefficient ‘a’) and the weighting multiplier coefficient is maintained at 0.75 (coefficient ‘b’).

Table 3-27: Characteristics of Alternative HDPUV4 – CI Vehicle Coefficients[85]

	2030	2031	2032	2033	2034	2035
e	0.00032813	0.00031500	0.00030240	0.00029031	0.00027869	0.00026755
f	2.528	2.427	2.330	2.236	2.147	2.061

Table 3-28: Characteristics of Alternative HDPUV4 – SI Vehicle Coefficients[86]

	2030	2031	2032	2033	2034	2035
c	0.00039859	0.00038265	0.00036734	0.00035265	0.00033854	0.00032500
d	3.068	2.945	2.828	2.715	2.606	2.502

These coefficients create equations that are represented graphically in Chapter 1.4 of the TSD.

3.3.7. Alternative HDPUV108 – Final Standards

Alternative HDPUV108 would increase HDPUV standard stringency by 10 percent per year, year over year for MYs 2030-2032, and by 8 percent per year, year over year for MYs 2033-2035 HDPUVs. The four-wheel drive coefficient is maintained at 500 (coefficient ‘a’) and the weighting multiplier coefficient is maintained at 0.75 (coefficient ‘b’).

Table 3-29: Characteristics of Alternative HDPUV108 – CI Vehicle Coefficients[87]

	2030	2031	2032	2033	2034	2035
e	0.00030762	0.00027686	0.00024917	0.00022924	0.00021090	0.00019403
f	2.370	2.133	1.919	1.766	1.625	1.495

Table 3-30: Characteristics of Alternative HDPUV108 – SI Vehicle Coefficients[88]

	2030	2031	2032	2033	2034	2035
c	0.00037368	0.00033631	0.00030268	0.00027847	0.00025619	0.00023569

[85] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.
[86] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.
[87] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.
[88] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.

d	2.876	2.589	2.330	2.143	1.972	1.814

These coefficients create equations that are represented graphically in Chapter 1.4 of the TSD.

3.3.8. Alternative HDPUV10

Alternative HDPUV10 would increase HDPUV standard stringency by 10 percent per year for MYs 2030-2035 for HDPUVs. The four-wheel drive coefficient is maintained at 500 (coefficient ‘a’) and the weighting multiplier coefficient is maintained at 0.75 (coefficient ‘b’).

Table 3-313-29: Characteristics of Alternative HDPUV10 – CI Vehicle Coefficients[89]

	2030	2031	2032	2033	2034	2035
e	0.00030762	0.00027686	0.00024917	0.00022425	0.00020183	0.00018165
f	2.370	2.133	1.919	1.728	1.555	1.399

Table 3-32: Characteristics of Alternative HDPUV10 – SI Vehicle Coefficients[90]

	2030	2031	2032	2033	2034	2035
c	0.00037368	0.00033631	0.00030268	0.00027241	0.00024517	0.00022065
d	2.876	2.589	2.330	2.097	1.887	1.698

These coefficients create equations that are represented graphically in Chapter 1.4 of the TSD.

3.3.9. Alternative HDPUV14

Alternative HDPUV14 would increase HDPUV standard stringency by 14 percent per year for MYs 2030-2035 for HDPUVs. The four-wheel drive coefficient is maintained at 500 (coefficient ‘a’) and the weighting multiplier coefficient is maintained at 0.75 (coefficient ‘b’).

Table 3-33: Characteristics of Alternative HDPUV14 – CI Vehicle Coefficients[91]

	2030	2031	2032	2033	2034	2035
e	0.00029395	0.00025280	0.00021740	0.00018697	0.00016079	0.00013828
f	2.264	1.947	1.675	1.440	1.239	1.065

Table 3-34: Characteristics of Alternative HDPUV14 – SI Vehicle Coefficients[92]

	2030	2031	2032	2033	2034	2035
c	0.00035707	0.00030708	0.00026409	0.00022712	0.00019532	0.00016798
d	2.749	2.364	2.033	1.748	1.503	1.293

These coefficients create equations that are represented graphically in Chapter 1.4 of the TSD.

[89] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.
[90] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.
[91] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.
[92] The PC, LT, and HDPUV target curve function coefficients are defined in Equations 1-1, 1-2, and 1-3, respectively.

4. Approach to Modeling CAFE Standards

CAFE Model Files Referenced in this Chapter

Below is a list of CAFE Model Files referenced in this chapter. See TSD Chapter 2.1.9 Where to Find the Internal NHTSA Files? for a full list of files referenced in this document and their respective file locations.

- Market Data Input File

This chapter describes NHTSA's approach to analyzing the wide range of effects of fuel economy and fuel efficiency standards. Over numerous prior rulemaking efforts, NHTSA has developed the CAFE model to facilitate the different analyses required for CAFE rulemakings. NHTSA continues to refine the CAFE Model's methodology to allow NHTSA to consider an increasingly wide range of impacts.

NHTSA analyses involves, among other things, estimating how the application of various combinations of technologies could impact vehicles' costs, fuel economy and efficiency levels, and 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 affect vehicle sales and operation; and estimating how the combination of these changes might influence national-scale energy consumption, emissions, highway safety, and public health. In addition, the Final Environmental Impact Statement (Final EIS) accompanying this final rule addresses the final rule's effect on air quality and climate, and the role that those changes have on the environment and human health. The analysis of these components informs and supports NHTSA's application of the statutory factors involved in determining "maximum feasible" fuel-economy under EPCA, including, among others, economic practicability and the need of the United States to conserve energy, and whether a given fuel efficiency standard would be appropriate, cost-effective, and technologically feasible. The CAFE Model plays a central role in NHTSA's analysis supporting this final rule.

In general, changes to the 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. This chapter provides an overview of these pillars of the CAFE Model's structure. 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 effects of changes to fuel economy and efficiency standards. The model documentation accompanying this final rule provides a comprehensive and detailed description of the model's functions, design, inputs, and outputs.[93]

The basic design of the CAFE Model is as follows: the system first runs a compliance simulation, which estimates how vehicle manufacturers might respond to a given regulatory scenario, using inputs that define, 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 or efficiency improvements; and the standards defining the regulatory scenario. A regulatory scenario involves specification of the form, or shape, of the standards (e.g., flat standards, or linear or logistic attribute-based standards), scope of regulatory classes,[94] and stringency of the CAFE, fuel efficiency, and CO_2 standards for each model year to be analyzed. The system then runs an effects calculation, which quantifies the manufacturers' response in terms of vehicle sales and retirements, fuel consumption, emissions, and economic externalities.

Manufacturer compliance simulation begins with a detailed, user-provided initial representation of the vehicle models offered for sale in a recent model year (MY 2022 for the LD fleet and the most recent representation available for the HDPUV fleet).[95] 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

[93] The CAFE Model is available at https://www.nhtsa.gov/corporate-average-fuel-economy/cafe-compliance-and-effects-modeling-system, with documentation and all inputs and outputs supporting this final rule.
[94] 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 No-Action Alternative in this final rule, to capture the regulatory classification of the GHG program which uses a similar, but not identical, scheme of classification.
[95] For more detail on the compliance data used to construct the light-duty and HDPUV fleets, see TSD Chapter 2.2.1.1.

define CAFE and fuel efficiency 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,[96] 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 consumer's willingness to pay for avoided fuel expenses. For a given manufacturer, the compliance simulation algorithm applies technologies either until the manufacturer runs out of cost-effective technologies,[97] until the manufacturer exhausts all available technologies, or, if the manufacturer is assumed to be willing to pay civil penalties, until paying civil penalties 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. This compliance simulation process is repeated for each model year included in the study period (through MY 2050 in this analysis).[98]

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 LD or HDPUV vehicle population in the United States. The CAFE Model then uses this fleet to generate estimates of the following (for each model year and CY 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 then uses these estimates to measure the benefits and costs associated with each regulatory alternative (relative to the No-Action Alternative).

4.1. Representing Manufacturers' Potential Responses to Standards

To simulate how manufacturers may respond to the modeled regulatory scenarios, the CAFE Model requires information outlining the engineering characteristics and technology content attributable to each vehicle, platform, engine, and transmission produced by that manufacturer. This information provides the model with an overall view of the initial state of the fleet, for each manufacturer regulated by the standards. The MY 2022 analysis fleet is contained in the Market Data Input File and includes information about each regulated manufacturer's:

- Vehicle models offered for sale – their current (again, for this rule, MY 2022) production volumes and MSRPs; fuel economy (as measured on the compliance test procedure); fuel saving technology content (relative to the set of technologies summarized in Table 2-4 and Table 2-5 of the TSD Chapter 2.2.1.3); footprint (necessary to compute the vehicle's fuel economy target under each regulatory alternative for the LD fleet); curb weight, GVWR, and Gross Combined Weight Rating (GCWR) (for computing the vehicle's work-factor and target for the HDPUV fleet); as well as other attributes (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; manufacturers' perception of consumer's willingness to pay for fuel economy

[96] When used to support NHTSA's analysis for standard-setting, the compliance simulation is constrained based on statutory limitations on what NHTSA may consider when setting CAFE standard. When the CAFE Model is used to support the analysis in the EIS, these constraints are removed.
[97] 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. (see Chapter 2.1.4). 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.
[98] 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 the regulated model years are used, age, and retire. EIA's 2022 Annual Energy Outlook also uses a modeling horizon that extends through 2050.

(we assume manufacturers add technologies that payback within 30 months); 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. Whether considering the LD or HDPUV fleet, each manufacturer's actual CAFE or fuel efficiency compliance obligation represents the production-weighted harmonic mean of their vehicles' targets in each regulated fleet. In the case of the LD fleet, the fuel economy target is a function of the vehicles' footprints, whereas for the HDPUV fleet, the target is defined as a function of the vehicles' WFs. 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 or fuel efficiency standards, each manufacturer's requirement is dynamically defined based on the specification of the standards for any simulation and the distribution of footprints or WFs within each fleet. The specific details of the MY 2022 analysis fleet are discussed in the TSD Chapter 2.2 and preamble Section III.C.

4.2. Representing Consumer Responses to Standards

As manufacturers apply technology to their vehicle offerings to comply with more stringent standards, the cost to supply vehicles will increase. We assume that all costs related to compliance (the cost of technology or civil penalties) are passed through to buyers of new vehicles. The CAFE Model explicitly simulates these price effects on the new vehicle market. The model uses a price elasticity to adjust aggregate new vehicle sales, relative to the No-Action Alternative. The price elasticity acts on an adjusted average price increase—the average price increase net of some portion of realized fuel savings (the first 30 months in this analysis) and any federal incentives passed through to consumers. 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 preamble Section III.E.1. NHTSA also explored the sensitivity of its results to this assumption in FRIA Chapter 9.2.3.6.

This portion of the sales response only creates deviations from the No-Action Alternative vehicle sales forecast. The reference baseline sales forecast is a function of macroeconomic inputs and trends in historical sales. The PC/LT composition of new vehicle sales in the light duty fleet is determined by the CAFE Model's fleet share module. Fleet share forecasts are determined by two possible mechanisms, selectable by the user. The first incorporates exogenous projections of vehicle fleet share. The second 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. These fleet share projections can be propagated across regulatory alternatives or can be adjusted based on estimated costs and fuel savings of PCs relative to LTs.

The sales and fleet share modules work together to modify the total number of new vehicles, the share of PCs and LTs, and, as a consequence, the number of each given model sold by a given manufacturer in the No-Action Alternative. Changes to aggregated sales (either total sales or PC/LT body styles) are distributed to individual manufacturers and vehicle models based on their observed shares in the MY 2022 fleet. The CAFE Model also adjusts the fleet shares of PCs and LTs in each regulatory alternative based on changes in their relative adjusted average price increases relative to the No-Action Alternative. For more detail on the CAFE Model's approach to sales and fleet share, 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 and body style 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 standards accelerates or decelerates the retirement (or scrappage) 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 the standard benefits and costs associated with the lifetimes of new vehicles produced under the rule. For more detail about the CAFE Model's approach to vehicle scrappage, see TSD Chapter 4.2.2.

Another critical element of the consumer response to changes in 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. This assumed behavior is often called the "rebound effect." The CAFE Model implements a travel demand function that governs total LD travel demand, absent rebound-induced demand, given a set of economic conditions related to travel. The function itself is the LD VMT forecasting model that the 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 rebound effect is incorporated into the VMT analysis via a rebound elasticity (i.e., the percentage change in VMT demanded for a given percentage change in fuel economy).

When modeling regulatory alternatives for the light duty fleet, 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 vehicle use will remain the same. That said, it is reasonable to assume that fleets with differing age distributions and inherent costs 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.

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 2022 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.

Analogous VMT projections for the HDPUV fleet are not currently available and VMT for this analysis is therefore not constrained in the same manner as LD VMT is constrained. Estimates of aggregate vehicle use in the HDPUV fleet are instead the product of a bottom-up accounting of vehicle use based on estimated mileage accumulation schedules. For more detail about the treatment of VMT for both vehicle fleets in the CAFE Model, see TSD Chapter 4.3.

4.3. Representing the Physical and Environmental Effects of Standards

The CAFE Model carries a complete representation of the registered vehicle population in each CY, starting with an aggregated version of the most recent available data about the registered population for the first year of the simulation. This national registered fleet is used to calculate both annual and lifetime: fuel consumption (by fuel type), VMT, pollutant emissions, and health impacts under each regulatory alternative. For the current analysis, MY 2022 is the first model year of the included vehicle fleet; therefore, the registered vehicle population enters the model as it appeared at the end of CY 2021.

For the LD fleet, the initial vehicle population is stratified by age (or model year cohort) and body style (cars, vans and sport utility vehicles [SUVs], and pickup trucks), while for the HDPUV fleet, the entirety of the population is grouped by model year cohort only (there is less variation in body style in the HDPUV fleet as most vehicles share similar chassis designs). 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 2023, the new vehicles (age 0) are MY 2023 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 2022 vehicles (added by the CAFE Model simulation), and the age 2 vehicles are MY 2021 vehicles (inherited from the registered vehicle population and carried through the analysis with less granularity).

The product of on-road fuel economy (or fuel efficiency) and VMT determines fuel consumption, by fuel type, of each vehicle and cohort in the analysis (vehicles produced after MY 2021 are simulated at the model level and all older vehicles as body-style/age cohorts). All 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 (CY) basis but can also compute the lifetime totals of any physical quantity by model year cohort. Importantly, the CY totals for quantities like fuel consumed or miles traveled include both the new vehicle fleet (produced after MY 2021) and the legacy fleet (produced before MY 2022). 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 CY totals of physical quantities to observed values in earlier years and some projections from other sources.

Rather than rely on the compliance values of fuel economy for either legacy 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 CNG), it does not vary over time, by vehicle age, or by technology combination. As discussed in the accompanying TSD Chapter 2, this analysis uses input values that range from 24 to 29 percent, depending on the fuel type as shown in Table 4-1. 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 4-1: "Gap" Between Test and On-Road MPG (by Fuel Type)

Fuel type	On-road Fuel Economy Gap
Gasoline	24%
Ethanol-85	24%
Diesel	24%
Electricity	29%
Hydrogen	29%
Compressed Natural Gas	24%

In addition to the above effects, the model also calculates emissions effects and projected revenue consequences of reduced fuel consumption. Emissions are identified and tracked separately as “downstream” emissions (i.e., a function of vehicle use) and “upstream” emissions (i.e., a function of fuel use). To calculate downstream emissions for most pollutants associated with a given alternative, the CAFE Model uses the entire on-road fleet, calculated VMT (discussed above), and per-mile emissions factors (which are an input to the CAFE Model, specified by model year and age). Downstream CO_2 emissions quantities are derived from the assumed carbon content (an input to the CAFE Model, specified by fuel type) and the estimated quantity of fuel consumed. Total upstream emissions estimates depend on the fuel type. Gasoline and diesel emissions factors account for multiple levels of the fuel cycle, including fuel extraction, transportation, refining, and distribution. Electricity emissions factors inputs are not differentiated by process and are based on resource extraction and generation. These emissions factors therefore vary with changes in the assumed U.S. electricity grid mix. For more detail about emissions inputs for the analysis, see TSD Chapter 5.

Because the model produces an estimate of the aggregate number of gallons sold in each CY, 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 in the input files represent an estimated average fuel tax across all U.S. states. While the model produces an estimate of HTF revenue changes, it is 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. Additionally, states and the federal government have occasionally raised motor fuel tax rates to partially compensate for revenue losses due to inflation and increased fuel economy.[99] However, such actions have been sporadic and not predictable, and so we assume continuation of the present fuel tax rates.

4.4. Costs and Benefits to Producers, Consumers, and Society

As the CAFE Model simulates manufacturer compliance with regulatory alternatives, it estimates and tracks several consequences that generate social costs and benefits. The most obvious cost associated with the CAFE and HDPUV FE programs 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.[100]

The other costs that manufacturers incur as a result of CAFE and FE standards are civil penalties resulting from non-compliance with the standards. When modeling the LD fleet, the CAFE Model applies the constant 2021 dollar fine rate based on statute. That is, fine rates are adjusted to constant 2021 dollars from an initial nominal rate of $16 per 1/10-MPG under the standard starting in MY 2023, multiplied by the number of vehicles produced in that fleet, in that model year.[101] The model reports as the full "regulatory cost" the sum of total technology cost and total civil penalties by the manufacturer, fleet, and model year.

The costs and benefits of each alternative are defined relative to the No-Action Alternative. For example, the CAFE Model reports absolute values for the amount of money spent on fuel in the No-Action Alternative, then reports the amount spent on fuel in the alternatives relative to this reference baseline. So, if standards in the No-Action Alternative were fixed at current levels, and an alternative requires fuel economy improvements, 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 LD market data are based on MY 2022 and this final rule is being published after MY 2023 planning and production is complete, MY 2024 planning is effectively complete, and after manufacturers have made tentative plans to comply with standards established during prior rulemakings (currently, LD standards are defined through MY 2026). If the CAFE Model did not impose the constraint that MYs 2023 to 2026 be identical across alternatives (and, in fact, identical to the No-Action Alternative for years within that range), the multi-year planning algorithm would reach back to as early as MY 2023 to apply additional technology under more stringent alternatives. In this analysis, we assume that manufacturers are unable to modify product offerings during MY 2022 under any alternative (No-Action or otherwise), or during MYs 2023 to 2026 (which have been fully or partially planned) under the Action Alternatives (beyond the level by which the manufacturers' fleet was improved to comply with the standards posed by No-Action Alternative). The technology outcomes of the compliance simulation in MYs 2022 to 2026 under the No-Action Alternative are, therefore, 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.[102]

[99] Greene, D.L. 2011. What is Greener Than a VMT Tax? The Case for an Indexed Energy User Fee to Finance US Surface Transportation. *Transportation Research Part D: Transport and Environment*. Vol. 16(6): pp. 451-58. Available at: https://doi.org/10.1016/j.trd.2011.05.003. (Accessed: Feb. 22, 2024).

[100] For more details on learning rates, see TSD Chapter 2.4.3.

[101] The rate at which fines are assessed increases over time with inflation. In nominal terms, for model years before model year 2019, the civil penalty is $5.50; for model years 2019 through 2021, the civil penalty is $14; for model years 2022, 2023, and 2024, the civil penalty is $15, $16, and $17, respectively. In the case of the HDPUV fleet, fines are not levied on a per-fuel-economy-unit basis. Currently, the specified fine rate acts as a proxy for per-vehicle fines. For additional detail, see preamble Section VI.

[102] In the case of the HDPUV fleet, we apply a similar constraint, but up to and including MY 2029. That is, the technology outcomes from the No-Action Alternative for MYs 2022 to 2029 are forced for all other alternatives during the same years.

Other social costs and benefits emerge as the result of physical phenomena, like 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 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 CY totals), regulatory class, fuel type, and social discount rate. The list of social costs and benefits is presented in Table 4-2, as well as the population of vehicles that determines the size of the factor (i.e., new vehicles, or all registered vehicles) and the mechanism that determines the size of the effect (i.e., vehicle use in terms of miles driven, the amount of fuel consumed, or the number of vehicles produced).

Table 4-2: Social Costs and Benefits in the CAFE Model

Cost/Benefit	Population	Mechanism
Technology cost	New vehicles	Production volume
Consumer surplus	New vehicles	Production volume
Benefit of additional mobility	New vehicles	Vehicle use
Benefit of less frequent refueling	New vehicles	Fuel consumption
Retail fuel savings	All vehicles	Fuel consumption
Fuel tax revenue	All vehicles	Fuel consumption
Energy security cost	All vehicles	Fuel consumption
Congestion and noise costs	All vehicles	Vehicle use
Non-fatal injuries	All vehicles	Vehicle use
Fatalities	All vehicles	Vehicle use
Criteria pollutant damages (NO_X, SO_X, PM)	All vehicles	Vehicle use, Fuel consumption
GHG emissions damages (CO_2, CH_4, N_2O)	All vehicles	CO_2: Fuel consumption CH_4, N_2O: Vehicle use

4.5. Representing the Safety Effects of Standards

In the context of the CAFE Modeling framework, there are three avenues by which adjusting standards affects fleet-wide safety: fleet size and composition, rebound-effect driving, and changes in vehicle mass. The first effect arises from changes in the price of new vehicles as manufacturers attempt to recover their incremental costs for complying with more demanding standards, which can alter total sales of new vehicles, the shares of PCs and LTs in total light-duty vehicles (LDV) sales, and retirement rates for used vehicles. Increased prices for new vehicles reduce their sales and slow the retirement of used models, and these two effects combine to slow the rate of fleet turnover. In turn, this causes a redistribution of some VMT from newer to older vehicles. In the light duty market, it may also shift sales and VMT between the PC fleet and the LT fleet.

Because the safety of new vehicles has gradually improved over time, redistributing VMT from newer to older vehicles reduces the overall safety of the entire vehicle fleet, increasing fatalities and injuries very slightly. We measure this effect by projecting differential fatality and injury rates for vehicles of different vintages (i.e., model years) and ages during future CYs, 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, when drivers choose to drive more and increase the VMT of new vehicles via the rebound effect, increasing the stringency of standards exposes their drivers and passengers as well as other road users to increased risks of being involved in crashes. Although vehicles produced during each successive model year are anticipated to be safer than their predecessors, their increased use 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 each future vintage of vehicles over their lifetimes, and the per-mile risks that occupants will suffer fatal and non-fatal injuries in crashes, which decline gradually over future model years. Because this additional driving is a choice made by individuals who are generally cognizant of the injury and fatality risks it involves, we assume that drivers internalize 90 percent of the increased safety risk and thus must experience an offsetting benefit of this magnitude.

Finally, manufacturers are expected to reduce the mass of some of their vehicle models as a strategy to comply with more stringent standards, since doing so can sometimes offer a low-cost strategy to improve their fuel economy or, for HDPUVs, fuel efficiency. 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 risks that occupants of these vehicles – and occupants of vehicles and non-motorists that would be involved in collisions with these vehicles – will be killed or injured if these vehicles become involved in crashes. We estimate this effect as the change in the risks that occupants of vehicles whose mass is reduced and occupants of vehicles and non-motorists that would be involved in collisions with 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. Each vehicle model produced in a future model year has a base fatality rate that changes as it ages and accumulates mileage, but that rate can be modified by changes in its mass. At the same time, it will be driven more if its manufacturer elects to improve its fuel economy/fuel efficiency, and it can then be driven more (or fewer) miles over its lifetime as its retirement probability at each age changes. The rebound and sales/scrappage effects are identified outside of statistical models, and hence do not have estimated confidence bounds (in turn, neither do the aggregated safety effects). The estimated effects associated with changes in mass are identified based on a statistical model, but the component estimates are not statistically significant at the 95-percent confidence level. For a detailed discussion of how the model measures safety outcomes, see TSD Chapter 7.

5. Economic Impact of Fuel Economy Standards

This chapter describes NHTSA's approach for measuring the economic costs and benefits that are likely to result from establishing CAFE and fuel efficiency standards for future model years. It distinguishes the impacts of raising standards on private actors such as vehicle manufacturers and buyers from their broader impacts on the U.S. economy and public, describes the agency's perspective for measuring benefits and costs, discusses procedures for comparing impacts that occur when new vehicles are produced and sold to those resulting from their subsequent use, and illustrates how the agency summarizes and reports benefits and costs. The agency's central empirical estimates of costs and benefits likely to result from the preferred and alternative standards it considered during this rulemaking are presented in Chapter 8 of this FRIA, and Chapter 9 describes tests of those results' sensitivity to variation in the assumptions and parameters used to develop the agency's central estimates.

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 reference baseline scenario. The following sections illustrate how our measures of benefits and costs from adopting higher standards are derived from economic analysis of markets for new and used vehicles, vehicle owners' decisions about how much to drive, and how U.S. production and imports of petroleum and gasoline are likely to respond to the reductions in fuel consumption resulting from requiring higher fuel economy and efficiency. As this discussion shows, raising standards is likely to change the behavior of a range of economic actors including vehicle manufacturers, buyers of new vehicles, owners of used vehicles, and suppliers of petroleum and refined fuel compared to a reference baseline in which standards remained at their currently prevailing levels.

5.1. Overview of Effects from Increasing Fuel Economy Standards

Figure 5-1 provides an overview of the inputs used in NHTSA's analysis of the standards, traces the influence of fuel economy and efficiency standards on the behavior of producers and consumers of vehicles and fuel, and highlights the resulting economic benefits and costs of higher standards. As it shows, vehicle manufacturers respond to increases in required fuel economy and efficiency by extending their use of currently available technology currently used and by deploying new technology to improve their individual models' efficiency. Doing so raises manufacturers' costs to produce the models whose fuel economy or efficiency that are improved, and producers will attempt to recover their additional costs and maintain profitability by raising prices for those—and perhaps other—models.

Producers may also elect to increase their vehicles' fuel economy or efficiency by postponing or forgoing planned improvements in other attributes that buyers also value but would inhibit efforts to improve fuel economy, such as by reducing their seating and cargo-carrying capacity, ride comfort, safety, or performance, but manufacturers are aware that sacrifices in these attributes make vehicles less attractive to buyers and are likely to approach making them warily. NHTSA recognizes the reluctance of both vehicle manufacturers and buyers to make such tradeoffs in exchange for higher fuel economy, as well as the conceptual and empirical challenges to measuring the "opportunity costs" that could arise from doing so.

Thus, the agency's analysis assumes that manufacturers will comply with stricter standards exclusively by using more advanced technology and vehicle designs to increase vehicle efficiency, while holding key vehicle attributes such as acceleration, towing, and hauling unchanged.[103] Its estimates of manufacturers' direct costs to improve fuel economy include only those for additional technology necessary to meet higher fuel economy standards while maintaining those attributes at current levels, while excluding any potential opportunity costs for sacrifices in other attributes. In a separate sensitivity case presented in Chapter 9.2.3.10 of this FRIA, NHTSA develops a possible approach for measuring these opportunity costs and examines the effect of including those costs this final rule's total social costs and net social benefits.

[103] Some technologies that manufacturers employ to improve fuel economy may produce incidental enhancements or sacrifices in other vehicle attributes, but the agency does not attempt to estimate these or any resutling changes in vehicles' value.

Figure 5-1: Overview of NHTSA's Analysis of Changes in Fuel Economy Standards

Inputs	Analysis	Outputs
• Technology and costs to improve fuel economy/efficiency • Economic assumptions (e.g., future fuel prices, income levels) • Sales, fuel economy/efficiency, and use of future model years under current standards • Number, retirement rates, fuel economy, and use of cars and light trucks currently in use	• Changes in prices, fuel economy/efficiency, and other attributes of new vehicles • Changes in sales and use of new vehicles • Changes in retirement rates and use of vehicles by model year and age	• Vehicle fuel consumption and fuel costs by model year and age • Safety of vehicle travel • Environmental externalities from refining and using fuel • Energy security costs from consuming and importing petroleum • Fuel tax revenue

In the "real world" market for new vehicles, manufacturers would be expected to design their models to provide at least the overall levels of fuel economy or efficiency that prevailing standards require, and to offer even higher levels if they believe buyers are willing to pay sufficiently higher prices to allow manufacturers to recover their additional costs for doing so. At the same time, producers would also presumably equip their models with combinations of other features and offer them at selling prices they believe will be most attractive to buyers and thus maximize their profits.[104] However, the agency does not have manufacturers' production costs, actual selling prices, or profit data for individual vehicle models, so it cannot simulate this expected behavior. Instead, the reference baseline alternative NHTSA used for this analysis assumes that manufacturers will supply fuel economy levels higher than prevailing standards require if doing so offers fuel savings that repay buyers for their higher purchase prices within 30 months, thus making them willing to pay prices sufficient to compensate manufacturers for their additional costs.

Increasing the stringency of standards requires manufacturers to raise some models' fuel economy or efficiency from this reference baseline, and in doing so they will presumably attempt to minimize any resulting impact on their revenue and profits by raising prices. NHTSA's analysis assumes that manufacturers will raise prices only for models whose fuel economy or efficiency they improve and will do so only as necessary to recover their increased costs for producing those models. The agency does not attempt to represent pricing strategies where manufacturers would attempt to recover their costs to improve one model's fuel economy by raising prices for other models, in effect "cross-subsidizing" improvements in some models' fuel economy by raising prices for others. Where tax credits or other subsidies are offered to manufacturers or buyers, the agency's analysis of costs and benefits from raising standards uses specific assumptions about how those will ultimately affect specific models' production costs and the fraction of those increased costs that will be passed on to buyers in the form of higher prices. Where it does so, the agency clearly identifies those assumptions.

The agency believes that setting standards it deems maximum feasible under its statutory mandate will provide economic benefits to vehicle buyers and users – as well as to the public – that exceed the costs of the additional technology manufacturers will utilize to achieve the higher fuel economy levels they require. Of course, manufacturers may change other vehicle attributes as part of their efforts to comply with the standards, both to facilitate making the required improvements in fuel economy and to enhance the attractiveness of their vehicles to consumers. As part of their efforts to comply with new standards, manufacturers may design vehicles with "less" of other attributes to enable them to achieve higher fuel economy, if doing so would reduce their compliance costs and preserve their profitability. While doing so could make those models less attractive to potential buyers, it might also reduce manufacturers' technology costs for meeting new standards and thus lead to smaller increases in vehicle prices relative to the reference baseline. Conversely, adding certain fuel economy technologies may also enable them to enhance vehicles' other attributes at the same time, thus making them more attractive to potential buyers. Again, because it

[104] Manufacturers will presumably increase fuel economy beyond what current standards require when they believe doing so will increase their profits, but raising CAFE standards is intended to require most or all producers to increase fuel economy beyond this market-determined level.

lacks information on costs to change other attributes and potential buyers' values of those changes, the agency does not attempt to anticipate whether specific manufacturers will engage in either of these alternative strategies; instead, it assumes that they will hold attributes of their vehicle models other than fuel economy and sales prices fixed.

The combination of improvements in some models' fuel economy or efficiency and accompanying increases in prices is likely to affect their sales, but the size of the market response (and even possibly its direction) depends on how potential buyers' value the savings in fuel costs that models offering improved fuel economy compares to the increase in their initial purchase prices. For the variety of reasons discussed previously in Chapter 2 of this FRIA, NHTSA assumes that typical buyers value future savings in fuel costs from purchasing models that offer improved fuel economy over only the first 30 months of those vehicles' lifetimes. The agency's analysis assumes that manufacturers will add technologies that offer fuel savings sufficient to repay their initial costs within this 30-month period under the reference baseline alternative, but meeting the new standards this final rule establishes will require them to employ additional technologies that require longer than 30 months to repay their initial costs via fuel savings. Adding these technologies to some models will produce some additional savings in buyers' fuel costs, thus making buyers willing to pay more to purchase them, but in any case, manufacturers will presumably attempt to raise those models' selling prices to recover their higher costs.

Because the resulting price increases will exceed buyers' willingness to pay for the incremental fuel savings,[105] the agency projects that total sales of new models will decline when it raises standards, and that the size of this decline will grow as it adopts more stringent standards. The clearest evidence that a decline in sales represents the most likely response is that if manufacturers could increase sales and profits by improving some models' efficiency and raising prices to recover their added costs, they would presumably do so even in the absence of higher standards.

The response of new vehicle sales will also be influenced by how the combination of price changes and higher fuel economy affects potential 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 when NHTSA adopts higher standards and consumers do not recognize the full value of fuel savings, some would-be new vehicle buyers are likely to purchase used models instead, while others may simply decide to retain their used vehicles for longer, and these responses will increase demand for used vehicles.

Higher demand will in turn 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 in Chapter 7 of this FRIA, as well as in TSD Chapter 4), so some vehicles that would otherwise have been retired will instead be maintained in working condition and driven longer. The combination of reduced sales of new vehicles and slower retirement of used ones will in effect transfer some travel from new to older vehicles, so a larger share of total driving will take place in used cars and light trucks after standards are raised than if prevailing standards remained in effect. At the same time, the resulting increases in prices for *both* new and used vehicles will raise their owners' depreciation-related costs for driving, which would be expected to reduce total travel slightly and offset some fraction of increased driving that occurs because of the fuel economy rebound effect.

As Figure 5-1 also shows, these responses will also generate various other economic consequences. Improving new vehicles' fuel economy or efficiency reduces their operating costs and prompts owners to increase the number of miles they drive. This is an example of the well-documented fuel economy "rebound effect," and the additional driving offsets a modest fraction of the fuel savings that raising standards would otherwise produce. New cars and light trucks featuring higher fuel economy and HDPUVs with higher fuel efficiency will also have extended driving ranges and require less frequent refueling, thus reducing the inconvenience of locating retail stations and economizing on their drivers' and passengers' time. Despite their increased use, the total amount of fuel new vehicles consume over their lifetimes will decline and enable their owners to economize on fuel costs, and while increased fuel used by older vehicles will offset an additional fraction of the anticipated savings, total fuel use will nevertheless decline. Finally, because new vehicles have become progressively safer over time, there continues to be a strong association between vehicles' ages,

[105] *See* Chapter 2.1.4 for a discussion of why buyers may undervalue fuel savings.

their involvement in crashes, and injuries their occupants sustain, so shifting travel from newer to older vehicles is likely to affect the safety of drivers and their passengers adversely.

Reducing the volume of fuel distributed and consumed will in turn lower global emissions of GHGs and domestic emissions of criteria air pollutants, thus reducing the costs that potential climate-related impacts and adverse health effects from air pollution impose on the public. Reducing the volume of fuel refined or imported may also reduce some adverse consequences of U.S. petroleum consumption and imports, including costs to businesses and households for adjusting to occasional rapid swings in fuel prices. These costs are distributed broadly across the U.S. economy, so reducing them by curtailing fuel consumption represents an economy-wide benefit of raising standards that extends well beyond the immediate savings in fuel costs and other benefits to buyers of more fuel-efficient new vehicles.

5.2. Measuring Benefits and Costs from Raising CAFE Standards

In theory, the economic benefits and costs resulting from higher standards are measured by the combined changes in consumers' and producers' welfare in all the markets they ultimately affect, plus any accompanying changes in environmental or economic externalities generated by producing and consuming fuel. The agency's assessment of alternative increases in standards focuses on benefits and costs arising in those markets that are most likely to be affected, either directly or indirectly. These include the markets for new cars, light trucks, and HDPUVs; used vehicles; transportation fuels (including those refined from petroleum and, increasingly, electricity); and crude petroleum. The agency examines benefits and costs in these markets in the order they arise: raising standards affects the market for new vehicles directly, and the consequences for the fuel economy and efficiency, prices, and sales of new vehicles in turn generate various indirect impacts. These include effects 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 and petroleum-based fuels.[106]

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 to producers, buyers, owners, and drivers of new and used vehicles, plus any changes in the value of externalities arising from vehicle use and from fuel production and consumption. Throughout its analysis, however, NHTSA makes various assumptions to simplify measuring these benefits and costs, one of which is that changes in demand for transportation fuels caused by changes to CAFE standards do not lead to changes in their prices.[107] The agency's analysis also assumes that the magnitude of 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.

5.2.1. Private Versus "External" Benefits and Costs

Throughout this analysis, the agency is careful to distinguish between costs and benefits from raising standards that are experienced by private actors and those likely to fall more broadly on the public or throughout the U.S. economy. The former includes private businesses that produce vehicles, households and businesses that purchase and use them, and suppliers of transportation fuels and crude petroleum. NHTSA reports estimated costs and benefits of alternative increases in standards using a format that clearly distinguishes between private benefits and costs they would create for vehicle manufacturers, households, and businesses that purchase vehicles, and benefits and costs that would be distributed more widely

[106] Some gasoline consumed in the United States is imported in already-refined form, rather than refined domestically.

[107] While acknowledging that this assumption may simplify real-world production conditions, the agency believes it is likely to have little effect on its estimates of benefits and costs from the final action. This is because 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. As Figure 7-9 in Chapter 7 of this FRIA demonstrates (using the case of the used vehicle market), assuming price-elastic supply means that prices will decline slightly in response to reduced demand. As that figure also suggests, the resutling gain in consumer surplus will be slightly more than offset by losses in producer surplus to suppliers, so the net change in welfare will be far smaller that either the impact on consumers or suppliers. This same result will prevail in the market for fuel, and the net effect on economic welfare will be change only modestly in response to varying assumptions about the the exact value of the price elasticity of fuel supply.

throughout the U.S. population and economy. This distinction highlights the fact that by far the largest shares of benefits and costs that result from raising standards would be experienced by private households and businesses – who could realize those same benefits and costs without regulation simply by purchasing higher-MPG models – while the external benefits and costs from raising standards are likely to be smaller, even if more widely distributed.

5.3. NHTSA's Perspective for Measuring Benefits and Costs

This analysis relies on many economic assumptions and forecasts, and while these generally do not differ between the reference baseline scenario and the various regulatory alternatives it evaluates, these inputs nevertheless contribute to the estimated benefits and costs of each regulatory alternative when compared to the regulatory reference 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 S&P Global Insight Forecast and U.S. Energy Information Administration (EIA)'s Annual Energy Outlook 2023 (AEO 2023).[108] This is also the source used for forecasts of U.S. fuel prices, global petroleum supply and prices, and U.S. imports of crude petroleum and refined fuel that are used throughout this analysis.[109] Finally, the agency relies on the U.S. Department of Transportation's (DOT) guidance for valuing travel time when assessing benefits from less frequent refueling, as well as for updating the estimates of vehicles' contributions to increased congestion costs originally reported in FHWA's 1997 Highway Cost Allocation Study.[110]

To assess the costs and benefits of the Final Rule, NHTSA first simulates the number of new vehicles produced during model years 2022 through 2050, as well as the number, usage, and total fuel consumption by all light-duty vehicles and HDPUVs in use during calendar years 2022 through 2089 (the last year when vehicles produced during model year 2050 remain in use). In this analysis, the agency assumes that CAFE and fuel efficiency standards for future model years would remain at the levels it is establishing for model year 2031 (for light-duty vehicles) and 2035 (for HDPUVs), the last model years covered by this rule, through model year 2050. Including future model years through 2050 in the analysis is necessary to estimate benefits and costs of establishing higher standards for all vehicles that will be produced during the period used for this regulatory analysis, which extends through calendar year 2050. Although this final rule does not explicitly establish standards for those later model years, NHTSA attributes both costs and benefits from doing so to this rule, because the agency views it as establishing minimum levels – a floor, in effect – for future standards.

NHTSA's FRIA measures and reports benefits and costs from increasing fuel economy and efficiency standards from two different perspectives. First, the agency's "model year" perspective focuses on benefits and costs of establishing alternative CAFE standards for model years 2027 through 2031 (and fuel efficiency standards for HDPUVs for model years 2030 through 2035), and measures these over each separate model year's entire lifetime.[111] A shortcoming of this perspective is that it omits the effects that establishing standards for a single model year can have on the number, use, and fuel consumption of vehicles produced during previous or subsequent model years. To address this shortcoming, NHTSA reports benefits and costs for groups of consecutive model years to recognize that establishing new standards for one model year can affect the number of vehicles from other model years that remain in use, how much they are driven, and their fuel consumption, all of which affect the benefits and costs of setting standards that apply to a single model year.

In contrast, the agency's "calendar year" perspective sums the costs and benefits of changing fuel economy standards for specific model years on the composition and use of the *entire* light-duty and HDPUV fleets during each future calendar year, and typically aggregates these impacts over a series of calendar years (in

[108] EIA. Annual Energy Outlook 2023. Reference Case Table 20. Available at: https://www.eia.gov/outlooks/aeo/tables_ref.php. (Accessed: Feb. 23, 2024).
[109] EIA. Annual Energy Outlook 2023. Reference Case Tables 11 and 12. Available at: https://www.eia.gov/outlooks/aeo/tables_ref.php. (Accessed: Feb. 22, 2024).
[110] DOT. 2016. The Value of Travel Time Savings: Departmental Guidance for Conducting Economic Evaluations. Revision 2. Available at: https://www.transportation.gov/office-policy/transportation-policy/revised-departmental-guidance-valuation-travel-time-economic. (Accessed: Feb. 14, 2024).
[111] The lifetime of each model year is assumed to begin in the calendar year when it is initially produced and sold (assumed to be contemporaneous with its model year designation) and to extend for 40 years. By the time a model year cohort reaches the 40-year mark, fewer than 2% of the vehicles originally produced and sold typically remain in use.

this analysis, 2022 to 2050). This perspective includes the effects of raising standards on the number, use, and fuel consumption of vehicles from all model years that are in use during each future calendar year.

Model year and calendar year accounting perspectives each offer different strengths and limitations. The strengths of model year accounting are that it allows NHTSA to focus on the costs and benefits for those vehicles for which it is currently setting standards. As indicated previously, however, the model year perspective omits many of the effects of raising standards for a single model year on the use and fuel consumption of vehicles produced during other model years that make up the remainder of the fleet. (In contrast, the agency's calendar year perspective includes the effects of establishing standards for a limited range of model years on the number, usage, and fuel consumption of vehicles produced during both earlier and later model years.)

For example, CAFE standards for model year 2032 and later will be higher under more stringent alternatives, because standards are assumed to remain fixed at the levels each alternative establishes for 2031, the last model year covered by this final rule. The higher prices for new vehicles produced and sold during model years 2032 and beyond that result from stricter fuel economy standards will reduce their sales, and by doing so increase the lifetime use of vehicles produced during earlier model years for which this final rule does establish higher CAFE standards (though NHTSA expects this effect will be extremely small). Although the agency's model year accounting would capture the indirect effects of higher standards for model year 2032 on those earlier model years (model years 2027 through 2031), it would not capture the other benefits and costs from setting higher standards for model years 2032 and beyond.

The strength of the calendar year approach is to avoid this potentially inconsistent accounting of benefits and costs, but it suffers from other limitations. For one, calendar year accounting inevitably misses a significant portion of the lifetime fuel savings and environmental benefits of higher fuel economy standards for vehicles produced late in the analysis period, because it omits those impacts during a significant fraction of their lifetimes. As an extreme example, only the first year of fuel savings will be included for model year 2050 vehicles, since the agency's calendar year analysis ends in that year. Second, calendar year accounting inevitably captures benefits and costs from establishing standards that cover many model years beyond those included in this final rule. In fact, the agency's 2022-2050 analysis period includes model years extending so far beyond those for which this rule establishes new standards that benefits and costs from imposing higher standards on those later model years dominate the estimated impacts of the standards we *are* establishing with this final rule.

This increases the significance of our assumption that the 2031 CAFE standard will also apply to later model years, and its implication that we can ascribe the benefits and costs of those assumed standards to this final rule. Finally, since the calendar year approach tends to be dominated by impacts stemming from assumed standards for those more distant future model years, and many of those impacts occur late in the analysis period. Key input values such as fuel prices, the effects of cumulative production volumes on technology costs, and the effectiveness of those technologies in reducing fuel consumption are more uncertain that far in the future.

Unlike CAFE standards for light duty vehicles, NHTSA's fuel efficiency standards for HDPUV would remain in place for model years produced after 2035, the last year for which we are establishing standards in this final rule. In other words, the standard we adopt today for model year 2035 will remain in place in perpetuity or until it is amended, so, the agency's analysis of HDPUV standards does not require it to assume what future standards will be. NHTSA believes that this feature makes the calendar year analysis more appropriate for accounting the benefits and costs of increasing HDPUV fuel efficiency standards, because it removes the largest source of uncertainty about the level of future standards and enables more reliable estimation of the costs of meeting them, the resulting fuel savings, and other benefits. Thus, the agency's analysis presents benefits and costs of establishing higher fuel efficiency standards for HDPUVs using only the calendar year approach.

When assessing potential buyers' likely response to requiring manufacturers to meet higher fuel economy targets, we assume that buyers of new vehicles value fuel costs over the first 30 months they own and use their newly purchased vehicles. If buyers discount future fuel costs at a rate of 3%, this is equivalent to assuming that they consider only about one-quarter of a vehicle's total fuel costs over its expected lifetime, and that they focus on the same fraction of future savings in fuel costs from choosing a model that offers higher fuel economy.[112] This assumption implies that competitive automobile manufacturers will voluntarily make any improvements in fuel economy that repay their initial costs within that 30-month period, since they would be able to recover those costs from buyers by raising the prices they charge. Hence manufacturers of new cars, light trucks, and HDPUVs would be expected to make these lower-cost improvements in fuel economy and efficiency voluntarily even in the absence of standards, and buyers would willingly purchase models that offer them. Although further improvements in fuel economy or efficiency that would require more than 30 months to repay their initial costs in the form of savings in fuel expenses will inevitably remain, manufacturers are assumed unlikely to make them because they believe that buyers are unwilling to pay higher prices to purchase models that feature them.

In contrast, when estimating social – that is, private plus external – benefits from raising the standards, the agency assumes that buyers and subsequent owners of new cars, light trucks, and HDPUVs will realize benefits 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 the standards can thus produce fuel savings that ultimately repay their initial costs, although those improvements will require longer than 30 months to do so. As long as further improvements in fuel economy with "payback periods" longer than 30 months (2½ years) but shorter than vehicles' expected lifetimes (15-16 years for cars and light trucks, and 17-18 years for HDPUVs) remain available, given the 30 month payback assumption, the agency's analysis will conclude that imposing stricter standards can provide fuel savings and other benefits that exceed the costs of achieving them, thus making vehicle buyers and owners *themselves* better off as a result.

This result relies on two critical assumptions: first, that new vehicle shoppers act myopically and are do not appear to consider the full value of fuel savings from purchasing a higher-mpg model over its entire lifetime; and second, that used car buyers act similarly and do not pay as much extra to buy a higher-mpg model as doing so would save in fuel costs over its remaining lifetime. Chapter 2 of this FRIA summarizes recent empirical research on these assumptions.

5.4. Discounting Future Costs and Benefits

OMB Circular A-4 establishes three rationales for discounting future benefits and costs. The first is that resources invested in capital will normally earn a positive return in the future, so it is important to account for the opportunity cost of diverting resources to the purposes a regulation serves. Second, people generally prefer current to future consumption, and it is important to account for this "impatience." Finally, while consumption tends to increase over time due to economic growth, successive increases contribute progressively less to improving economic welfare, making consumption in the future incrementally less valuable than consumption today.[113]

Until recently, OMB Circular A-4 recommended that Federal agencies discount future benefits and costs of regulatory actions that affect opportunities for investment using a 7 percent rate and the economic effects of regulations that will primarily affect households' future consumption opportunities at a 3 percent rate, and this guidance continues to apply to this final rule.[114] Increases in costs to produce new vehicles that meet higher targets will initially be borne by vehicle manufacturers, but we assume that market conditions will enable them to protect their profitability by passing these cost increases on to buyers in the form of higher selling prices, thus ultimately affecting their buyers' other consumption opportunities. Fuel savings and most other benefits from tightening standards will be experienced directly by owners of vehicles that offer higher fuel efficiency and also affect their future consumption opportunities, while benefits or costs that are experienced by other than buyers of new vehicles will also primarily affect their future consumption. Circular A-4 indicates that discounting at the consumption rate of interest is the "analytically preferred method" when a regulation is likely to primarily affect consumption opportunities, or when its effects are presented in consumption-equivalent

[112] This issue is discussed further in TSD Chapter 4, FRIA Chapter 2, and FRIA Chapter 9.
[113] OMB Circular A-4 (2003).
[114] On November 13, 2023, OMB finalized an update to Circular A-4. *See* 88 FR 77615. The revised Circular A-4 (2023) takes effect March 1, 2025, for regulatory analyses supporting final rules with already published proposals. The revised Circular A-4 (2023) encourages agencies when feasible and appropriate to implement the new guidance earlier. NHTSA is implementing portions of the revised Circular A-4 (2023) in the regulatory documents supporting the final rule, but excluding other changes as they are infeasible to incorporate without an extensive delay to the final rule. Throughout the rest of the document, any references without a calendar year noted in parentheses should be assumed to mean Circular A-4 (2023).

units. Thus, applying OMB's guidance to NHTSA's final rule suggests the 3 percent rate is the appropriate rate.

Because there is some uncertainty about whether and how completely manufacturers can recover their increased costs for providing higher fuel economy from buyers, however, and any costs that cannot be recovered are likely to displace other investment rather than consumption opportunities, 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 other than benefits from reducing GHG emissions discounted using a 7 percent rate. Benefits and costs are discounted using both rates to their present values as of 2022 and are expressed in constant dollars reflecting economy-wide price levels prevailing during 2021.

One important exception is reductions in climate damages resulting from lower GHG emissions. In this FRIA, , The agency discounts all other costs and benefits of the final rule at 3 and 7 percent, but combines these with estimates of benefits from reducing GHG emissions discounted at each of three rates used by the EPA to develop its estimates of the SC-GHGs. Where NHTSA does not present the full range of SC-GHG estimates, NHTSA presents SC-GHG values discounted at the 2 percent rate, which is the rate EPA uses to construct its central estimates of the SC-GHG. [115] The agency's analysis showing non-climate impacts discounted at 3 and 7 percent together with climate-related benefits discounted at each rate recommended by the EPA can be found in Chapter 8.2.4.6, Table 8-14, and Table 8-15 of this FRIA.[116]

5.5. Reporting Benefits and Costs

NHTSA believes it is important to report the benefits and costs of the alternative increases in standards we evaluate in a format that illustrates *how* such action will generate the economic impacts that ultimately produce benefits and costs; while also highlighting their incidence on households, private businesses, and the remainder of the U.S. population. As an illustration, Table 5-1 presents the categories of economic benefits and costs from raising standards that NHTSA estimates and indicates where within this FRIA each category is discussed in more detail. 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. and global population (labeled "Other" costs and benefits in the table, but sometimes referred to as "external" costs and benefits elsewhere in this FRIA).

Alternative versions of Table 5-1 that include dollar estimates of costs and benefits for each of the regulatory alternatives we considered before selecting the preferred alternative for this final rule also appear in Chapter 8.2.4.6, Table 8-14, and Table 8-15 of this FRIA. These alternative presentations reflect differing perspectives for measuring benefits and costs, time horizons, and discount rates.

Table 5-1: Benefits and Costs Resulting from the Agency's Regulatory Action

Entry	Location of Explanation in FRIA
Private Costs	
Technology Costs to Increase Fuel Economy	Chapter 8.2.2.2
Increased Maintenance and Repair Costs	Chapter 8.2.4.6
Sacrifice in Other Vehicle Attributes	Chapter 8.2.4.6
Consumer Surplus Loss from Reduced New Vehicle Sales	Chapter 8.2.3.1, 8.2.3.2
Safety Costs Internalized by Drivers	Chapters 8.2.4.5, 8.2.4.6

[115] Pg. 101 of EPA. 2023. EPA Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances. National Center for Environmental Economics, Office of Policy, Climate Change Division, Office of Air and Radiation. Washington, DC. (hereinafter, "2023 EPA SC-GHG Report"). Available at: https://www.epa.gov/environmental-economics/scghg. (Accessed: February 23, 2024). NHTSA is likely to focus primarily on the SC-GHG estimates that incorporate a 2 percent discount rate, because that corresponds to the rate that OMB's revised Circular A-4 recommends be used (after incorporating an appropriate risk premiium) to discount other costs and beenfits.

[116] In Chapter 9 of this FRIA, NHTSA presents results of a sensitivity analysis where all impacts are discounted at 2 percent.

Subtotal - Private Costs	Sum of above entries
Other Costs	
Congestion and Noise Costs from Rebound-Effect Driving	Chapter 8.2.4.3
Safety Costs Not Internalized by Drivers	Chapters 8.2.4.5
Loss in Fuel Tax Revenue	Chapter 8.2.4.6
Subtotal – Other Costs	Sum of above entries
Social Costs	Sum of private and external costs
Private Benefits	
Savings in Retail Fuel Costs[117]	Chapter 8.2.3.2
Benefits from Additional Driving	Chapter 8.2.3.2
Less Frequent Refueling	Chapter 8.2.3.2
Subtotal – Private Benefits	Sum of above entries
Other Benefits	
Reduction in Petroleum Market Externality	Chapter 8.2.4.4
Reduced Climate Damages	Chapters 8.2.4.1
Reduced Health Damages	Chapters 8.2.4.2
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 Table 5-1 shows, many impacts of the regulatory action will fall directly on private businesses and households or individuals, including manufacturers of cars and light trucks, buyers and subsequent owners of the new models they produce, and owners of used vehicles – that is, vehicles produced during model years prior to those considered in this analysis. The largest category of costs is vehicle producers' expenses for added technology to enable their models to meet higher fuel economy and fuel efficiency targets, although as indicated previously, the agency assumes these increased costs will be reflected in higher purchase prices and thus ultimately borne by new vehicle buyers.

Table 5-1 also includes entries for changes in 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 buyers' value of changes in vehicles' other attributes that manufacturers introduce as part of their efforts to improve fuel economy. Including these entries in the table but not quantifying them in our analysis is intended to emphasize that these could represent real economic costs of requiring manufacturers to comply with higher standards but that the agency lacks sufficient information to confidently estimate them. Other privately borne costs include losses in consumer surplus to would-be new

[117] 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.

car and light trucks buyers who are deterred by their higher prices, and the economic cost of safety risks that drivers consider (or “internalize”) when deciding whether to travel additional miles.

Other costs reported in the table include the contributions of additional rebound-effect driving to traffic congestion, delays, and roadway noise. Although delay costs are borne by drivers (and their passengers) *as a whole*, roadway noise also affects pedestrians, nearby residents, and other non-drivers; in either case, individual buyers of new vehicles whose decisions about how much to drive impose these costs on others are unlikely to consider them when deciding whether to make additional trips. Similarly, those drivers may not account for all safety risks they create for themselves and other road users (including users who are not vehicle occupants) by making additional trips, and the economic value of risks they do not consider represent external costs they impose on other vehicles’ passengers, pedestrians, cyclists, 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. (The agency assumes that states or localities do not respond to declining fuel purchases by raising tax rates to maintain total tax revenues, but still other costs would result if they did so.) Of course, lower fuel tax payments by drivers were already reflected in the savings in fuel costs reported previously, because those are valued at retail prices (which include taxes), so the net effect of including this transfer is zero, as expected.

By far the largest category of benefits from raising standards is the cost of fuel that would be saved by buyers of cars, light trucks, and HDPUVs that achieve higher fuel economy or fuel efficiency, which as Table 5-1 shows represents 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 significant “external” benefits to the broader population, including greater energy security from lower reliance on fossil fuels, which are subject to global markets, some reduction in future economic damages caused by expected changes in the global climate, and improved health from less frequent exposure to harmful levels of air pollution. These represent the Other Benefits reported in Table 5-1.

Finally, the table reports Social Costs, which are the sum of private and other costs, and social benefits, the sum of private and other 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 and fuel efficiency standards generates social benefits exceeding its social costs, while negative values suggest the opposite. The table also reports net private benefits, which are equal to the difference between private benefits and private costs, as well as net external benefits, or the difference between external or “Other” benefits and costs. Reporting the private and external components of net benefits separately enables readers of this FRIA to clearly distinguish the value of NHTSA’s action to manufacturers and buyers of new cars and light trucks themselves from the broader benefits it provides throughout the U.S. economy.

6. Simulating Manufacturers' Potential Responses to the Alternatives

CAFE Model Files Referenced in this Chapter

Below is a list of CAFE Model Files referenced in this chapter. See TSD Chapter 2.1.9 Where to Find the Internal NHTSA Files for a full list of files referenced in this document and their respective file locations.

- Market Data Input File
- Technologies Input File
- Scenarios Input File
- CAFE Model Documentation
- CAFE Model Input File
- CAFE Analysis Autonomie Documentation

The CAFE Model utilizes a variety of data and algorithms to characterize real vehicle fleets, fuel-saving technology, and real-world technical and economic constraints to build an assessment of how each manufacturer could comply with a given regulatory alternative. The CAFE Model compliance analysis includes detailed information about each regulated manufacturer's vehicles models offered for sale in a given model year (or years), production constraints, compliance constraints and flexibilities. The regulatory alternatives, while applicable to all manufacturers in the analysis, affect individual manufacturers differently. Each manufacturer's actual fuel economy 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 for LD and work factors for HDPUV. 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 fuel economy standards, each manufacturer's requirement is dynamically defined based on the specification of the standards for any simulation and the distribution of footprints or WFs within each fleet.

6.1. Representing Manufacturer's Decisions

In the real world, vehicle manufacturers subject to fuel economy regulations make choices about which technologies are appropriate to apply in response to those regulations. In order to simulate these decisions, the CAFE Model considers a number of factors including a manufacturer's current technology, the array of fuel-saving technologies that are available, the cost of such technologies, and a variety of real-world constraints related to vehicle manufacturing and sale. The CAFE Model ultimately chooses technologies that, for a certain manufacturer's vehicle fleet, would offer a cost-effective path toward compliance with fuel economy regulations.

The first step to represent manufacturer's decisions about which fuel economy-improving technologies could be applied to their vehicles in a future MY is to define the relevant list of technologies available for application. The CAFE Model has extensive technology options and pathways available for application to vehicles. These technologies and pathways are detailed in TSD Chapters 2 and 3 and they include restrictions around which more advanced technologies can be applied based on already applied technologies. The model selects the most cost-effective technologies, subject to additional real-world constraints that are discussed below, that allow manufacturers to meet fuel economy standards.

The Market Data Input File forms the starting point for the CAFE Model analysis. It includes detailed information about the vehicle models available for sale in a model year or years and their respective fuel-saving technologies; the model years for which the CAFE Model will have opportunities to apply technology; what engines, transmissions, and platforms are shared between vehicles; vehicle sales, fuel economy, footprints, and safety classes; and various other critical pieces of information.[118,119]

[118] See TSD Chapter 2 for additional details about the Market Data Input File.
[119] See the Market Data Input File, which can be found on the NHTSA CAFE Model website.

The effectiveness of each technology is based on simulations run from the Department of Energy (DOE) Argonne National Laboratory (Argonne) Autonomie model.[120,121] Argonne runs ten sets of simulations for LDVs and four sets of simulations for HDPUVs that differ by vehicle "technology class." Technology classes are used to accurately represent how vehicles with different characteristics may benefit from fuel economy-improving technologies. All vehicles in the Market Data Input File are assigned a technology class that allows the model to use the effectiveness values that most closely match a vehicle's characteristics.[122]

The costs of each technology considered in this analysis are stored in the Technologies Input File.[123] The costs are either assigned by vehicle technology class or engine class, depending on whether a technology is deemed a platform technology or an engine technology. All technology costs represent an average direct manufacturing cost (DMC) with a retail price equivalency factor of 1.5 and decrease in successive MY based on a learning rate that represents manufacturers getting better at producing a technology over time. Battery costs included in the CAFE Model and the Technologies Input File include a battery learning rate that allows those costs to decrease in future years when more technology adoption is expected.[124]

Some technologies have federal incentives tied to their application, which are included in the modeling. The Scenarios Input File includes tax credits that are applicable to vehicles and/or batteries during the years modeled.[125] These incentives are defined by regulatory class and technology. The amount of battery tax credits applied for PHEVs, BEVs, and FCVs is based on the average battery pack size for each respective technology type.[126] These incentives reduce the cost of applying a technology when and if the technology is allowed by modeled statutory constraints.[127]

Technology application in the CAFE Model is determined by the "effective cost" of a technology. The effective cost of a technology represents the tradeoffs that manufacturers must make between compliance costs, civil penalties, and consumer demand for fuel economy improvements, among other factors. Thus, the calculation of effective cost includes the incremental cost of the technology itself, the value of fuel savings to a potential buyer over the first 30 months of ownership,[128] avoidance of civil penalties from applying a given technology, and the cumulative value of additional vehicle and battery tax credits (or, Federal incentives) resulting from application of a candidate technology evaluated on a group of selected vehicles. The CAFE Model attempts to apply technology to each manufacturer's fleet in a manner that minimizes these effective costs. CAFE Model Documentation Chapter 2 Section 5.3.2 has an in-depth discussion of the relevant effective cost equations.

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. It 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:

- Reaches compliance with fuel economy standards or GHG standards, depending on the operating mode and the regulatory alternative, possibly through the accumulation and application of compliance credits.

[120] Technology effectiveness values are included in the CAFE Model release and are not selectable by the user.
[121] For more information about how the Autonomie model was used, see the Argonne Natinoal Laboratory's report which is titled "Vehicle Simulation Process to Support the Analysis for MY 2027 and Beyond CAFE and MY 2030 and Beyond HDPUV FE Standards**"**. For ease of use and consistency with TSD document, it is referred as "CAFE Analysis Autonomie Documentation".
[122] See TSD Chapter 3 for additional details about technology effectiveness values.
[123] See the Technlogies Input File, which can be found on the NHTSA CAFE Model website.
[124] See TSD Chapter 2 and TSD Chapter 3 for more discussion on specifc technology costs and technology types.
[125] See the Scenarios Input File, which can be found on the NHTSA CAFE Model website.
[126] See TSD Chapter 2 for more discussion on technology incentives and tax credits.
[127] See TSD Chapter 2 for a discussion on model standard setting constraints.
[128] 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 Chapters 1.4.1 and 4.2.1 discuss the basis for this model input.

- Reaches a point at which it is more cost effective to pay civil penalties than to add more technology.[129] This option only exists for some LD manufacturers and functionally none of the HDPUV fleet.[130]
- Reaches a point (beyond compliance) where the cost of additional fuel-saving technology begins to exceed the fuel savings projected to occur during the first 30 months of vehicle ownership.

The algorithm stops applying additional technology to a manufacturer's vehicles once the above criteria are met.[131] This process is repeated for each manufacturer present in the input fleet. It is then repeated for each model year. Once all MYs have been processed, the compliance simulation algorithm concludes.

The effective cost equations work with a set of rules that determine which technologies are available to be applied and in what quantity. These rules reflect real-world 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.[132] Phase-in caps work like a gate in allowing the application of certain technologies. For LD analysis only, manufacturers have a fine paying preference that allows the model to determine if it is more cost effective to pay fines or apply technology. Sharing of engines, transmissions, and platforms restricts technology application so that sharing cannot be broken except with certain electrification technologies. Some technologies might be skipped for specific vehicle types or manufacturers. These rules work together to allow the CAFE Model compliance simulation to better reflect manufacturer's technology application decisions. So-called "standard setting" years have additional rules relating to the application of certain electrification technologies including not allowing BEVs and only accounting for the gasoline fuel economy of PHEVs. The basis for these rules and more explanation is discussed in Chapter 2 of the TSD.

6.2. Compliance Example

To better demonstrate how the CAFE Model simulates manufacturer compliance with CAFE standards, we walk through a solution for a single manufacturer, recognizing that no simulation can precisely predict what a manufacturer will do to meet its compliance obligations and that the CAFE Model's modeled technology pathway is just one potential, cost-effective way that a manufacturer could meet CAFE standards. The example below examines Nissan's modeled fleet and the simulated compliance actions in the preferred alternative (Alternative PC2LT002). This example illustrates different CAFE Model features intended to reasonably simulate manufacturer-decision making, given a full set of assumptions about technology costs and effectiveness (among others), as well as the statutory constraints on technology options.

In MYs 2023-2026, Nissan faces requirements under 3 programs: NHTSA's CAFE program (with standards finalized in 2022 for MYs 2024-2026), EPA's GHG program through MY 2026, and CARB's ZEV program, which requires a particular number of ZEVs produced and sold in both California and so-called "Section 177" states that follow CARB's program.[133] These simultaneous frameworks interact to influence Nissan's decisions about how to increase the fuel efficiency of its various fleets, and the pace at which it must do so. For MYs 2027 and beyond, the CAFE Model considers requirements under NHTSA's Alternative PC2LT002 fuel economy standards, EPA's MY 2026 standards,[134] CARB's ZEV program, and the additional electric vehicles manufacturers have committed to deploy consistent with ACC II.

At the start of the simulation, in MY 2022, Nissan produces 13 unique engines shared across 19 unique nameplates, 56 model variants (that differ by nameplate, technology content, curb weight, footprint, or fuel economy), and 3 regulatory classes (domestic passenger cars (DPCs), imported passenger cars (IPC), and LT). The CAFE Model attempts to preserve the observed level of component sharing throughout the

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[129] This is only true for light-duty analysis as HDPUV does not consider paying fines over the application of technology.
[130] See the Market Data Input File for information about which manufactures are allowed to pay fines.
[131] See Chapter Two Section 5 of the CAFE Model Documentation for a full explanation of how the compliance simulation works. The criteria for adding technology can vary depeding on runtime settings and inputs.
[132] For a detailed description of the CAFE Model Input File please see the CAFE Model Documentation.
[133] The CAFE Model's handling of CARB's ZEV program components and use of ACC II as a proxy for additional non-regulatory electric vehicle deployment areis discussed in TSD Chapter 2.
[134] 88 FR 29236. 2023.Available at https://www.govinfo.gov/content/pkg/FR-2023-05-05/pdf/2023-07974.pdf. Accessed: Feb. 23, 2024). As discussed elsewhere, ACC II has not been granted a Clean Air Act preemption waiver and is not currently enforceable. However, NHTSA is using consistency with ACC II as a modeling proxy for the additional electric vehicles that automakers have committed to deploy.

simulation to avoid introducing additional production complexity for which we do not estimate additional cost. Seventeen transmissions and eight platforms are shared across the 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 model types 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 Nissan's portfolio as the simulated company attempts to comply with regulations, within the bounds of our model. 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 ICE improvements have occurred over the last decade, for manufacturers like Nissan, and starting from MY 2022, there are fewer such opportunities remaining in the model's technology tree given statutory constraints on technology that must be considered for NHTSA's rulemaking.

The following example follows the progression of the Nissan Pathfinder 4WD Platinum (Vehicle Code: 2214003), a Medium SUV in Nissan's Light Truck regulatory class, during Nissan's path towards achieving compliance with various regulatory requirements from MY 2022 through MY 2031. As shown in Table 6-1, the Pathfinder 4WD Platinum shares an engine (Engine Code: 223503) and transmission (Transmission Code: 222291) with the Nissan Pathfinder 4WD (Vehicle Code: 2214002) and Infiniti QX60 AWD (Vehicle Code: 2254002). While all these vehicles share a single engine (i.e., a 3.5L V6 with DOHC and SGDI) and a single transmission (i.e., AT9L2), the Pathfinder 4WD has the greatest sales volume within the group, and therefore serves as a candidate component leader for its engine and transmission — meaning that the engine and transmission adopt the redesign cadence of that specific Nissan Pathfinder variant in the CAFE Model. All other vehicles that share the Pathfinder 4WD's engine and/or transmission will inherit the improvement(s) from its upgraded engine and/or transmission. Vehicles that share the same refresh and/or redesign schedule as the Pathfinder 4WD's engine and/or transmission apply the improvement(s) during the same MY; vehicles that do not share the same schedule inherit the improvement(s) during their next refresh or redesign year.

In addition to two other Pathfinder model variants (Vehicle Codes: 2214001 and 2214002), the Pathfinder 4WD Platinum shares its platform (Platform Code: 221101) with some model variants of the Infiniti QX60 (Vehicle Codes: 2254001 and 2254002), Nissan Murano (Vehicle Codes: 2209001 and 2209002), Nissan Altima (Vehicle Codes: 2202001, 2202002, 2202003, 2202004, 2202005, and 2202006), and the Nissan Maxima (Vehicle Code: 2208001). The Nissan Altima SV/SL (Vehicle Code: 2202005) has the greatest sales volume within the group and is, therefore, the candidate component leader for its platform. As a result, upgrades to this platform will occur during the design cadence of the Nissan Altima SV/SL, with the Pathfinder 4WD Platinum inheriting those upgrades from the platform during future redesign years. As Table 6-1 shows, from MYs 2022 through 2031, the Murano and Maxima variants have the same redesign cadence (MYs 2024 and 2030), which differs from those of the Pathfinder, QX60, and Altima variants (MY 2028 for the Pathfinder variants, MY 2029 for the QX60 variants, and MYs 2025 and 2031 for the Altima variants).

Table 6-1: Nissan's Compliance Example for the Various Nissan and Infiniti Variants with Component Sharing

Brand	Model[135]	Regulatory Class	Vehicle Code	Platform Code	Engine Code	Transmission Code	MY 2022 Sales Volume	Candidate Component Leader	Redesign MYs	Refresh MYs
Nissan	Pathfinder 4WD Platinum	Light Truck	2214003	221101	223503	222291	9,819	N/A	2028	2026 and 2031
Nissan	Pathfinder 2WD	Light Truck	2214001	221101	223503	221291	38,345	Transmission	2028	2026 and 2031
Nissan	Pathfinder 4WD	Light Truck	2214002	221101	223503	222291	49,570	Engine and Transmission	2028	2026 and 2031
Infiniti	QX60 FWD	Light Truck	2254001	221101	223503	221291	12,707	N/A	2029	2026
Infiniti	QX60 AWD	Light Truck	2254002	221101	223503	222291	15,585	N/A	2029	2026
Nissan	Murano FWD	Domestic Car	2209001	221101	223502	221312	21,937	Transmission	2024 and 2030	2027
Nissan	Murano AWD	Domestic Car	2209002	221101	223502	222312	26,811	Engine and Transmission	2024 and 2030	2027
Nissan	Altima	Domestic Car	2202001	221101	222501	221311	22,462	N/A	2025 and 2031	2028
Nissan	Altima AWD	Domestic Car	2202002	221101	222501	222311	12,952	N/A	2025 and 2031	2028
Nissan	Altima AWD SR/Platinum	Domestic Car	2202003	221101	222501	222311	14,945	Transmission	2025 and 2031	2028
Nissan	Altima SR	Domestic Car	2202004	221101	222501	221311	27,806	N/A	2025 and 2031	2028
Nissan	Altima SV/SL	Domestic Car	2202005	221101	222501	221311	50,086	Platform, Engine, and Transmission	2025 and 2031	2028
Nissan	Altima SR	Domestic Car	2202006	221101	222011	221312	3,985	Engine	2025 and 2031	2028
Nissan	Maxima	Domestic Car	2208001	221101	223501	221312	13,050	Engine	2024 and 2030	2027

[135] "AWD" and "FWD" refer, respectively, to all wheel drive and front-wheel drive.

Table 6-2 through Table 6-6 present technology walks for the Pathfinder and QX60 variants in our example. The technology walks contain the technology key ("tech key"),[136] fuel economy target, and compliance fuel economy (via simulation) for each MY in our analysis. A tech key is a series of abbreviations that succinctly describe a vehicle's technology content for a particular MY. Differences in tech keys in successive MYs represent the CAFE Model applying higher levels of technology to comply with standards. Higher levels of technology can only be added to a vehicle in a redesign or refresh MY. For MYs in which a vehicle is not redesigned or refreshed, the CAFE Model simply carries forward its technology content from the previous MY. The light grey rows in the tables reflect MYs when the vehicle is eligible for a refresh and the dark grey rows are MYs when the vehicle is eligible for a redesign. In each technology walk, the fuel economy target increases as the stringency of the CAFE standard increases from MY 2022 through MY 2031. The compliance fuel economy of the Pathfinder and QX60 variants only change in MYs where a technology application occurs.

The Pathfinder 4WD's transmission is upgraded from an AT9L2 to an AT10L3 in MY 2026 (see Table 6-1) — its first opportunity to do so after MY 2022, which in this case is a "refresh" rather than a full redesign. The model applies the same transmission upgrade to the Pathfinder 4WD Platinum and Pathfinder 2WD in MY 2026. In addition to the upgraded transmission, all three Pathfinder model variants each receive an upgrade from ROLL10 to ROLL30 in MY 2026.[137] In the first and only MY that the Pathfinder model variants are eligible for a vehicle redesign during the compliance evaluation years (i.e., MY 2028), the CAFE Model upgrades the Pathfinder 4WD's engine from a DOHC with SGDI to an HCR. When the model upgrades the Pathfinder 4WD's engine, it applies the same engine improvement to the Pathfinder 2WD and a vehicle upgrade to the Pathfinder 4WD Platinum (see the next paragraph). In MY 2028, the model upgrades the Pathfinder 4WD Platinum from a MHEV (i.e., SS12V with DOHC and SGDI) to a SHEV (i.e., P2HCR) powertrain. During an upgrade from a MHEV to a SHEV, the CAFE Model removes the vehicle's engine and transmission and replaces them with alternate hybrid-specific versions. In this example, the Pathfinder 4WD Platinum's engine and transmission (i.e., DOHC with SGDI and AT10L3, respectively) are removed and replaced with an HCR engine and an AT8L2 transmission, which are then mated to a P2 hybrid system during its vehicle redesign in MY 2028. As a result, the Pathfinder 4WD Platinum does not inherit the engine upgrade in MY 2028 and will no longer be eligible to inherit an engine or transmission upgrade from its former assigned engine or transmission code during future redesign and refresh years.[138] Beginning with MY 2029, the Pathfinder variants are not eligible for additional redesign actions for the remainder of the analysis period. Similar to the Pathfinder 4WD Platinum, the QX60 model variants get upgraded from a MHEV (i.e., SS12V with DOHC and SGDI) to a SHEV (i.e., P2HCR) powertrain in the first MY it is eligible for a vehicle redesign (i.e., MY 2029), and will no longer be able to inherit an upgrade from its former engine or transmission.

Table 6-2: Technology Walk for the Pathfinder 4WD Platinum

Model Year	Tech Key	Fuel Economy - Target [mpg]	Fuel Economy - Compliance [mpg]
2022	DOHC; SGDI; AT9L2; SS12V; ROLL10; AERO10; MR2	32.4	30.1
2023	DOHC; SGDI; AT9L2; SS12V; ROLL10; AERO10; MR2	32.9	30.1
2024	DOHC; SGDI; AT9L2; SS12V; ROLL10; AERO10; MR2	35.8	30.1
2025	DOHC; SGDI; AT9L2; SS12V; ROLL10; AERO10; MR2	38.9	30.1
2026	DOHC; SGDI; AT10L3; SS12V; ROLL30; AERO10; MR2	43.2	33.1
2027	DOHC; SGDI; AT10L3; SS12V; ROLL30; AERO10; MR2	43.2	33.1
2028	P2HCR; ROLL30; AERO20; MR3	43.2	44.9
2029	P2HCR; ROLL30; AERO20; MR3	44.1	44.9

[136] A technology walk is a tabular representation of how a vehicle's technology (and other charateristics) progress over time.
[137] See CAFE Model Documentation Chapter Two Section 4 for additional details regarding the descriptions, application levels, and application schedules of the technologies available within the CAFE Model.
[138] This is a change in the CAFE Model's logic. See CAFE Model Documentation Chapter Two Section 4.4 for more information.

2030	P2HCR; ROLL30; AERO20; MR3	45.0	44.9
2031	P2HCR; ROLL30; AERO20; MR3	45.9	44.9

Table 6-3: Technology Walk for the Pathfinder 2WD

Model Year	Tech Key	Fuel Economy - Target [mpg]	Fuel Economy - Compliance [mpg]
2022	DOHC; SGDI; AT9L2; SS12V; ROLL10; AERO10; MR2	32.4	31.1
2023	DOHC; SGDI; AT9L2; SS12V; ROLL10; AERO10; MR2	32.9	31.1
2024	DOHC; SGDI; AT9L2; SS12V; ROLL10; AERO10; MR2	35.8	31.1
2025	DOHC; SGDI; AT9L2; SS12V; ROLL10; AERO10; MR2	38.9	31.1
2026	DOHC; SGDI; AT10L3; SS12V; ROLL30; AERO10; MR2	43.2	33.8
2027	DOHC; SGDI; AT10L3; SS12V; ROLL30; AERO10; MR2	43.2	33.8
2028	HCR; AT10L3; SS12V; ROLL30; AERO20; MR3	43.2	39.8
2029	HCR; AT10L3; SS12V; ROLL30; AERO20; MR3	44.1	39.8
2030	HCR; AT10L3; SS12V; ROLL30; AERO20; MR3	45.0	39.8
2031	HCR; AT10L3; SS12V; ROLL30; AERO20; MR3	45.9	39.8

Table 6-4: Technology Walk for the Pathfinder 4WD

Model Year	Tech Key	Fuel Economy - Target [mpg]	Fuel Economy - Compliance [mpg]
2022	DOHC; SGDI; AT9L2; SS12V; ROLL10; AERO10; MR2	32.4	31.0
2023	DOHC; SGDI; AT9L2; SS12V; ROLL10; AERO10; MR2	32.9	31.0
2024	DOHC; SGDI; AT9L2; SS12V; ROLL10; AERO10; MR2	35.8	31.0
2025	DOHC; SGDI; AT9L2; SS12V; ROLL10; AERO10; MR2	38.9	31.0
2026	DOHC; SGDI; AT10L3; SS12V; ROLL30; AERO10; MR2	43.2	34.1
2027	DOHC; SGDI; AT10L3; SS12V; ROLL30; AERO10; MR2	43.2	34.1
2028	HCR; AT10L3; SS12V; ROLL30; AERO20; MR3	43.2	39.5
2029	HCR; AT10L3; SS12V; ROLL30; AERO20; MR3	44.1	39.5
2030	HCR; AT10L3; SS12V; ROLL30; AERO20; MR3	45.0	39.5
2031	HCR; AT10L3; SS12V; ROLL30; AERO20; MR3	45.9	39.5

Table 6-5: Technology Walk for the QX60 FWD

Model Year	Tech Key	Fuel Economy - Target [mpg]	Fuel Economy - Compliance [mpg]
2022	DOHC; SGDI; AT9L2; SS12V; ROLL0; AERO10; MR2	32.4	30.6
2023	DOHC; SGDI; AT9L2; SS12V; ROLL0; AERO10; MR2	32.9	30.6

2024	DOHC; SGDI; AT9L2; SS12V; ROLL0; AERO10; MR2	35.8	30.6
2025	DOHC; SGDI; AT9L2; SS12V; ROLL0; AERO10; MR2	38.9	30.6
2026	DOHC; SGDI; AT10L3; SS12V; ROLL30; AERO10; MR2	43.2	34.0
2027	DOHC; SGDI; AT10L3; SS12V; ROLL30; AERO10; MR2	43.2	34.0
2028	DOHC; SGDI; AT10L3; SS12V; ROLL30; AERO10; MR2	43.2	34.0
2029	P2HCR; ROLL30; AERO20; MR3	44.1	46.4
2030	P2HCR; ROLL30; AERO20; MR3	45.0	46.4
2031	P2HCR; ROLL30; AERO20; MR3	45.9	46.4

Table 6-6: Technology Walk for the QX60 AWD

Model Year	Tech Key	Fuel Economy - Target [mpg]	Fuel Economy - Compliance [mpg]
2022	DOHC; SGDI; AT9L2; SS12V; ROLL0; AERO10; MR2	32.4	29.3
2023	DOHC; SGDI; AT9L2; SS12V; ROLL0; AERO10; MR2	32.9	29.3
2024	DOHC; SGDI; AT9L2; SS12V; ROLL0; AERO10; MR2	35.8	29.3
2025	DOHC; SGDI; AT9L2; SS12V; ROLL0; AERO10; MR2	38.9	29.3
2026	DOHC; SGDI; AT10L3; SS12V; ROLL30; AERO10; MR2	43.2	32.9
2027	DOHC; SGDI; AT10L3; SS12V; ROLL30; AERO10; MR2	43.2	32.9
2028	DOHC; SGDI; AT10L3; SS12V; ROLL30; AERO10; MR2	43.2	32.9
2029	P2HCR; ROLL30; AERO20; MR3	44.1	44.6
2030	P2HCR; ROLL30; AERO20; MR3	45.0	44.6
2031	P2HCR; ROLL30; AERO20; MR3	45.9	44.6

While no individual vehicle is required to exceed its fuel economy target for a manufacturer to achieve compliance, compliance fuel economy values not evolving as fast as fuel economy targets is just one factor manufacturers must consider during their multi-year planning. Because compliance with CAFE standards is determined at the fleet level for each regulatory category, the fuel economy performance of a single model type does not determine final compliance. All vehicles within a regulatory category contribute to its fuel economy performance. The poor performance of a single model type can be offset by the above average performance of one or more other vehicles in that regulatory category. For instance, in MY 2028, the Pathfinder 2WD's achieved fuel economy falls short of its target fuel economy. However, the Pathfinder 2WD's regulatory category (i.e., the LT regulatory category), exceeds its fuel economy standard and generates an ample number of credits (see Table 6-7).[139] This is due to other vehicles within the LT fleet, like the Pathfinder 4WD Platinum, that exceed their targets.

All vehicle-level technology application decisions occur in the larger context of fleet-level compliance — where the CAFE Model identifies least-cost solutions across the entire fleet to bring it into compliance. The example of Nissan's compliance in Alternative PC2LT002 (presented in greater detail in Table 6-7 for CAFE and Table 6-8 for GHG) illustrates the tradeoffs that the CAFE Model makes between applying technology to vehicles in a fleet in a specific MY (including the resulting effects across the product portfolio in future MYs), applying banked credits, transferring credits between fleets, and generating credits in a higher-performing fleet to assist another fleet that struggles to meet its standard. The meaning of "compliance" is also complicated by

[139] See CAFE Model Documentation for a discussion of how "Standard Setting" limitations restrict credit use for compliance in standard setting model years.

the fact that three frameworks – CAFE (MY 2022 final standards), GHG, and ZEV – and the additional non-regulatory ZEV deployment all operate simultaneously in MYs 2023-2031. As the example demonstrates, no one framework represents the binding constraint in all MYs.

The compliance simulation begins with Nissan's compliance status in MY 2022, in each fleet, for all frameworks, relative to the MY 2022 standards that were finalized in 2020. In this case, Nissan faces several binding constraints; however, the CAFE Model does not apply technology to the MY 2022 fleet, which 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 Nissan's case, there are existing CAFE and expiring GHG credits that can be transferred into its fleets and applied to its deficits. However, the application of these credits varies by framework.

In MY 2022, the achieved fuel economy values of Nissan's DPC and LT fleets are below their associated standards, which generates a credit deficit for each fleet. The model applies banked CAFE credits to the credit deficits earned in the DPC and LT fleets in MY 2022. However, approximately half of the initial credit deficit remains in the DPC fleet after the banked credits have been applied. The model then estimates a civil penalty representing the credit deficit remaining in the DPC fleet. In practice, it is more likely that Nissan will either apply non-expiring banked DPC credits, transfer and apply banked LT credits, or acquire and apply CAFE credits from another manufacturer to completely resolve the credit deficit in its DPC fleet. Unlike its DPC and LT fleets, Nissan's IPC fleet exceeds its standard in MY 2022 and generates credits, which the CAFE Model accrues for use in future years.

Under the GHG standards, Nissan's PC fleet (i.e., the union of its DPC and IPC fleets) and LT fleet are out of compliance with its standard in MY 2022. Nissan banked compliance credits, which the model applies to its PC and LT deficits in MY 2022 (652,000 total credits in the "Credits In" column in Table 6-8). The number of banked credits is not sufficient to resolve either deficit in MY 2022. As a result, Nissan would likely acquire GHG credits from another manufacturer to completely resolve the deficits. 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 MY in which they were earned. As such, Nissan can take expiring credits and push them into the PC or LT fleets in MY 2022. In this way, a manufacturer can renew expiring credits if a single fleet performs sufficiently better than its standard. In CAFE compliance, this is not the case. Because earned credits are tied to both a specific fleet and a specific MY, the credits must be used to offset deficits in the fleet in which they were earned (or 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 credit accounting regimes, while simulating compliance with the two programs simultaneously.

In the CAFE Program in MY 2023, Nissan's DPC fleet falls short of its standard while its IPC and LT fleets exceed theirs and generate credit surpluses. The model uses credits to resolve Nissan's MY 2023 DPC shortfall rather than paying a civil penalty. In the GHG Program in MY 2023, Nissan's PC fleet generates credits, but its LT fleet generates a credit deficit. The model applies the PC credits Nissan generates to its LT credit deficit; however, the number of credits is not sufficient to completely resolve the shortfall.

Table 6-7: Simulated CAFE Compliance (Alternative PC2LT002), Nissan[140]

Model Year	Regulatory Class	MDPCS [mpg]	Standard [mpg]	CAFE [mpg]	Civil Penalty	Credits Earned	Credits Out[141]	Credits In[142]
2022	Domestic Car	40.6	44.5	43.4	32,884,100	-4,686,825	0	2,346,000
2022	Imported Car	-	45.2	46.9	0	2,765,169	0	0
2022	Light Truck	-	32.9	32.6	0	-1,243,155	0	1,243,155

140 As disccused in the preamble, NHTSA rulemaking analysis doesn't allow credits transfers or trades between regulatory fleets in the standard setting analyses as directed by 49 U.S.C. 32902(h)(3).
141 "Credits Out" indicates excess credits that are used in for compliance in other model years.
142 "Credits In" indicates credit transfers used in that model year towards compliance. Note none are used during standard setting years due to modeling and statutory restrictions.

2023	Domestic Car	41.1	45.2	44.6	0	-2,607,996	0	2,607,996
2023	Imported Car	-	45.9	68.7	0	37,833,180	0	0
2023	Light Truck	-	33.4	35.6	0	9,777,614	7,537,885	0
2024	Domestic Car	44.3	49.1	49.1	0	0	0	0
2024	Imported Car	-	49.9	72.0	0	35,910,953	0	0
2024	Light Truck	-	36.3	36.8	0	2,231,540	0	0
2025	Domestic Car	48.1	53.4	54.7	0	5,123,599	0	0
2025	Imported Car	-	54.3	72.7	0	27,683,536	0	0
2025	Light Truck	-	39.5	39.5	0	0	0	0
2026	Domestic Car	53.5	59.3	62.2	0	11,350,571	0	0
2026	Imported Car	-	60.3	73.1	0	19,124,864	0	0
2026	Light Truck	-	43.9	42.2	0	-7,537,885	0	7,537,885
2027	Domestic Car	55.2	60.5	61.8	0	5,195,879	0	0
2027	Imported Car	-	61.5	70.8	0	14,189,754	0	0
2027	Light Truck	-	43.9	41.8	20,372,312	-9,629,571	0	0
2028	Domestic Car	56.3	61.8	61.1	43,191,031	-2,819,999	0	0
2028	Imported Car	-	62.8	69.1	0	9,688,644	0	0
2028	Light Truck	-	43.9	44.2	0	1,412,043	1,396,269	0
2029	Domestic Car	57.5	63.0	60.5	149,949,287	-10,005,100	0	0
2029	Imported Car	-	64.0	67.0	0	4,583,280	0	0
2029	Light Truck	-	44.8	44.9	0	471,742	0	0
2030	Domestic Car	58.6	64.3	64.5	0	788,422	0	0
2030	Imported Car	-	65.4	66.1	0	1,053,430	0	0
2030	Light Truck	-	45.7	46.7	0	4,648,620	0	0
2031	Domestic Car	59.8	65.6	66.7	0	4,280,540	0	0
2031	Imported Car	-	66.7	67.5	0	1,188,408	0	0
2031	Light Truck	-	46.6	47.4	0	3,671,416	0	0
2032	Domestic Car	58.6	64.3	64.5	0	788,422	0	0
2032	Imported Car	-	65.4	66.1	0	1,053,430	0	0
2032	Light Truck	-	45.7	46.7	0	4,648,620	0	0

In the CAFE Program in MY 2024, Nissan's DPC fleet meets its standard, while its IPC and LT fleets exceed their standard and generate credits that are banked for later use. Similar to MY 2023, Nissan's PC fleet generates a credit surplus, and its LT fleet generates a credit deficit in the GHG Program in MYs 2024 through 2029. The model once again applies the credits Nissan earns in its PC fleet to the shortfall it earns in its LT fleet. In each of these MYs except MY 2027, the credits earned in the PC fleet are sufficient to completely resolve the shortfall earned in the LT fleet.

In the CAFE Program in MY 2025, Nissan's DPC and IPC fleets generate CAFE credits, while its LT fleet meets its standard and does not generate credits. In MYs 2026 and 2027, Nissan's DPC and IPC generate CAFE credits, but its LT fleet falls short of its standard and generates a credit deficit. In MY 2026, the model applies credits to completely resolve the LT shortfall but in MY 2027, it resolves the deficit with a civil penalty. In MYs 2028 and 2029, Nissan's DPC fleet falls below its standard and generates a credit deficit. In contrast, Nissan's IPC and LT fleet exceed their standard and generates credit surpluses; the IPC credits remained banked, but the LT credits are moved to resolve a LT credit shortfall in a future MY. For the remainder of the analysis period, all three compliance categories exceed their standards and generate credits in the CAFE Program.

The CAFE Model attempts to use expiring credits to the fullest extent allowable but may allow some credits to expire. Since Nissan can achieve compliance via the application of cost-effective technology, and even over-comply by large margins in some cases, any credit balances available from prior years (or generated by the model during analysis) may end up expiring. On balance, Nissan's combined fleet exceeds its GHG constraint under Alternative PC2LT002, by either employing previously earned credits or through the benefits resulting from technology application. Starting with MY 2030, the simulation shows Nissan generating large CAFE and GHG credit surpluses, which are attributed to application of significant amounts of cost-effective technology to the fleet. As the ZEV columns in Table 6-8 illustrate, some of the improvements in Nissan's compliance position between MYs 2023 and 2031 are due to the increases in the ZEV targets, which result in Nissan producing additional BEVs.[143]

Table 6-8: Simulated GHG Compliance (Alternative PC2LT002), Nissan

Model Year	Regulatory Class	Standard [g/mi]	Rating [g/mi]	Credits Earned	Credits Out	Credits In	ZEV Target	ZEV Credits
2022	Passenger Car	180	187	-804,707	0	435,000		
2022	Light Truck	252	259	-655,165	0	217,000		
2022	TOTAL	210	217	-1,459,872	0	652,000	34,025	33,578
2023	Passenger Car	165	164	117,276	117,276	0		
2023	Light Truck	225	231	-602,297	0	117,276		
2023	TOTAL	191	192	-485,021	117,276	117,276	43,695	232,763
2024	Passenger Car	157	149	918,748	918,748	0		
2024	Light Truck	214	223	-907,248	0	907,248		
2024	TOTAL	182	181	11,500	918,748	907,248	49,614	275,107
2025	Passenger Car	148	135	1,382,372	1,382,372	11,500		
2025	Light Truck	199	205	-592,873	0	592,873		
2025	TOTAL	171	166	789,499	1,382,372	604,373	63,498	380,351
2026	Passenger Car	132	119	1,372,814	1,158,289	789,499		
2026	Light Truck	180	191	-1,101,646	0	1,101,646		
2026	TOTAL	154	151	271,168	1,158,289	1,891,145	49,785	151,081
2027	Passenger Car	132	121	1,186,204	1,242,847	56,643		
2027	Light Truck	180	192	-1,242,847	0	1,242,847		
2027	TOTAL	154	153	-56,643	1,242,847	1,299,490	94,600	154,848
2028	Passenger Car	132	124	869,542	425,241	0		
2028	Light Truck	180	183	-318,931	0	425,241		
2028	TOTAL	154	151	550,611	425,241	425,241	121,300	156,905
2029	Passenger Car	132	126	647,863	213,100	0		
2029	Light Truck	180	181	-106,550	0	213,100		
2029	TOTAL	154	151	541,313	213,100	213,100	148,035	156,288

[143] The application of ZEV compliance logic and how it is applied in conjunction with the CAFE and GHG logic is discussed in TSD Chapter 2.3.1.

2030	Passenger Car	132	120	1,276,326	0	0		
2030	Light Truck	180	173	734,972	0	0		
2030	TOTAL	154	144	2,011,298	0	0	177,431	177,452
2031	Passenger Car	132	117	1,574,875	0	0		
2031	Light Truck	180	172	829,244	0	0		
2031	TOTAL	154	142	2,404,119	0	0	206,066	206,087
2032	Passenger Car	132	119	1,372,814	1,158,289	789,499		
2032	Light Truck	180	191	-1,101,646	0	1,101,646		
2032	TOTAL	154	151	271,168	1,158,289	1,891,145	49,785	151,081

7. Simulating Consumers' Potential Responses and Related Impacts to Regulatory Alternatives

7.1. Impacts on Markets for New and Used Vehicles

Raising CAFE and fuel efficiency standards requires manufacturers to improve the fuel economy of some – and perhaps most – car, light truck, and HDPUV models, and by doing so increase manufacturers' costs to produce those vehicles. Together with the reductions in fuel consumption that stem from higher fuel economy, manufacturers' costs to improve fuel economy and efficiency are the initial source of all economic costs and benefits that ultimately result from imposing higher standards. This chapter outlines the process by which costs to increase vehicles' fuel economy and the accompanying reduction in their operational costs are transmitted through the markets for vehicles, driving, and fuel itself to generate various economic costs and benefits of alternative increases in CAFE and fuel efficiency standards.

New vehicles' purchase prices are likely to rise as manufacturers attempt to recover their costs for improving fuel economy and sustain their profitability. This will directly affect sales of new models, and indirectly affect the market value of used vehicles and the number of them kept in use. Imposing higher standards may also cause manufacturers to scale back or even forego planned improvements in vehicles' other features, as they attempt to comply with more demanding standards while minimizing any impact on prices, vehicle sales, and their overall profitability. The agency's analysis assumes that manufacturers will not compromise other attributes of models whose efficiency they improve, and instead will incur the incremental costs of technology necessary to meet higher standards without changing the other features those vehicles currently offer.[144] At the same time, however, they may choose to postpone, modify, or even completely forgo improvements in their models' other features that they would otherwise have made. To the extent new FE standards cause consumers to forego other vehicle attributes, the cost to the manufacturer to install those features and the revenues they generate are also reduced. Presumably, these features would have been added because the marginal revenue would have exceeded their marginal cost.

The economic impact of meeting higher CAFE and fuel efficiency standards includes losses in consumer welfare to would-be buyers of new vehicles who elect not to buy a new car as a result of the increased price, as well as losses to buyers who continue to purchase new vehicles at those higher prices (though they do receive some fuel savings in return). Under the agency's assumption that buyers consider only the first 30 months of fuel savings from purchasing higher-mpg models, those who still elect to purchase new cars value the fuel savings they experience at less than the increased prices they pay to buy those new models, and the difference between the two amounts to is a loss in welfare. This loss is partly offset, however, by any value buyers attach to fuel savings occurring *after* the agency's assumed 30-month "payback period" has elapsed; in fact, some of these buyers may actually value the fuel savings they experience at *more* than the increased prices they pay (and thus be better off).[145]

The welfare effects of setting higher standards also include any losses in manufacturers' profits ("producer surplus") stemming from their inability to raise their models selling prices sufficiently to recover increases in their production costs for meeting tougher standards. Without detailed models of manufacturers' costs to produce vehicles offering 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 magnitude of these costs.[146] Instead, the agency makes several simplifying assumptions that enable it to approximate the economic costs and benefits of imposing alternative CAFE and fuel efficiency standards for future model years.

[144] Gradual technological progress in vehicle design and production methods may enable manufacturers to improve vehicles' fuel economy slowly over time at no cost, thus reducing their incremental costs to meet higher targets, but the agency's analysis does not account for this potential effect and may thus overstate compliance costs slightly.
[145] The agency's economic evaluation of higher standards implicitly assumes that the typical buyer falls into this category, because it includes the fuel savings they experience over their new vehicles' *entire lifetimes* as a benefit from requiring higher fuel economy.
[146] Much of the information necessary to estimate cost increases, higher prices for specific models, and changes in their sales is closely held by manufacturers and not publicly available.

First, we assume that vehicle manufacturers will be able to recover their full incremental costs for producing vehicles that meet higher fuel economy and fuel efficiency targets by raising selling prices for at least some new vehicles. The agency does not attempt to estimate price increases for specific car, light trucks, or HDPUV 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 targets, or to value welfare losses to buyers resulting from any sacrifices in those other features that producers make to meet more demanding standards. For such welfare losses to occur, some buyers must be unwilling to pay the increased prices that would be necessary to compensate manufacturers for the cost to improve those attributes (some buyers, for example, may have budgetary constraints), or the technology that would have been employed to improve those attributes must have been redeployed to improve fuel economy. As described in Chapter 2.1.4, economic evidence on the extent of these conditions is mixed. We hold performance constant in order to focus our analysis on manufacturers' direct monetary costs for complying with stricter standards and the consequences of the resulting increases in prices for new vehicles.

Nor does NHTSA's analysis account for increases in the fuel economy of future vehicles that may occur as a result of unforeseen innovations in vehicle technology that would be adopted even if CAFE standards remained unchanged.[147] Nevertheless, it does assume that learning effects reduce the costs of existing technology and enable gradual improvement in fuel economy under the baseline alternative, because those cost reductions will broaden the range of technologies that repay their initial costs within the 30-month payback period buyers are assumed to demand. In addition, the agency accounts for fuel economy improvements manufacturers would voluntarily make in response to increasing fuel prices, to meet vehicle buyers' resulting demands for higher fuel economy.

Manufacturers' use of more advanced technology to improve fuel economy may also increase or decrease vehicle buyers' and owners' maintenance or repair expenses. Although some minor deterioration in vehicles' fuel economy as they age and accumulate use appears normal, owners must respond to unexpected deterioration by undertaking the maintenance or repairs necessary to preserve their expected savings in fuel costs.[148] On the other hand, BEVs may require lower maintenance costs than ICE vehicles, which would lower maintenance costs for these vehicles. Due to NHTSA's statutory constraints on considering the fuel economy of BEVs and the full fuel economy of PHEVs in determining maximum feasible CAFE standards, however, any reduction in maintenance and repair costs due to electrification would have a limited impact on NHTSA's analysis. Changes in the costs of maintenance and repairs to sustain vehicles' original fuel economy (and other capabilities) represent changes in the cost of requiring new vehicles to meet higher fuel efficiency targets, and while we do not attempt to estimate such expenses, doing so would increase our estimates of the costs of meeting higher standards.

The agency's analysis first assembles data on sales, prices, fuel economy, and other attributes of the car and light trucks models each manufacturer produced during model years 2022 (the "reference fleet"). It then projects reference baseline values of these variables for future MYs under the assumption that previously adopted standards would remain in effect, including fuel economy improvements that manufacturers would make to "catch up" with prevailing standards, to respond to increased market demand for fuel economy, or to take advantage of normal improvements in technology that enable higher fuel economy. Using this regulatory reference baseline, the agency's CAFE Model simulates the improvements in fuel economy each manufacturer could make to specific models in its reference fleet that would minimize its total incremental costs for complying with alternative increases in CAFE and fuel efficiency standards examined for future model years.

Because the regulatory reference baseline does not allow for fuel economy increases beyond those that would repay their costs in the form of reduced fuel expenses within the initial 30 months they are owned and driven, the agency may understate the adoption of fuel economy technologies by manufacturers into the reference fleet and therefore may overstate manufacturers' costs for improving the fuel economy of their

[147] We note, however, that our analysis does account for reductions in technology costs due to learning effects and the resulting increases in fuel economy.
[148] *See* Burnham, Andrew, Gohlke, David, Rush, Luke, Stephens, Thomas, Zhou, Yan, Delucchi, Mark A., Birky, Alicia, Hunter, Chad, Lin, Zhenhong, Ou, Shiqi, Xie, Fei, Proctor, Camron, Wiryadinata, Steven, Liu, Nawei, and Boloor, Madhur. Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains. United States: N. p., 2021. Web. doi:10.2172/1780970.

reference fleets to meet higher standards. At the same time, that reference baseline does not incorporate improvements in vehicles' other desirable attributes that normal technological progress would enable, so the agency's analysis fails to recognize any costs to buyers could result if for some reason—such as a technological constraint or a shift in profit maximization strategy--manufacturers delay or forego those improvements in their effort to meet higher standards. It is difficult to anticipate the net effect of these various omissions, but the agency's view is that on balance they are likely to have only modest effects on the true economic costs of meeting stricter standards.

7.1.1. Near-Term Effects in the Market for New Vehicles

This section describes how we estimate the effects of higher 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 agency believes that changes in prices and fuel economy resulting from manufacturers' efforts to comply with higher CAFE and fuel efficiency standards are likely to reduce total sales of new vehicles during future model years, because we assume that at the time they choose which models to purchase, buyers value the required improvements in fuel efficiency at less than manufacturers' costs to make them.

The logic underlying this assertion is simple: if manufacturers believed that potential buyers valued higher fuel efficiency (and adjusted their purchasing decisions accordingly) sufficiently that improving it while raising vehicle prices to cover their incremental costs would increase sales, they would do so even in the absence of higher standards, because their profits would rise. Conversely, the assumption that manufacturers would not voluntarily provide the improvements in fuel economy that even the least aggressive alternative considered would require suggests that they believe doing so would reduce their sales and profits.[149]

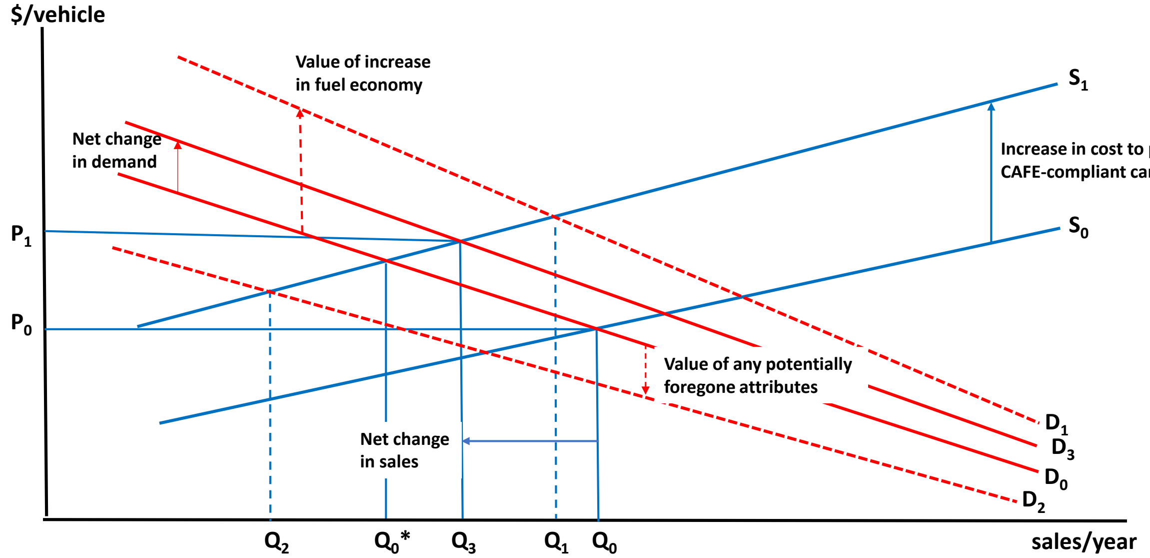
Admittedly, the relative importance of prices, fuel economy, and vehicles' other attributes to potential buyers at the time they consider purchasing a new model and subsequently as they own and drive it is not fully understood. Their relative importance is also likely to vary widely among consumers, so their combined effect on sales of new vehicles and the market shares of individual models is difficult to anticipate. The following paragraphs detail our approach to estimating changes in new car, light trucks, and HDPUV prices, the assumptions we use to anticipate the response of sales to higher prices, and their implications for consumer welfare.

Figure 7-1 illustrates the likely near-term effect of requiring higher efficiency on total sales of new models. Under the reference baseline scenario, total demand for new vehicles is shown by the demand curve D_0, which relates the number that will be purchased to their average selling price. The industry-wide supply curve – which depicts the number produced during a model year and offered for sale at each price – is shown by S_0 in the figure; in the reference baseline alternative (where standards remain at previously-established levels), 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 and fuel efficiency 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 seek to charge higher prices that reflect 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 Q_0*, where the original demand curve D_0 intersects the new supply curve S_1.

[149] Note that this could occur due to a variety of market failures, including short-termism among manufacturers, market power allowing manufacturers to focus on attributes that maximize their profits rather than those that would maximize consumer welfare, first-mover disadvantages among manufacturers with respect to experimenting with new fuel-efficiency technologies, as well as manufacturers' observation of consumer preferences as influenced by demand-side market failures and behaivoral biases.

Figure 7-1: Effect of Changes in Price, Fuel Economy, and Other Attributes on Demand and Sales of New Vehicles[150]



As indicated in the previous chapter, however, the fuel economy and potentially other features of some new models will also change, as their manufacturers employ more advanced technology to increase fuel efficiency but potentially forgo some improvements they would otherwise have made in those models' other desirable features. Both changes will affect consumer demand for new vehicles, and they are likely to do so in opposite directions. 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 7-1. Some fuel savings technologies may be attractive to consumers because they enhance performance or other valued attributes, which would further shift the demand curve upward. The specific form of the upward shift in demand shown in the figure – a larger upward shift at lower sales levels – reflects a presumed 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. This distribution would arise, for example, if buyers who intend to drive more were willing to pay more for models offering higher fuel economy, which seems likely.

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. At the same time, however, any accompanying sacrifice in improvements to other features that manufacturers make as part of their efforts to increase fuel efficiency could reduce new models' desirability to potential buyers; this would reduce market demand, as illustrated in Figure 7-1 by the downward shift in the demand curve to D_2.[151] In conjunction with higher prices that fully compensated manufacturers for their higher costs, the sacrifice in improvements to vehicles' other desirable features would reduce their sales to Q_2 if it were not accompanied by improved fuel efficiency.[152]

[150] Note that this graph represents the impacts from this final rule only does not show the impact of other policies such as the Inflation Reduction Act tax credits or California's ZEV program. To see how NHTSA has modeled these policies, please see TSD Chapter 2.
[151] Note that NHTSA does not include any estimate of the foregone value of other vehicle attributes in the primary analysis of light-duty fuel economy standards or the the primary analysis of the HDPUV fuel efficiency standards.
[152] NHTSA notes that some elements of performance are held constant across regulatory alternatives. Since we do not allow them to vary in response to changes in the standard, the CAFE Model does not provide a mechanism through which these tradeoffs can be directly analyzed. Thus it would be inappropriate for NHTSA to monetize any opportunity cost associated with those attributes. Similarly, there are other vehicle attributes that could trade off with fuel economies such as size, as heated seats, advanced entertainment systems, or panoramic sunroofs, which are amenities consumers value but are unrelated to the performance of the drivetrain (e.g. these attributes do not impact the engine's horsepower). Some of these attributes such as panoramic sunroofs are unlikely to to have a significant impact on fuel efficiency. It is possible that some consumers value a sunroof, for example, but do not pay both for the sunroof and for the fuel economy improvements. Modeling these attributes goes beyond the scope of the model and so we do not assign an opportunity cost associated with these potential tradeoffs in the primary analysis.

The net effect of these two changes on demand for new cars, light trucks, and HDPUVs 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 7-1 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 would decline to the level Q_3 shown in the figure, because the effect of higher prices would outweigh the increase in new vehicles' overall desirability.

More generally, sales of new vehicles will decline as long as some potential buyers find that the combination of higher prices and any improvements in vehicles' other features that they forgo outweighs the value they place on improved fuel efficiency and any ancillary improvements they may provide. The agency's assumption that buyers value only a fraction of the lifetime savings in fuel costs that purchasing a vehicle with higher fuel economy offers implies that this is the likely response even in the absence of any sacrifices in other attributes that buyers value. Our analysis assumes that increases in new car and light trucks prices become effective at the outset of the model year when higher standards take effect, and that the resulting decline in their sales occurs throughout the period when that model year is on sale (usually about two years, although a few new models sometimes remain unsold for longer).

7.1.2. Near-Term Effects on the Used Vehicle Market

By affecting the fuel economy, selling prices, and other features of new vehicles, raising CAFE and fuel efficiency standards will not only affect sales of new vehicle models, but will also change the demand for used vehicles. This is because used vehicles – especially those produced during recent model years – offer a close potential substitute for new models, so changes in prices and other attributes of new models will influence demand for used versions of similar models. This will affect the market value and selling prices of used vehicles of various ages – not just relatively new ones – and in turn this will influence some owners' decisions about whether to make the repairs necessary to keep their older used models in service and how much to drive them.

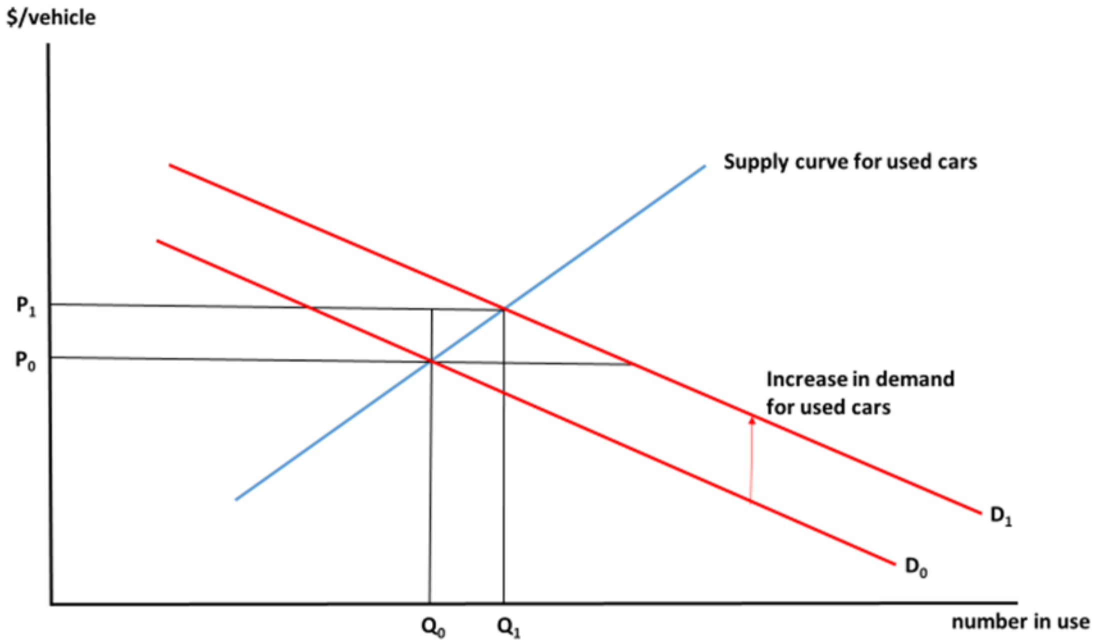
Regulations on new cars can also directly affect used vehicle durability and retirement rates over their lifetimes by changing their costs to repair and maintain and thus affecting their owners' decisions about how long to keep them in use. Changes in the number of used vehicles kept in service and how 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 standards will affect the number and use of older vehicles. The indirect effect of regulations that raise prices for new vehicles on the size and utilization of the used vehicle fleet has been well documented and is the subject of extensive empirical research; it is often referred to as the "Gruenspecht effect," after one of the earliest researchers to quantify its importance.[153]

Figure 7-2 illustrates the immediate effects of higher standards on the market for used cars, light trucks, and HDPUVs. Faced with higher prices for new models that feature improved fuel economy, some households and businesses will choose to rely on used cars or light trucks as an alternative to purchasing new ones. Their decisions to do so will increase demand for used vehicles, 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 vehicles 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. In contrast, the outdated features and accumulated usage of older vehicles make them less satisfactory substitutes, so their demand is likely to be less responsive to higher prices for new models. Thus, demand for nearly new vehicles is likely to increase when prices for new models rise, while increases in the demand for older vehicles are likely to be progressively smaller.

[153] This reference is to the author who originally identified and analyzed this effect; see Howard Gruenspecht. See Gruenspecht, Howard. 1982. "Differentiated Regulation: The Case of Auto Emissions Standards." American Economic Review 72 (2): 328–31.

Figure 7-2: Effect of Increasing CAFE Standards on the Market for Used Vehicles



In Figure 7-2 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 corresponding calendar year. Although the supply of used vehicles is likely to be relatively insensitive to changes in their price (or "inelastic"), it is not fixed. For example, owners can increase the number of vehicles 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 7-2, which reflects the fact that the repairs and maintenance necessary to increase the number of used vehicles in usable condition are likely to be progressively costlier as more owners who would otherwise have retired their vehicles decide instead to keep them in use.

The interaction of increased demand for used models and the upward sloping supply will cause their average market value and selling price to rise, from P_0 to P_1 in Figure 7-2. Some owners who would previously have retired their used vehicles will find that their higher market value justifies the expense of the added maintenance and repairs necessary to keep them in use longer, so the increase in their price will raise the number remaining in service, from Q_0 to Q_1. Because the market for used vehicles is very active – annual sales of used vehicles have averaged nearly 40 million in recent years, nearly three times the number of new models sold– these responses are likely to occur rapidly, probably within the same model year as those in the new car market shown previously in Figure 7-1. Upward shifts in demand and the resulting price increases are likely to be more pronounced for used vehicles produced during more recent model years, reflecting their closer substitutability for new models.

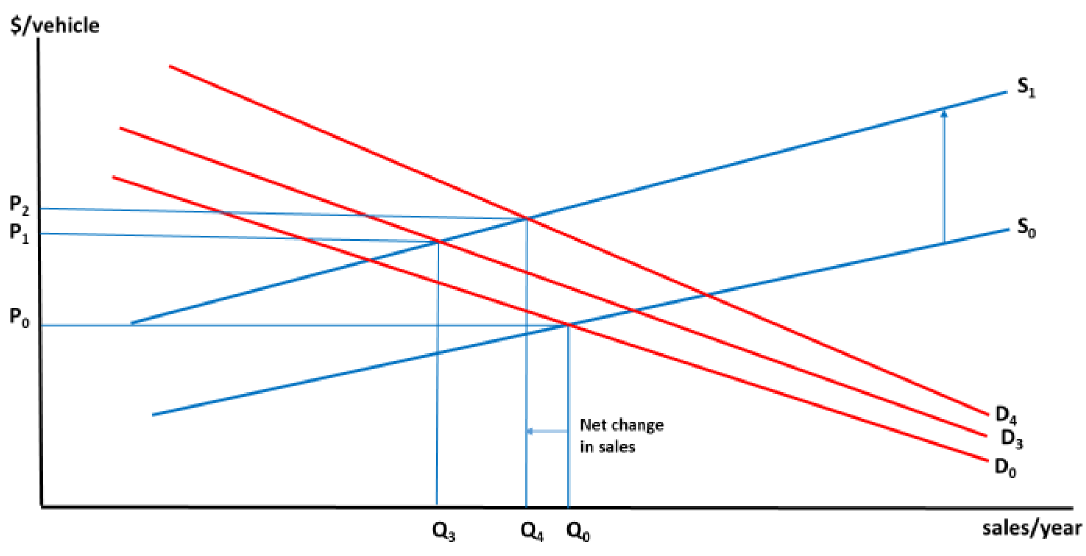
These indirect effects of raising CAFE and fuel efficiency standards on the used vehicle market will continue as long as those standards continue to be raised. In effect, this process will slow the "turnover" of the nation's vehicle fleet from its pace under the reference baseline, by reducing the rate at which models enter the fleet to replace the used vehicles that are retired each year. Coupled with the reduction in sales of new vehicles likely to result from raising standards, the resulting increase 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 producing and consuming fuel.

7.1.3. Longer-Term Effects on New and Used Vehicle Markets

Because new and used vehicles can substitute for each other in meeting households' and businesses' demands for transportation services, the change in used vehicle prices will have secondary effects in the markets for new cars, light trucks, and HDPUVS, as Figure 7-3 illustrates. Higher prices for used vehicles, despite having originally resulted from increased costs and prices for new models, will in turn increase demand for new models. This effect is shown in Figure 7-3 as a shift in demand for new vehicles outward from D_3, its final near-term position shown previously in Figure 7-1, to D_4 in Figure 7-3. In conjunction with the upward-shifted supply curve shown previously in Figure 7-1, which reflects manufacturers' increased costs to produce CAFE-compliant new cars and light trucks and new HDPUVs that meet higher standards for fuel efficiency, this secondary increase in demand raises their prices further from their ultimate level P_1 in Figure 7-1 to P_2 in Figure 7-3.

At the same time, this further outward shift in the demand curve for new vehicles mitigates the near-term decline in their sales at least partially; in Figure 7-3, new car and light trucks sales ultimately settle at Q_4, a level higher than their near-term equilibrium level Q_3 shown previously in Figure 7-1, although still lower than their reference baseline level Q_0. Thus, the longer-term effect of raising standards on sales of new vehicles 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 prices for new vehicles may be larger than the immediate effect, although the secondary increase in response to higher used car prices is likely to be modest compared to the primary effect from higher production costs, as Figure 7-3 suggests.

Figure 7-3: Longer Term Effects on Sales and Prices of New Vehicles



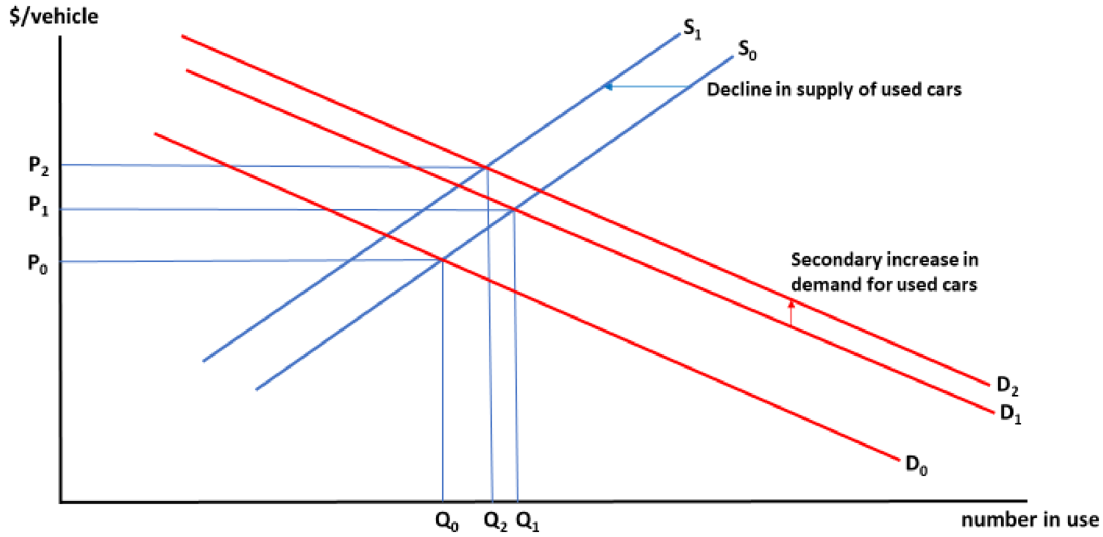
Finally, there are also likely to be important secondary impacts on the market for used vehicles. First, the secondary increase in prices for new vehicles will raise demand for their used counterparts, again because – within limits imposed by evolution in their design over time and the effects of accumulated 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 vehicles during the current model year reduces the supply of used models available in future years, as the current model year's newly-produced models subsequently enter the used vehicle market. The resulting reduction in the total supply of used vehicles of all ages will accumulate over time, particularly if CAFE and fuel efficiency standards are raised year after year as has recently been the case.

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 thus 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 more gradually over time.

Figure 7-4 illustrates these longer-term effects. The secondary increase in prices for new vehicles increases demand for used cars further relative to the near-term effect of higher new car prices, shifting the demand curve further outward from its previous position at D_1 in Figure 7-2 to D_2 in Figure 7-4. At the same time, the reduction in sales of new models reduces the supply of used versions available in future years, and this effect – which accumulates over time, as noted above – is represented in Figure 7-4 as an inward shift in the supply curve for used vehicles, from S_0 to S_1. Increased demand and reduced supply of used vehicles interact to raise their average price further beyond its near-term increase to P_1 shown previously in Figure 7-2, to the higher level P_2 in Figure 7-4.

In response to this secondary 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 7-4 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). However, the more certain – and more important –effect is that the final equilibrium size of the used vehicle fleet (Q_2 in Figure 7-4) is larger than it would have been if CAFE and fuel efficiency standards were not raised and instead remained at their reference baseline levels (Q_0).

Figure 7-4: Longer Term Effects on Prices for Used Vehicles and the Number Remaining in Use



In theory, these reciprocal responses of new-car 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 vehicle prices and sales should be largely complete within the same model year when higher standards take effect. However, the complete effects on prices and sales of used vehicles shown in Figure 7-4 are likely to require considerably longer to be fully felt, because as indicated, they depend in part on the longer-term cumulative effect of lower new vehicle sales on the supply of used models.[154]

7.1.3.1. Estimating Impacts in the New and Used Vehicle Markets

We use an econometric model that captures the historical relationship of new car and light trucks sales to the number of U.S. households, disposable personal income, and other economic variables to project future sales of new vehicles under the reference baseline alternative. To estimate the effect of increased costs to produce new vehicles and the resulting higher prices when CAFE standards for future model years are raised, NHTSA applies a price elasticity of new vehicle sales of -0.4, which implies that for example, a 10 percent increase in new vehicles' average price causes a 4 percent decline in their total sales.[155]

The agency estimates the shares of future sales accounted for by cars and light trucks by incorporating EIA's fleet share projection in the reference baseline alternative and adjusting those reference baseline shares under each regulatory alternative it considers. Those adjustments are based on relative changes in regulatory costs for cars and light-trucks between the No-Action Alternative and each regulatory alternative. Finally, NHTSA uses a combination of historic compliance data, EIA's forecast of HDPUV sales reported in that agency's 2023 AEO, and, like LDVs, the change in regulatory costs across alternatives to model HDPUV sales for this analysis. Development and use of these forecasts are described in detail in Chapter 4.2 of the TSD accompanying this final rule.

To estimate the effects of raising new vehicle standards on the used vehicle fleet, we use a detailed econometric model relating prices, fuel economy, and other characteristics of new vehicles to age-specific retirement rates for each vintage of used vehicles making up the current year's 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.

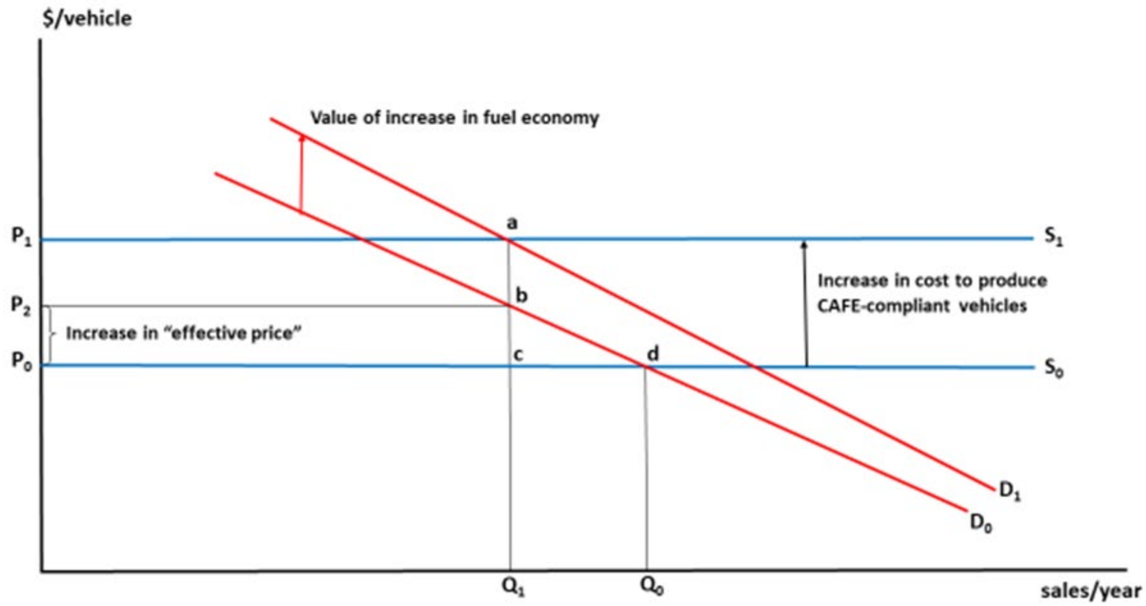
7.1.4. Welfare Effects in the New and Used Vehicle Markets

The likely decline in sales of new vehicles during future model years when stricter CAFE and fuel efficiency standards take effect produces two potential sources of economic costs. Figure 7-5 illustrates these costs for the simplified case where demand for new vehicles 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. 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 thus 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 7-5 shows, as the discussion accompanying Figure 7-1 above indicated. On the other hand, 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 less than perfectly elastic supply of new vehicles, manufacturers would absorb some of their increased costs to meet a stricter standard, so the increase in prices and resulting decline in sales would be slightly smaller than Figure 7-5 shows.[156]

[154] For more information on this effect, see Jacobsen, et al. 2021. The Effects of New-Vehicle Price Changes on New- and Used-Vehicle Markets and Scrappage. EPA-420-R-21-019. Washington, DC. Available at: https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=OTAQ&dirEntryId=352754. (Accessed: Feb. 23, 2024).
[155] This estimate is drawn from *ibid*., Chapter 7.
[156] Of course, in that case there would also be a reduction in producer surplus, which represents a welfare loss to manufacturers and those owning a financial interest in them. The sum of losses in consumer and producer surplus with varying elasticities of supply is slikely to be comparable to the loss in consumer surplus in the "perfect elaticity" case shown in Figure 7-5.

Figure 7-5: Welfare Effects in the Market for New Vehicles



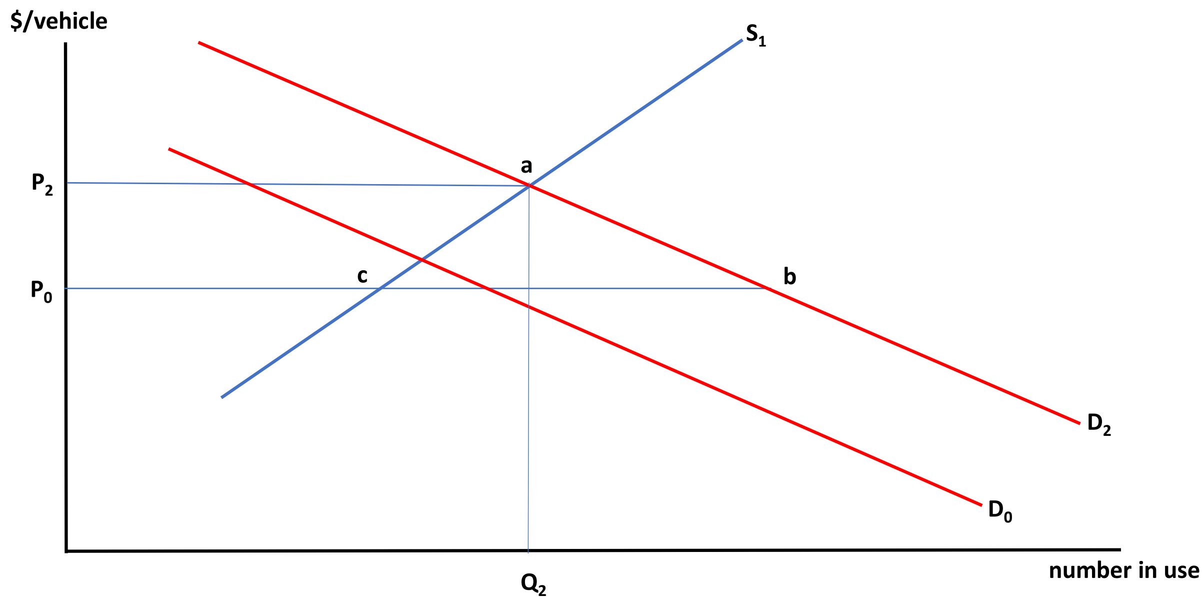
First, although buyers who continue to purchase new vehicles even at their increased price are likely to be those with the highest values of improved fuel economy, they nevertheless experience some loss in welfare from the combination of higher prices and improved fuel economy. Buyers' net loss in welfare is measured by their increased outlays to purchase Q_1 new vehicles, shown as rectangle P_1acP_0 in Figure 7-5 (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.

The value they collectively ascribe to their savings in fuel costs is the smaller rectangle P_1abP_2, whose area equals the marginal buyer's valuation of the improvement in fuel economy (the distance ab, or the upward shift in the demand curve at sales level Q_1) multiplied by the number of new vehicles that continue to be sold (Q_1). Together, these partly offsetting impacts leave net losses to continuing buyers equal to rectangle P_2bcP_0. 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, which again is rectangle P_2bcP_0.

Second, some buyers who would have purchased new vehicles under the reference baseline standard will decide not to do so once stricter CAFE and fuel efficiency standards take effect, and these buyers experience smaller losses in welfare, both individually and collectively. Their valuation of higher fuel economy is lower than those who continue to purchase new vehicles (it ranges from slightly to significantly below that of continuing buyers, as the convergence between demand curves D_1 and D_0 in the figure suggests), and consequently the increase in average prices deters their purchases and reduces the number sold from Q_1 to Q_0. The individual welfare loss to buyers who forego purchases they would otherwise make because of new vehicles' higher "effective price" averages one-half of those to continuing buyers of new vehicles, or $\frac{1}{2}*(P_2-P_0)$, and the collective loss is represented by triangle bcd in Figure 7-5.

The previously discussed consequences of higher standards in the used vehicle market 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 7-6 below (a simplified version of the previous Figure 7-4, omitting the initial supply curve S_0 and the intermediate demand curve D_1 shown in Figure 7-4 for simplicity) 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 7-6, which offsets much of the loss in consumer surplus to buyers; the remaining uncompensated loss in consumer surplus is the smaller 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. Because the agency lacks such detailed information, it has not attempted to estimate the dollar magnitude of this effect; doing so would reduce the net private and social benefits estimate to result from the standards this final rule establishes.

Figure 7-6: Welfare Effects in the Market for Used Vehicles



As discussed previously, however, the increase in used vehicle prices that creates these welfare effects in the used vehicle market also 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 (to position D_4) shown previously in Figure 7-3. 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.[157] 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 standards.

7.1.5. Safety Implications of Fleet Turnover

As manufacturers introduce new vehicles into the market, these vehicles are anticipated to include new safety technologies and designs that confer additional safety advantages relative to older vehicles. The increased application of Advanced Driver Assistance Systems (ADAS) technologies is a key example of this trend. Rulemaking also affects the safety of new vehicles, for example, NHTSA has recently proposed rules on Automatic Emergency Braking (AEB) and Pedestrian Automatic Emergency Braking (PAEB) effectiveness.

[157] Boardman, A., et al. 2001. Cost-Benefit Analsyis: Concepts and Practice. 2nd edition. Prentice Hall Inc. Upper Saddle River, NJ.; Mohring, H.. 1993. Maximizing, Measuring, and Not Double-Counting Transportation Improvement Benefits: A Primer on Closed- and Open-Economy Cost-Benefit Analysis. Chapter 5. *Transportation Research*. Vol. 27(6): pp. 413-24. Available at: https://www.sciencedirect.com/science/article/abs/pii/0191261593900142. (Accessed: Feb. 23, 2024).

These rules support the adoption and improve the effectiveness of these safety systems in new vehicles.[158,159]

The CAFE model simulates how OEMs respond to different standards and more stringent standards can result in OEMs applying more technologies to ensure simulated vehicles comply with CAFE standards. The application of these technologies increases the cost of new vehicles to consumers. As a result, some consumers forgo purchasing a new vehicle. These consumers might purchase a used vehicle or opt to continue driving their current vehicle instead. These older vehicles may lack the safety features of newer vehicles and thus have higher relative crash risks. In aggregate, more stringent CAFE standards slow vehicle turnover. Relative to less stringent standards, this reduction in vehicle turnover increases the prevalence of older vehicles and vehicles without new safety technologies in the fleet. This in turn affects the number and severity of crashes that occur.

7.2. The Effect of Higher Standards on Vehicle Use

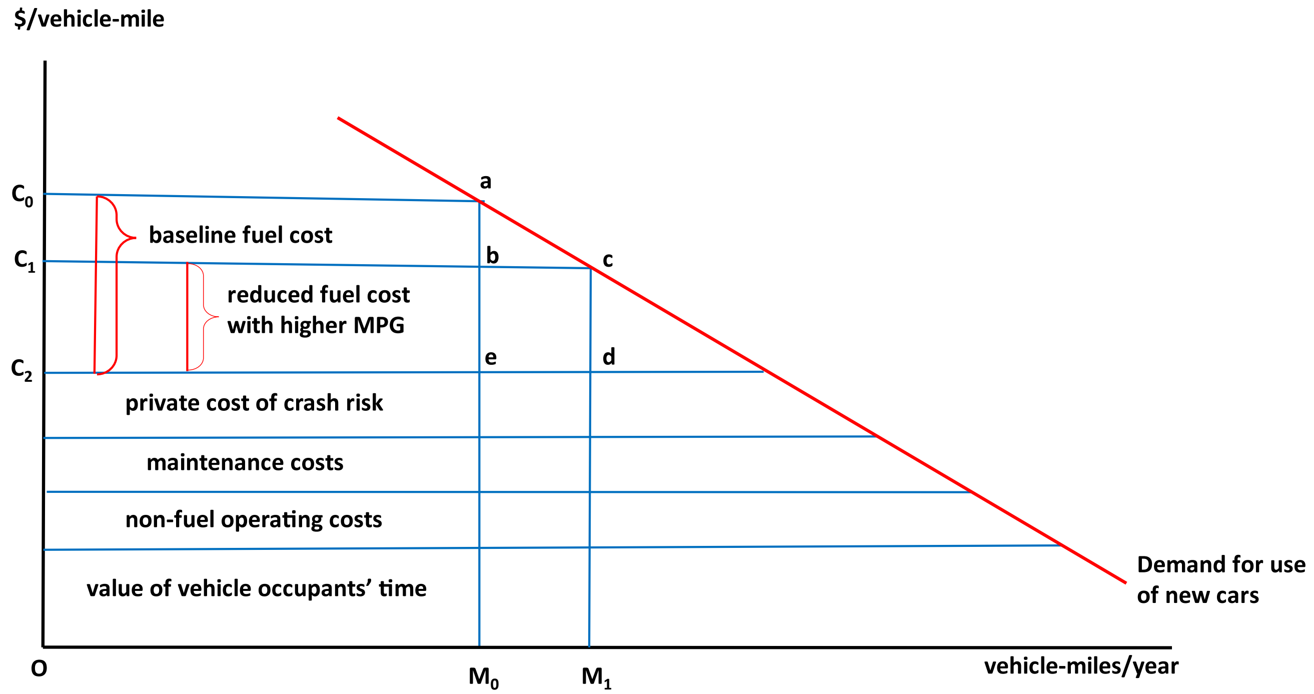
The fuel economy rebound effect – a specific example of the well-documented energy efficiency rebound effect for energy-consuming capital goods – refers to the tendency of motor vehicles' use to increase when their fuel economy is improved and the cost of driving each mile to decline as a result. Increasing CAFE and fuel efficiency standards will lead to higher fuel economy for new cars, light trucks, and HDPUVs, 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 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 a 10 percent increase in fuel economy will produce a 1 percent increase in average annual driving throughout vehicles' lifetimes. For more information see TSD Section 4.3.5.

7.2.1. The Fuel Economy Rebound Effect and Vehicle Use

Figure 7-7 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, operating costs other than fuel (oil, tire wear, etc.), maintenance and repair outlays, the expected cost associated with potential crashes, and the value of their occupants' travel time. The figure's vertical axis measures cost per mile driven, and C_2 represents the per-mile cost of driving excluding fuel costs. Cost C_0 indicates the total cost of driving each mile with the reference baseline fuel economy standards in effect, while C_1 shows the lower per-mile total cost of driving with higher standards in effect. Requiring new vehicles to achieve higher fuel economy or efficiency reduces the amount of fuel they consume each mile they are driven and lowers their per-mile fuel cost from (C_0-C_2) to (C_1-C_2), thus reducing 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. However, the decline in their driving costs leads to a downward movement along the demand curve for vehicle use, increasing the average number of miles that individuals choose to drive new cars and light trucks annually from M_0 to M_1.

158 Automatic Emergency Braking Systems for Light Vehicles: https://www.regulations.gov/docket/NHTSA-2023-0021. (Accessed: Jan. 17, 2024).
159 Heavy Vehicle Automatic Emergency Braking; AEB Test Devices https://www.regulations.gov/docket/NHTSA-2023-0023. (Accessed: Jan. 17, 2024).

Figure 7-7: Effect of Increasing CAFE Standards on New Vehicle Use



While this increase in driving offsets a small fraction of the fuel savings that would otherwise result, it also creates additional economic benefits (as well as a variety of indirect economic benefits and costs, which are discussed in subsequent chapters). Most important, vehicle buyers' annual outlays for fuel will decline throughout the lifetimes of the models they purchase, as raising standards leads to higher fuel economy levels for some new models and reduces their fuel consumption. The magnitude of this benefit depends on how much new vehicles' 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 the cost of fuel consumed by the additional driving (area bcde) and the savings in fuel costs on the amount of driving that would have been done under the baseline, measured by area C_0abC_1. Although Figure 7-7 is drawn to emphasize the reduction in fuel costs and the resulting increase in driving and thus makes it appear otherwise, area C_0abC_1 will be much larger than area bcde so the difference between them will be negative, indicating that on balance there will be a large net savings in total fuel consumption and costs.

The agency estimates the savings in new vehicles' annual fuel costs using improvements in the fuel economy of individual car, light trucks, and HDPUV models projected to result from raising CAFE and fuel efficiency standards, estimates of 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 AEO 2023. As indicated above, this savings declines over vehicles' lifetimes as they are driven progressively less and gradually retired from use, although their future annual use also varies in response to forecast changes in fuel prices. The savings in fuel costs for a new vehicle produced during each future model year required to meet higher CAFE and fuel efficiency standards will equal this same area during the year it is initially sold and decline similarly over its lifetime in the fleet.

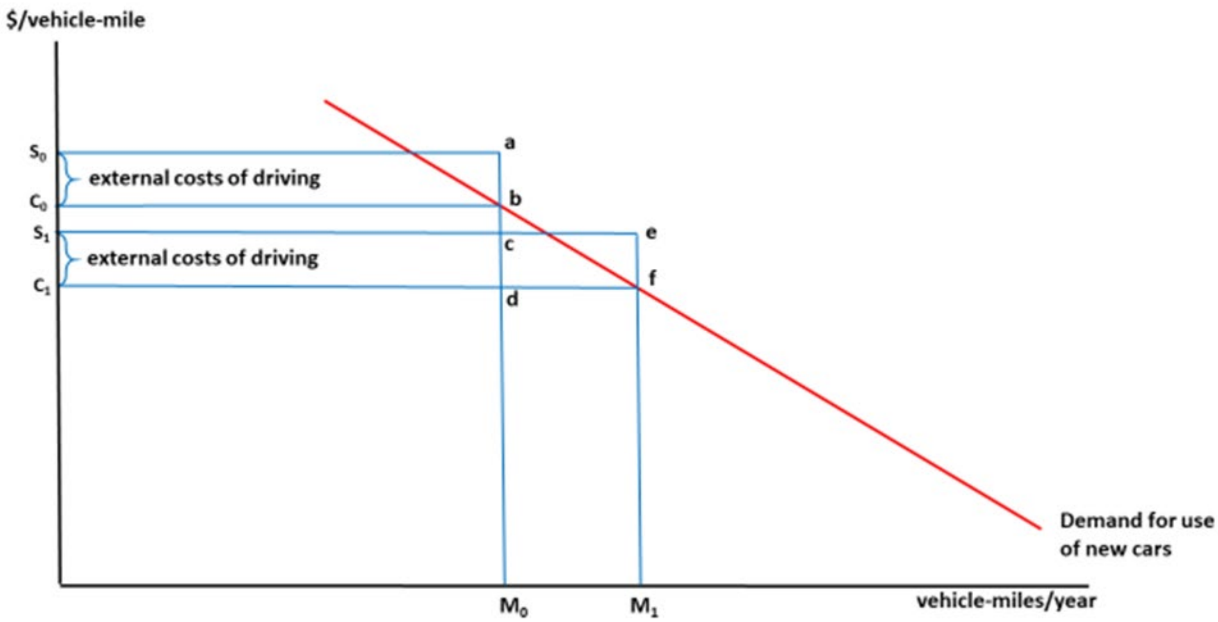
Second, the additional mobility associated with increased driving provides some benefits to new vehicle buyers. These benefits must be more than sufficient to offset the costs of their additional driving, including expenses for fuel, vehicle depreciation, other operating costs, maintenance, the value of travel time, and the increased safety risks they assume; if they were not, no additional driving would occur. In Figure 7-7, mobility benefits from increased driving are equal to the area M_0acM_1, which exceeds the total cost of the additional driving, measured by area M_0bcM_1. The amount by which they do, shown as the triangular area abc in Figure 7-7, measures the net benefit (or gain in "consumer surplus") to buyers of new vehicles trucks from their additional driving. Following the usual procedure, we estimate the dollar value of this welfare gain as one-half of the product of the decline in driving costs ($C_0 - C_1$) and the resulting increase in vehicle use ($M_1 - M_0$).

7.2.2. Externalities from Increased Rebound-Effect Driving

Additional vehicle use generates external costs via increased traffic congestion and roadway noise, more exposure to accident risks, adverse health effects from air pollution, and climate-related damages caused by emissions of GHGs. The increase in driving by buyers of new vehicles in response to their improved fuel economy can offset some of the health and climate benefits from lower fuel consumption and emissions, while also increasing traffic congestion and roadway noise. Although setting more stringent fuel economy standards will *on balance* reduce adverse health effects from air pollution and climate related damages caused by GHG emissions, the increases in these external costs caused by added rebound-effect driving represent additional costs of setting higher fuel economy targets that must be accounted for alongside their benefits.

Figure 7-8 illustrates how NHTSA estimates these costs; like the preceding figure, it shows the demand for travel using new vehicles 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 7-8 omits the detailed breakdown of total driving costs shown in the previous figure, 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. We assume that the per-mile value of these costs is unaffected by the change in vehicle use that occurs in response to improved fuel economy.

Figure 7-8: Externalities Caused by Increasing Use of New Vehicles



As in Figure 7-7 previously, Figure 7-8 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 total social costs associated with each mile driven, denoted S_0 and S_1. At the level of new vehicle use with the reference 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 7-8) and the initial level of vehicle use M_0, or the rectangular area S_0abC_0. With the increased driving that occurs when fuel economy increases (M_1 in Figure 7-8), 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 illustrates (that is, the distances S_1 - C_1 and S_0 - C_0 are equal), 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 ($S_1 – C_1$). 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 and fuel efficiency standards in effect, and the value of those costs if the reference baseline standards had remained in effect. It is a direct consequence of the additional driving estimated to result from the fuel economy rebound effect.

The agency's 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 standards, since this net reduction reflects the decline in fuel production and use after accounting for the additional fuel consumed by increased driving. Increases in emissions of criteria air pollutants are calculated from the increased number of miles driven in new cars, light trucks, and HDPUVs, together with per-mile emission factors for future model year vehicles of these three types derived from EPA's Motor Vehicle Emission Simulator (MOVES) model. (which reflect previously adopted changes in future emission standards, but not changes still under consideration).

Increases in costs of congestion and road noise are calculated using incremental per-mile contributions of car and light trucks use to delays and noise originally estimated by the DOT's Federal Highway Administration and updated by NHTSA for this analysis. Finally, we assume that drivers consider only 90 percent of the added risk of injuries and property damage in crashes they impose when they elect to travel more, so 10 percent of the increase in these costs also represents an external cost of added rebound-effect driving.

7.3. Safety Implications of Higher Standards

In setting standards, there are secondary effects on vehicle safety resulting from changes in fuel economy. NHTSA, as a safety agency, has long considered the potential effects of CAFE standards on safety when establishing new CAFE standards. The safety consequences include all impacts from motor vehicle crashes, including fatalities, nonfatal injuries, and property damage.

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

1. Change in Vehicle Mass: Change in vehicle mass affects the prevalence of injuries and fatalities on roadways. Increases in vehicle mass might confer additional safety to vehicle occupants while also reducing safety for pedestrians, cyclists, and other vulnerable road users, as well as for road users with lower mass vehicles. Reductions in mass, which are one way of achieving better fuel efficiency, could have the opposite effect. The CAFE Model incorporates information on societal fatality rates for different vehicle classes within both the reference baseline and changes across alternatives. In turn, changes in fleet composition projected in the model – both within vehicle classes, through changes in mass, and across vehicle classes, through changes in the shares of the fleet comprised of each vehicle class – account for risk factors that change as vehicle and fleet composition change.
2. Impacts of Vehicle Prices on Fleet Turnover: ADAS reduce the frequency (and severity) of certain crash types. As manufacturers adopt these technologies and as the technologies improve, newer vehicle models confer additional safety benefits. Since standards could increase the price of vehicles, more stringent standards can slow the turnover of vehicles in the fleet and thus reduce the prevalence of ADAS technologies in the on-road vehicle fleet.
3. Increased Driving from Improved Fuel Economy (Rebound Effect): More stringent standards lower the marginal cost of operating a vehicle which may lead operators to drive additional miles because of increased fuel economy. The additional driving of new vehicles from this rebound effect translates into additional fatalities and injuries.[160]

[160] Chapter 7 of the TSD describes the modeling of future fatalities and injuries from a safety reference baseline, the modeling of specific ADAS technologies on safety, the modeling of the impact of weight reduction on safety, and the modeling of the impact of the rebound effect on safety.

The contribution of the three factors described above generate the differences in safety outcomes among regulatory alternatives.[161] The agency's analysis makes extensive efforts to allocate the differences in safety outcomes among these three factors. Fatalities expected during future years under each alternative are projected by deriving a fleet-wide fatality rate (fatalities per vehicle mile traveled) that incorporates the effects of differences in each of the three factors from reference baseline conditions and multiplying it by that alternative's expected VMT. Fatalities are converted into societal costs by multiplying the number of fatalities by DOT's recommended value of a statistical life (VSL), supplemented by other economic impacts that are excluded from the VSL measure.[162] VSL measures the social benefit from reducing the expected number of fatalities among a population by one (usually per year), and represents the total amount individuals making up that population would collectively be willing to pay to avoid the unexpected death of one of them.[163] In 2021 dollars, the estimated VSL applied in this analysis is $12.2 million.[164] Traffic injuries and property damage are also modeled directly using the same process and valued using the costs that are specific to each injury severity level.[165]

7.4. Effects of Higher Standards on Fuel Consumption

Raising standards for the fuel economy of new cars and light trucks and the fuel efficiency of HDPUVs will significantly reduce demand for transportation fuels. Because gasoline and diesel – which account for the vast bulk of energy consumed by these vehicles – are refined from petroleum, U.S. demand for petroleum will decline. Since the U.S. is now a net exporter of both crude petroleum and products refined from it, this will be reflected in some combination of reduced domestic petroleum production or fuel refining, and increased U.S. net exports of crude oil or domestically refined fuels. Extracting and transporting crude petroleum, refining it into fuel, and distributing fuel for retail sale produce additional emissions of criteria air pollutants and GHGs beyond those from vehicles' consumption of fuel, so any reduction in the domestic fuel consumption will generate additional benefits by reducing the climate and health damages those emissions cause. Finally, reduced spending for fuel by drivers of new vehicles will lower tax revenues to both Federal and state governments, which may impose additional costs to society because these revenues typically fund spending on transportation infrastructure or other programs, and this will offset part of those drivers' savings in retail outlays for fuel.

7.4.1. Impacts on Fuel Use and Spending

Imposing more stringent CAFE and fuel efficiency standards will reduce U.S. demand for petroleum-based transportation fuels, shown in Figure 7-9 as an inward shift in the U.S. demand curve for fuel from D_0 to D_1. Vehicles subject to the higher standards will save fuel throughout their lifetimes, and while added rebound-effect driving and the shift of some driving to used cars will partly offset this savings, on balance domestic demand for fuel will decline. The global supply of refined transportation fuels appears to be extremely "price-elastic" – that is, increasing production does not require higher-cost extraction or refining – so reducing domestic demand is not expected to lower fuel prices, as the figure indicates.[166] Because of lower demand, domestic fuel consumption will decline from G_0 to G_1 in Figure 7-9, and U.S. drivers' spending on fuel will be reduced by the rectangular area G_1beG_0. 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 $G_0 – G_1$.

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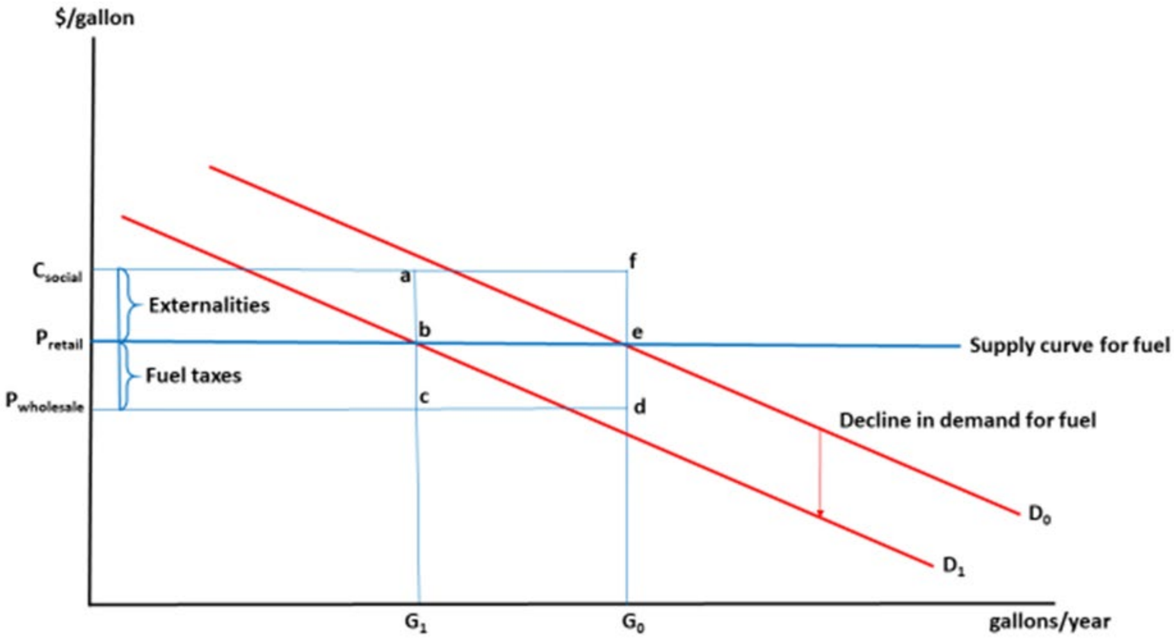
161 The terms "safety performance" and "safety outcome" represent different related concepts. "Safety performance" refers to intrinsic safety of a vehicle based on its design and features. "Safety outcome" describes whether a vehicle has been involved in a crash and the severity of the crash. Safety outcomes are influenced by safety performance, and other factors such as behavioral characteristics of vehicle operators or driving environment.
162 These economic impacts include medical costs, emergency medical service costs, market productivity losses, household productivity losses, workplace costs, insurance costs, legal costs, property damage costs, and congestion costs.
163 Department of Transportation. Department Guidance on Valuation of a Statistical Life in Economic Analysis. Available at: https://www.transportation.gov/office-policy/transportation-policy/revised-departmental-guidance-on-valuation-of-a-statistical-life-in-economic-analysis (Accessed: April 23, 2024).
164 Blincoe, L., et at. 2023. The economic and societal impact of motor vehicle crashes, 2019 (Revised) (Report No. DOT HS 813 403). National Highway Traffic Safety Administration.
165 For additional descriptions on the valuation of safety impacts please refer to Chapter 7.7 of the TSD.
166 This is admittedly a simplification, and in fact global prices may decline very slightly in response to lower U.S. demand. At present the U.S. is a modest net exporter of refined gasoline, on balance exporting about 0.25 million barrels/day, with this projected to grow to about 0.40 MMB/d by 2030. In contrast, the standards this Final Rule establishes are projected to reduce U.S. gasoline consumption by about 0.01 MMb/d over that same period, so any impact on the global price seems likely to be extremely modest. Thus the analysis presented in Figure 7-9 is likely to represent a close approximation to the Rule's actual effects on the domestic gasoline market.

Figure 7-9: Effect of Increasing CAFE Standards on Fuel Consumption and Spending



The agency's analysis measures savings in fuel spending by car, light trucks, and HDPUV owners using retail fuel prices, which include a significant tax component – Federal, state, Tribal, and some local governments impose taxes on gasoline and diesel that together average approximately $0.55 per gallon. Thus, some fraction of drivers' savings in fuel costs – shown as the rectangle bedc in Figure 7-9 – represents lower tax payments; their yearly dollar value is the product of average fuel taxes per gallon (P_{retail} – $P_{wholesale}$) and the decline in the number of gallons consumed annually (G_0 – G_1). However, the loss in benefits from marginally lower spending on programs funded from fuel tax revenue should be almost exactly offset by the part of drivers' savings in retail fuel costs that represents lower fuel tax payments, so on balance this revenue transfer leaves net social benefits from requiring higher fuel economy unaffected.

7.4.2. 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 vehicles' use of petroleum-derived fuels. By reducing the volume of fuel produced and consumed, adopting higher CAFE and fuel efficiency 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 air 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 efficiency.

In Figure 7-9, the economic cost of climate and health damage externalities is shown as the difference between the SC 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 thus the rectangular area labeled afeb 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. In turn, benefits from reduced costs of climate damages result from reduced global emissions of GHGs, while those from reduced health impacts stem from lower domestic emissions of criteria air pollutants.[167]

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 GHGs, Regulated Emissions, and Energy Use in Transportation (GREET) model and following procedures described in Chapter 5.2 of the TSD accompanying this final rule. As with GHG

[167] Following guidance in OMB Circular A-4 (2003), NHTSA's analysis includes the value of reductions in global climate-related damages, but only the value of lower domestic health damages resulting from the U.S. population's exposure to criteria air pollutants.

emissions from fuel use itself, the agency uses updated unit damage costs of GHG emissions recently developed and published by the U.S. Environmental Protection Agency to convert these reductions in global GHG emissions to economic benefits. These updated estimates of the damage costs of GHG emissions are described in Chapter 6.2 of the TSD, as well as in recent EPA documents.[168]

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. Although the U.S. population may also be exposed to criteria emissions from Canadian and Mexican fuel production, NHTSA does not attempt to estimate the value of reduced health impacts resulting from lower exposure to emissions originating outside the U.S. Health damage costs resulting from increased population exposure to harmful accumulations of criteria pollutants were obtained from recent EPA analyses; these costs differ between vehicle and upstream emissions, reflecting differences in their geographic dispersal, accumulation, and resulting population exposure. Detailed descriptions of the sources used to develop these inputs appear in Chapter 6.2.1 of the TSD.

7.4.3. 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.[169] This would reduce the transfer of revenue from consumers of petroleum products 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 economic benefit from raising U.S. CAFE standards. In the case where large oil producers (e.g., OPEC, Russia) can exercise market power to sustain global prices above competitive levels, a reduction in price caused by decreased U.S. oil consumption would also contribute to greater potential economic growth.

Reducing U.S. petroleum consumption via higher fuel economy will also reduce the exposure of U.S. consumers to the disruptive impacts of sudden increases in oil prices. If households and businesses that use petroleum products do not directly bear all of these shock-induced adjustment costs (that is, if they are partly "external" to petroleum consumers), reducing their consumption could provide additional benefits to the U.S. economy beyond reduced spending on petroleum products. 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, particularly as demand reductions from successive increases in fuel efficiency standards accumulate over time.

These three effects are usually referred to collectively as "energy security externalities" caused by U.S. petroleum consumption and reducing each of them is often cited as a potential economic benefit of lowering U.S. oil demand. Thus, each of these effects represents another potential benefit of adopting the more stringent CAFE and fuel efficiency standards analyzed here. 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 caused by sudden increases in petroleum prices, which U.S. consumers have experienced repeatedly in recent decades, represents a potentially significant and measurable economic benefit from tightening standards. We thus include estimated reductions in the external costs from petroleum consumption to measure the improvement in U.S. energy security from imposing stricter CAFE and fuel efficiency standards but exclude any reduction in revenue transfers from lower prices or savings in U.S. military spending.

[168] EPA. 2023. EPA Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances. National Center for Environmental Economics, Office of Policy, Climate Change Division, Office of Air and Radiation. Washington, DC. (hereinafter, "2023 EPA SC-GHG Report"). Available at: https://www.epa.gov/environmental-economics/scghg. (Accessed: February 23, 2024).
[169] As Figure 7-9 illustrates, this agency assumes that it will not, but recognizes that it is important to acknowledge this possibility.

8. Effects of Regulatory Alternatives for the LD and HDPUV Fleets

8.1. Overview

CAFE Model Files Referenced in this Chapter

Below is a list of CAFE Model Files referenced in this chapter. See TSD Chapter 2.1.9 Where to Find the Internal NHTSA Files? for a full list of files referenced in this document and their respective file locations.

- CAFE Model Documentation
- Parameters Input File
- CAFE Model Output File

Fuel economy and fuel efficiency standards produce wide-ranging effects in the vehicle market, society, and the environment, and NHTSA considers such impacts when making decisions about new standards. This final rule considers several regulatory alternatives for LDVs across MYs 2027 through 2031, and augural standards for MY 2032 and alternatives for HDPUV standards for MY 2030 and beyond. The CAFE Model explicitly estimates manufacturers' responses to each set of alternatives in each fleet and quantifies numerous effects of these alternatives throughout the lifetimes of vehicles in both the LD and HDPUV fleets. The analysis supporting this final rule should be interpreted not as a forecast, but rather as an assessment of impacts that could occur, reflecting, in some cases, best judgments regarding different and often uncertain factors. The light-duty fleet analysis is conducted subject to a set of constraints as outlined in EPCA/EISA. Those constraints include the prohibition of considering the fuel economy of dedicated alternative fuel vehicles (AFVs) when determining maximum feasible standards and a number of limitations on the transfer and use of compliance credits. These constraints are in place for the analysis discussed in this chapter and referred to as the central analysis. In addition to the results of the central analysis case discussed below, the agency conducted a sensitivity analysis to assess a variety of potential changes in key analytical inputs (e.g., fuel prices, macroeconomic forecasts, technology assumptions). This sensitivity analysis is presented in Chapter 9 of this FRIA.

This chapter describes the effects of each of the five LD and four HDPUV alternatives in relation to each fleet's No-Action Alternative scenario (described in detail in Chapter 3 of this FRIA and in Chapter 1.4 of the TSD). The discussion in this chapter is split into parts, first by fleet (i.e., LD and HDPUV), and then by the space the standards affect: (i) vehicle manufacturers, (ii) new vehicle buyers, (iii) society as a whole, and (iv) the physical environment. Effects for vehicle manufacturers include compliance outcomes (e.g., achieved average fuel economy and fuel efficiency levels), technology application choices, costs associated with technology adoption and compliance, and changes to sales and sector employment. Assessment of new car and truck buyer impacts include vehicle price changes, fuel savings, and other mobility-related benefits (i.e., consumer benefits from additional travel from reduced expenditure on fuel). 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. This final rule also directly affects the physical environment by altering overall vehicle use (e.g., vehicle miles traveled (VMT)) and fuel consumption, which, in turn, alter GHG emission quantities, and criteria pollutant and toxic air pollutant emission quantities.

As discussed in the TSD, the underlying CAFE Model explicitly accounts for each MY from 1983 to 2050, simulating fleet turnover and mileage accumulation until all 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). For CAFE standards, this final rule considers alternatives for each MY between 2027-2031, and augural standards for MY 2032. Therefore, many impacts are most meaningfully understood by considering the vehicles produced in those *model years*. 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 U.S. 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, this analysis presents most physical impacts on a *CY* basis—that is, showing projected total or incremental quantities through CY 2050, accounting for all vehicles projected in service in each CY (including vehicles produced during MYs 2033-2050). Because fuel efficiency standards for HDPUV vehicles remain in place until new standards are set, HDPUV market benefits and costs are reported on a CY basis (i.e., CYs 2022-2050).

Underlying CAFE Model Output Files are available (along with input files, model, source code, and documentation) on NHTSA's website.[170] A comprehensive appendix of detailed tables (e.g., results by manufacturer) is also available in Appendix I LDV Data Book for the LD fleet and Appendix III HDPUV Data Book for the HDPUV fleet.

An additional and more detailed analysis of the environmental impacts of the CAFE LD regulatory alternatives is provided for in the accompanying Final EIS. Results presented here for the CAFE standards differ slightly from those presented in the Final EIS. 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,[171] NEPA does not impose such constraints on analysis presented in corresponding EISs, and the Final EIS presents results of an "unconstrained" analysis that considers manufacturers' potential application of alternative fuels and use of CAFE credits. Detailed manufacturer and MY tables of results for the Final EIS are available in Appendix II EIS Data Book.

Throughout this chapter, 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 are applied to most social and private benefits and costs in the analysis, social costs of GHGs are discounted at rates selected by EPA in its SC-GHG report.[172] NHTSA presents non-GHG related impacts of the final rule discounted at three and seven percent alongside estimates of the SC-GHG valued at each of the discount rates included in the SC-GHG source document, providing additional useful information to decision-makers.

The agency's analysis showing our primary non-GHG impacts at three and seven percent alongside climate-related benefits discounted at each provided rate may be found in Chapter 8.2 for LD and Chapter 8.3 for the HDPUV analysis. For the sake of simplicity, most tables throughout this analysis pair both the three percent and the seven percent discount rates with a 2 percent value for SC-GHGs. The discount rates referenced in this chapter refer to the social discount rate applied to non-GHG cost streams. Unless otherwise noted, the compliance simulation portion of the LD analysis is limited to all MYs up to MY 2031; for tables and figures in this chapter, costs and benefits of the regulatory alternatives are reported in 2021 dollars and are associated with MYs 1983-2031 under the model year perspective unless otherwise noted, and CYs 2022-2050 under the CY perspective; and calculation of costs and benefits assume a 3 percent social discount rate and a 2 percent discount rate for climate-related benefits.

This chapter 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.

8.2. LD Fleet

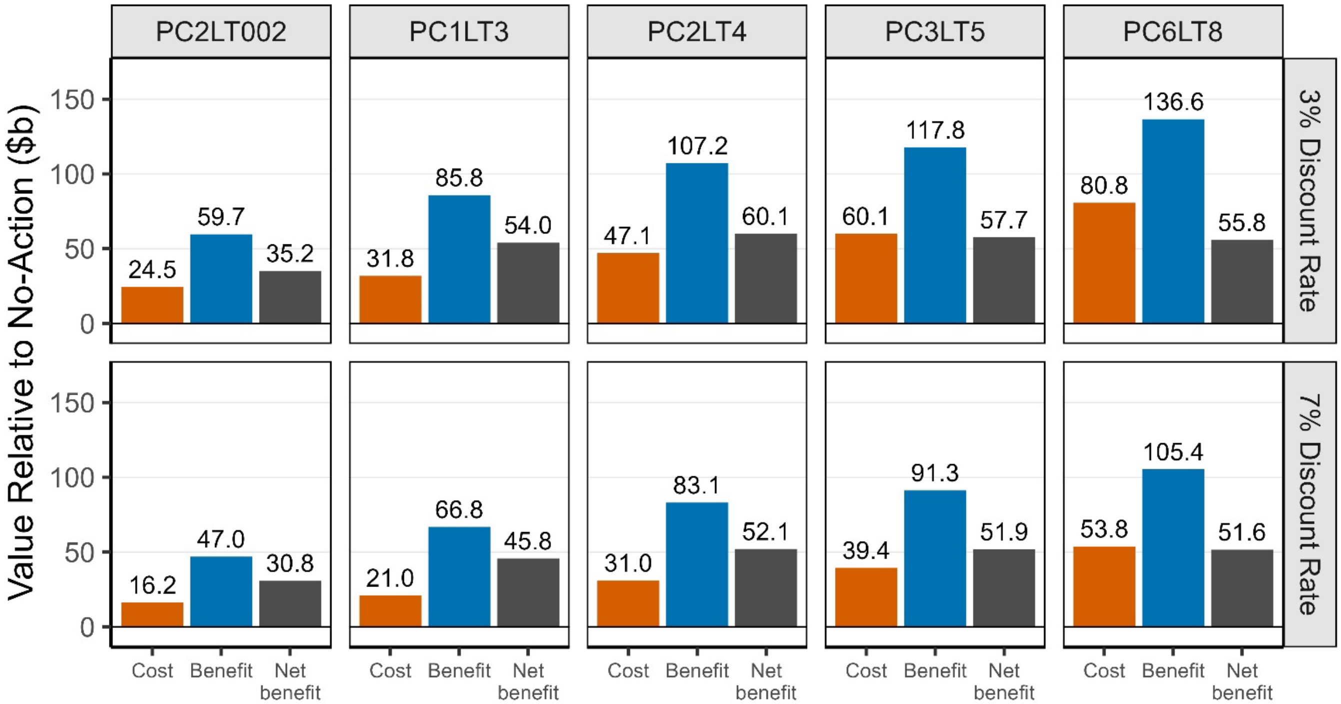
8.2.1. Summary of Benefits and Costs

To assess the effect of the 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. Figure 8-1 presents the outcome of this calculation for MYs 1983 through 2031 at both a three

[170] NHTSA. 2024. CAFE Compliance and Effects Modeling System: The Volpe Model. Last Revised: 2024. Available at: https://www.nhtsa.gov/corporate-average-fuel-economy/cafe-compliance-and-effects-modeling-system. (Accessed: Mar. 19, 2024).
[171] 49 U.S.C. 32902(h).
[172] 2023 EPA SC-GHG Report, avaliable at https://www.epa.gov/environmental-economics/scghg. For more details on the SC-GHG and discounting, please see preamble Section III.G.2.b.

and seven percent social discount rate.[173,174] Costs and benefits increase across alternatives, corresponding with increased stringency. Relative to the No-Action Alternative, program net benefits are positive across all alternatives.

Figure 8-1: Costs and Benefits for the LD Vehicle Fleet, MYs 1983-2031



Chapter 8.2.4 outlines the main categories of costs and benefits aggregated to produce Figure 8-1. 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 private benefit component; climate benefits from GHG reductions make up the largest external benefit category.

8.2.2. Effects on Vehicle Manufacturers

The CAFE Model produces industry-level achieved fuel economy values, as plotted in Figure 8-2 (all fleets) and Figure 8-3 (by regulatory class). These figures report achieved fuel economy relative to the estimated fuel economy targets across alternatives; the figures also include results showing the achieved levels computed that exclude adjustments of both AC and OC credits and the DOE-prescribed PEF.[175] For this analysis, to ensure that simulation of each action alternative begins from the same reference baseline, the CAFE Model copies the compliance result for the No-Action Alternative for model years prior to the first standard setting year. The result of this approach is displayed in Figure 8-2 and Figure 8-3; standards and achieved average fuel economy values are identical across all solutions for MYs 2022-2026. In these model years, manufacturers generally meet—and in some cases exceed—the standards with the PEF applied and AC/OC effects included. Initial over-compliance in these cases is driven in part by manufacturer redesign

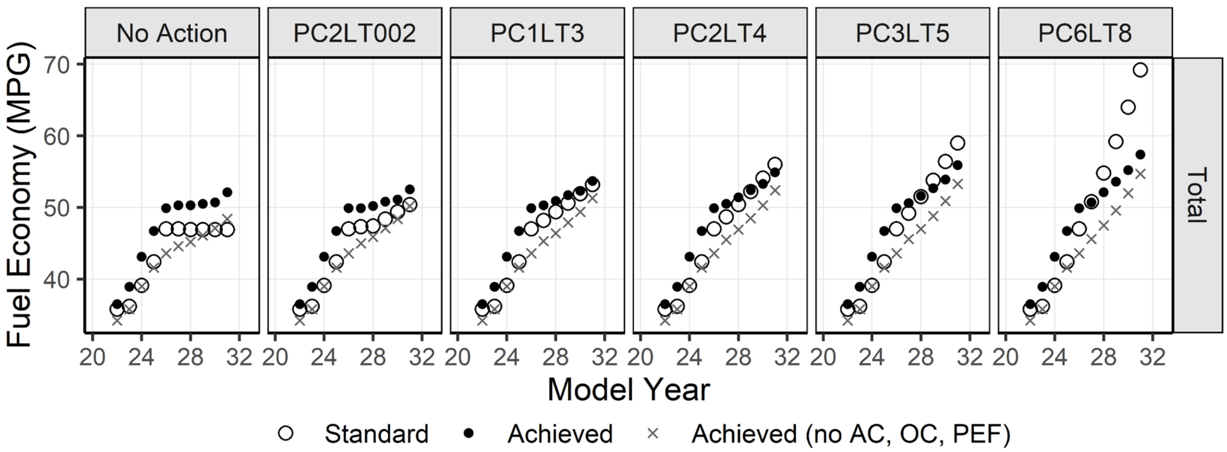
[173] The reporting includes vehicles as far back as MY 1983 because new CAFE standards can affect any vehicle in the on-road fleet – as one example, higher costs for new vehicles may lower their sales and shift VMT to older vehicles, with consequent effects on fuel consumed and pollution rates. After 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.
[174] Results are presented for SC-GHG discount rates of 2.0 percent. Benefit summaries for alternate SC-GHG discount rates are included in Chapter 8.2.4.1, Table 8-14.
[175] To calculate equivalent fuel economy for electric vehicles, a direct energy-based conversion is used with a value of 33,705 Wh/gal (the energy in a gallon of gasoline), a conversion factor used by EPA, in place of the DOE-prescibed PEF values. Figues 8-2 and 8-3 show the fleet modeled fuel economy achieved, excluding both AC/OC credits and the DOE-prescribed PEF. This achieved fuel economy is the CAFE 2-cycle value, measured using a a vehicle model's fuel economy prior to the PEF being applied, and is not used to measure compliance.

schedules and cost-based decisions regarding technology application. In practice, manufacturers may 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. The CAFE Model allows for such an approach, and this can drive some amount of overcompliance.[176]

Examining achieved and target efficiency levels by regulatory class, Figure 8-3 shows that the domestic car fleet consistently exceeds compliance targets across all scenarios, while the achieved fuel economy levels for the imported car fleet remain very close to each alternative's corresponding targets. The imported car fleet falls short of targets in the later model years under the most stringent alternative (PC6LT8). The LT fleet is in compliance under the No-Action and PC2LT002 alternatives. For each of the other action alternatives, the LT fleet's achieved fuel economy levels do not reach the targets in all model years, with shortfalls increasing along with stringency.

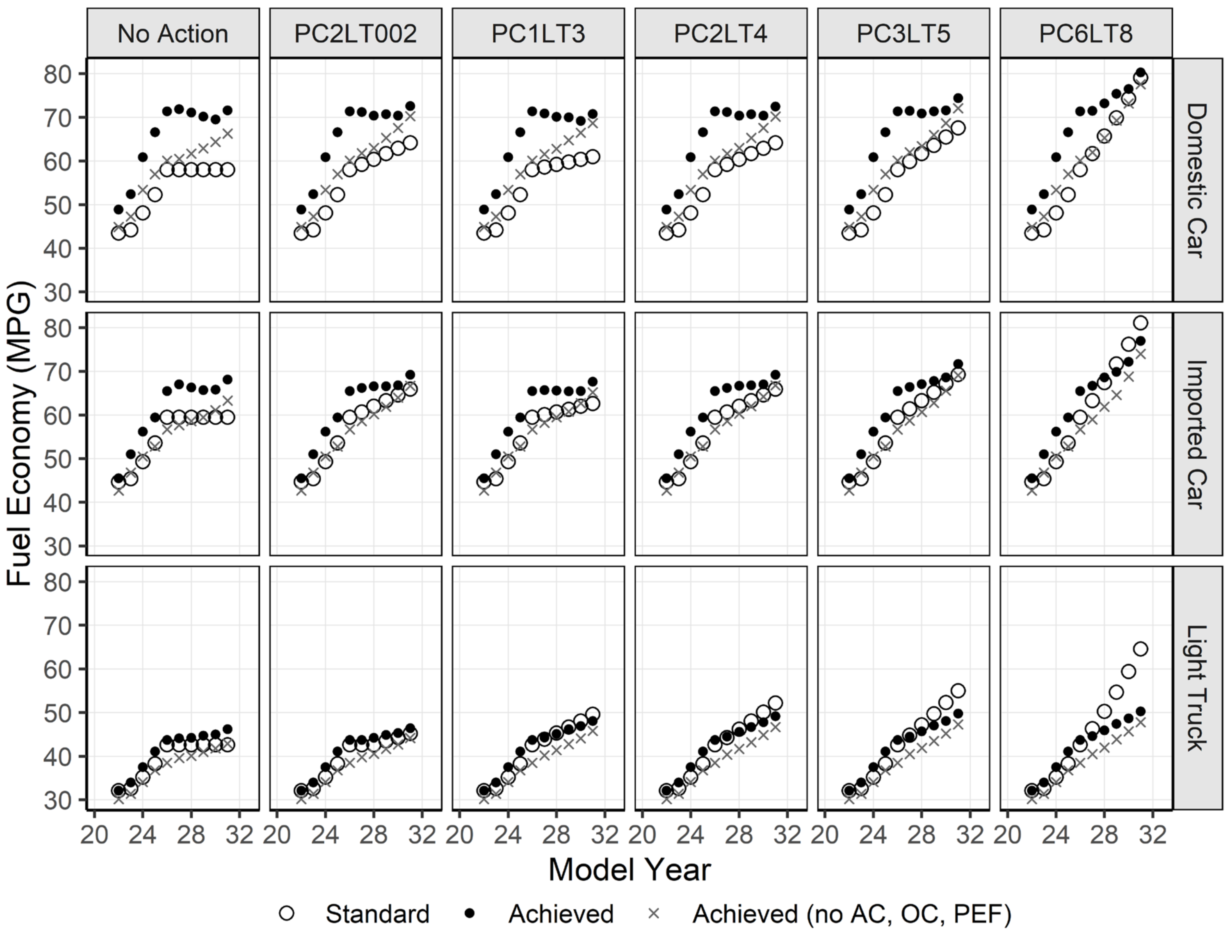
Some of the over-compliance observed in the fleets is the result of projected "inheritance" of technologies (e.g., changes to engines shared across multiple vehicle model/configurations) applied in earlier MYs, though other modeling elements, such as fuel prices, also play a role. As in past rulemakings over at least the last decade, NHTSA assumes that beyond fuel economy improvements necessitated by CAFE standards, EPA-GHG standards, and the ZEV/ACC I program, manufacturers could also apply fuel economy improvements that, given projected fuel prices, would pay for themselves within the first 30 months of vehicle operation. Further, NHTSA assumes that manufacturers will voluntarily deploy additional electric vehicles, which they have committed to do, modeled here using ACC II consistency as a proxy.

Figure 8-2: Fleet Modeled Fuel Economy



[176] The No-Action Alternative includes increasing standards through MY 2026 based on standards from the 2022 Final Rule. Standards for MY 2027 and beyond are then held fixed at MY 2026 levels. Because the model applies a multi-year planning algorithm, and allows manufacturers to "reach back" to prior model years (e.g., to take advantage of existing model refresh and redesign years), some overcompliance during the MY 2022-2026 period is the result of manufacturers' compliance actions in MYs beyond 2026. However, because standards are held constant at MY 2026 levels in the No-Action Alternative, and this solution is then carried over to all action alternatives, overcompliance across all alternatives in MYs 2022-2026 is not the result of anticipated stringency increases for any of the action alternatives. Note as well that the decision algorithm can only apply technology in anticipation of future changes in targets; it cannot delay compliance decisions in response to future technology price decreases or changes in compliance simulation constraints (e.g., removing limits on availability of vehicle electrification).

Figure 8-3: 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 8-4 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.[177] In practice, manufacturers do not have to meet their fuel economy targets exclusively through technology application to their vehicles in any given model year. Manufacturers may make up deficits between their target and achieved fuel economies through the use of over-compliance credits (by credit carry-forward, transfer, or trade subject to restrictions), all of which require fuel economy improvements at some point or by some manufacturers.[178] Manufacturers unable to comply even with these flexibilities are still nevertheless allowed to sell their vehicles without making up the shortfall. However, civil penalty payments would incur as a result, which leads to "costs" to the manufacturers (and presumably consumers) without attendant fuel economy improvements, though these effects are considered "transfers" for purposes of economic accounting. The vertical black line in the figure indicates MY 2027, the first period of the standards.

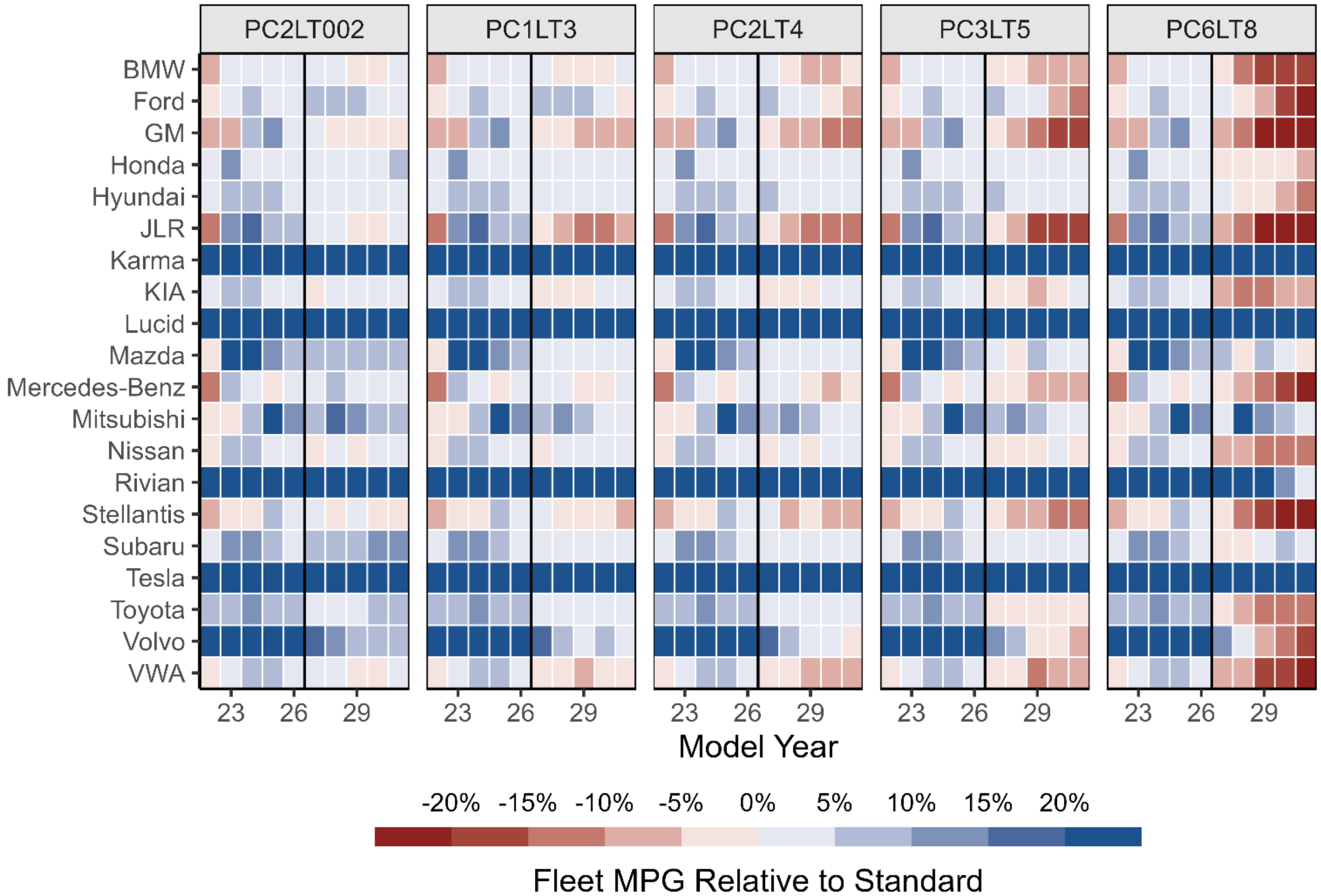
Figure 8-4 illustrates how all the manufacturers in the fleet comply with CAFE requirements. Unsurprisingly, manufacturers that exclusively produce BEVs exceed their regulatory requirements for each fleet in each alternative analyzed under this final rule (PC2LT002 through PC6LT8) for all years. Subaru meets all targets

[177] To preserve the color gradient in Figure 8-4 and Figure 8-5, compliance that exceeds standards by more than 20 percent (or falls short by more than 20 percent) falls into the highest (lowest) color category. Karma, Lucid, Rivian, and Tesla exceed the standards by a wide margin in all alternatives due to their BEV-only fleets; these manufacturers are excluded from Figure 8-5.

[178] Additional detail on alternative compliance flexibilities is included in Section VII.B.1 of the preamble. In the CAFE Modeling framework, the current approach to modeling over-compliance credits allows credit carry forward and credit transfers within a manufacturer but does not allow trades among manufacturers. These capabilities are disabled during standard-setting model years. For additional detail, see TSD Chapter 2.2.2.3. and the CAFE Model Documentation.

under all alternatives except for scenario PC6LT8, and the same is true for Toyota except for scenarios PC3LT5 and PC6LT8. Volvo initially over-complies, but overcompliance begins to decline shortly after MY 2027; this is especially true in the most stringent alternative, PC6LT8. Manufacturers such as Ford, Honda, Hyundai, Kia, Nissan, and Mazda always stay close to the regulatory line (sometimes above, sometimes below) for all the scenarios except under the most stringent alternative (PC6LT8). Jaguar Land Rover (JLR), Stellantis, and General Motors (GM) fall short of CAFE targets in many of the alternatives and time frames subject to the statutory constraints reflected in the reference baseline. In the PC2LT002 alternative the manufacturers that are projected to under-comply are only modestly below CAFE targets, with projected fleet MPGs measuring between 0 percent to 5 percent below the standard.

Figure 8-4: Modeled Fleet-Wide Achieved CAFE by Manufacturer



Within manufacturer fleets, there is heterogeneity in modeled response by regulatory class. Figure 8-5 separates achieved fuel economy levels by manufacturer and fleet and shows relative compliance in each alternative.[179] 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 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, can over-comply with its imported car fleet but struggles to comply with its light truck fleet. Hyundai over-complies to a significant extent with its domestic car fleet and, on-average, complies with its import car fleet and with light trucks. Toyota, Subaru, and Mazda show generally consistent performance across regulatory classes and stringency alternatives.

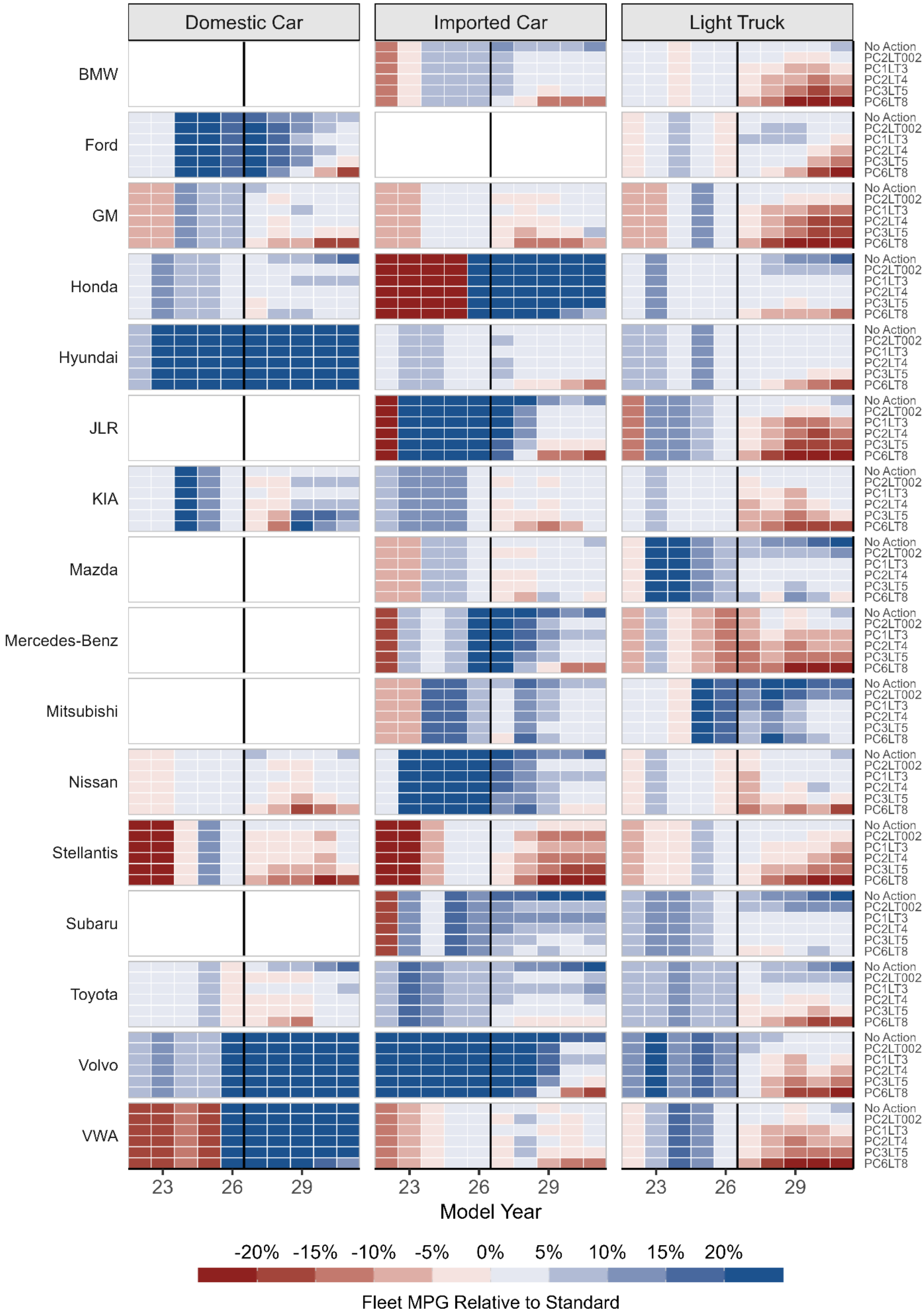
In some cases, in Figure 8-5, there is a significant change in the level of compliance in manufacturer fleets between MY 2026 and MY 2027. While some of this change may be due to increasing standards, the

[179] Note that the No-Action Alternative holds standards at the MY 2026 level in the absence of new regulation. In the No-Action Alternative, this figure measures compliance relative to that (flat) standard.

changes in compliance flexibilities, such as changes in the off-cycle program, and changes to the PEF value may have notable effects on manufacturers' computed compliance levels in the reference baseline.[180]

[180] The PEF is a scalar, expressed in Watt-hours per gallon, that converts energy use of an electric vehicle into a petroleum-equivalent value for purposes of calculating manufacturers' compliance with CAFE standards. DOE determines the PEF based on a set of statutory factors; see 89 FR 22041 for a full description of these factors and the subsequent PEF calculations. The average achieved fuel economy level includes BEVs for all years (that occur in the fleet for reasons other than CAFE standards) and PHEVs for standard-setting years (standard setting years include PHEV gasoline operation only). For additional discussion on the use of the PEF in the CAFE analysis, see Chapter 2, Section 5 of the CAFE Model Documentation. See Chapter 9.2.5.4 of this document for model results under an alternative PEF scenario that retains the value used in the 2022 Final Rule. See Section VII of the preamble for a discussion on the changes in the Off-Cycle and AC Efficiency program and see AC/OC sensitivity runs in Chapter 9.2.2.3 of this FRIA.

Figure 8-5: Modeled Achieved CAFE Levels by Manufacturer and Regulatory Class



8.2.2.1. Technology Application

To meet the required CAFE standards 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 8-6, the quantity of technology application varies across action alternatives with higher stringency alternatives seeing more fuel economy technology applied in the earlier years of the analysis [181] Some technology changes occur after the period of increasing fuel economy targets as the model continues to apply cost effective technologies to the fleet and considers the constraints of manufacturer redesign schedules.[182] In particular, starting in MY 2037, higher stringency no longer correlates with the quantity of technology application changes. In this time frame across stringencies, there is an increase in BEV and AERO20 technology penetration in the reference baseline as the cost of these technologies decrease relative to their predecessors and the technology changes are due to these shifting costs, rather than due to a path of compliance.[183]

Figure 8-6: Timing of Technology Application in Response to Regulatory Alternatives

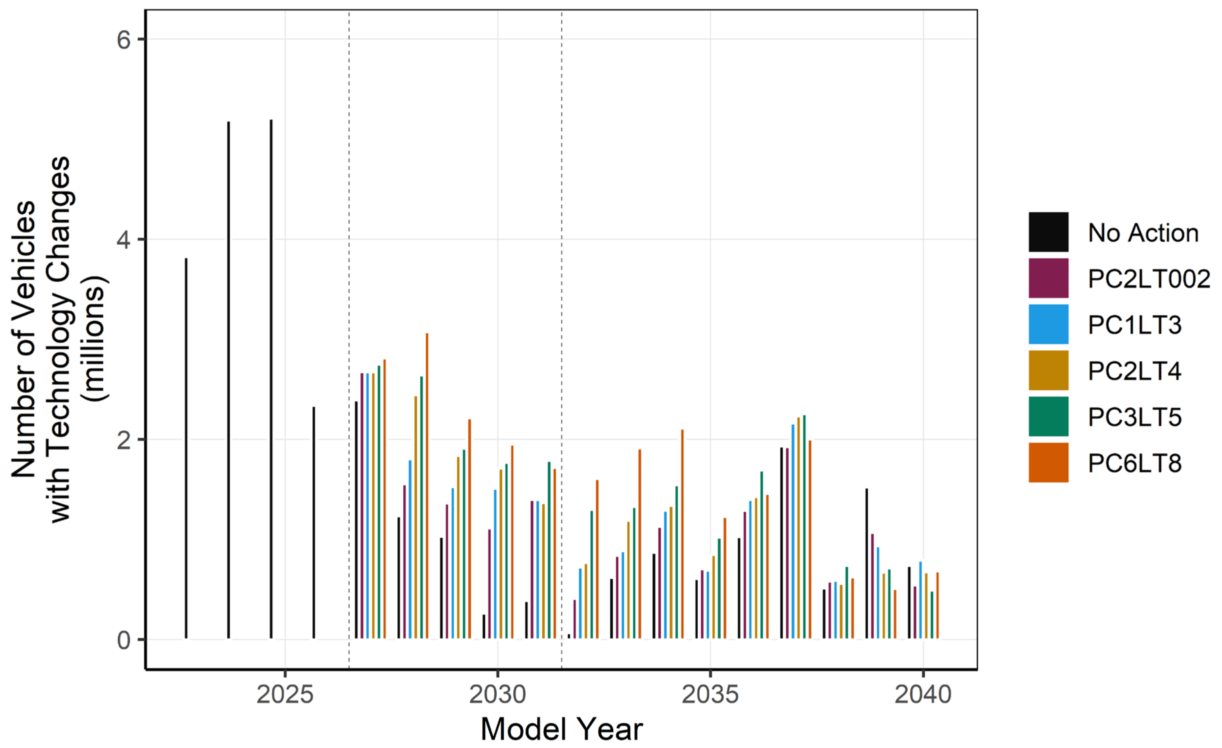
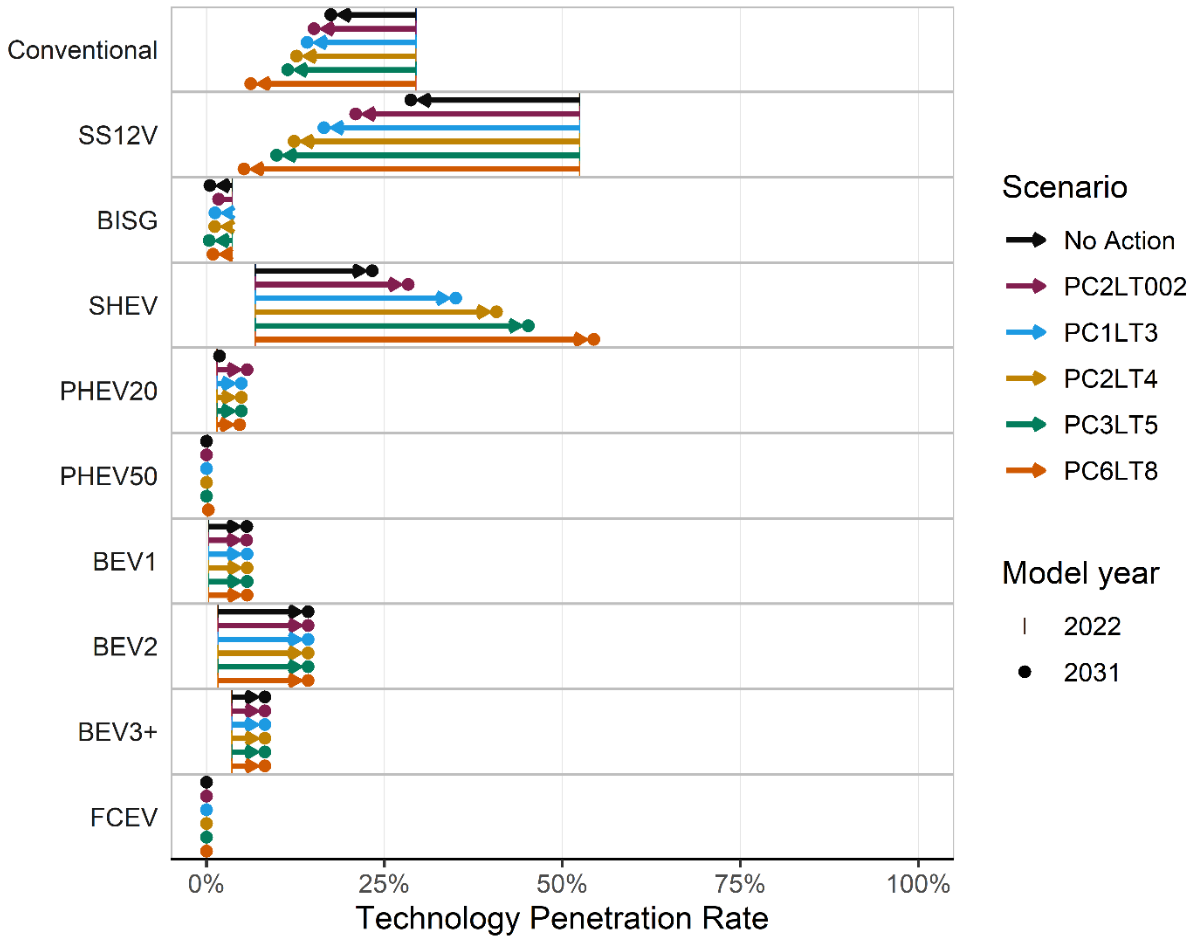


Figure 8-7 through Figure 8-11 present the resulting industry-wide technology penetration rates across scenarios. Each horizontal line segment in the figure represents the change in technology penetration between MY 2022 (represented by a short vertical line segment) and MY 2031 (represented by a circle). Arrows indicate the direction of the change and line colors represent the regulatory alternative. Between MY 2022 and MY 2031, CAFE Model estimates reveal several trends, including:

[181] Figure 8 includes values for the No-Action Alternative only for MYs 2023-2026. As noted previously in Chapter 3.1, technology application in the action alternatives prior to MY 2027 is identical to the No-Action Alternative by construction.
[182] Please note that after the standard-setting years, the CAFE model applies the MY 2031 standard for future model years. For a detailed explanation of each regulatory alternative and existing standards, please refer to Section IV of the Preamble.
[183] The model makes these technology application decisions based on technology cost-effectiveness and to meet existing regulstions, but not in an effort to generate over-compliance credits to address complaince shortfalls in prior model years.

Figure 8-7: Prevalence of Electrified Powertrain Technology in the Fleet Under Different Regulatory Alternatives



Powertrain technology (Figure 8-7 and Figure 8-8):

- Penetration of SHEV and PHEV technology increases from MY 2022 penetration and peaks in between MY 2029 and MY 2031. After MY 2031, SHEV penetration rates decline rapidly, and PHEV rates decrease slightly.
- The variation in SHEV penetration rates across regulatory alternatives is due to differences in the fuel economy gain relative to the change in cost compared to the superseded powertrain technology.
- BEV penetration rates do not differ between No-Action Alternative and the action alternatives during the regulatory timeframe due to statutory constraints on modeling.
- During the standard-setting years, penetration rates of SHEVs increase significantly as stringency increases, and PHEVs increase marginally across all alternatives.[184] The shift to SHEVs and PHEVs renders more traditional technologies for ICE powertrains (e.g., conventional, SS12V, belt-integrated starter generator (BISG)) passé which leads to a decrease in the prevalence of these technologies over the course of the simulation with a particularly steep decline in the action alternatives beyond MY 2027.[185]
- SHEV technology and PHEV technology penetration rates decline when the constraints imposed on standard-setting years are removed and prevalence of these technologies drops to nearly zero percent by 2050.
- All scenarios show nearly complete adoption of electric powertrain technology by 2050.

[184] Note that for the purposes of computing manufacturer compliance, the model only counts the gasoline operation component of PHEVs.
[185] For more detail on the differences in relevant powertrain technology used in hybrid vehicles, see TSD Chapter 3.3.1. For more detail on the technology application choices the CAFE model makes during compliance modeling, see the technology supersession tables in the CAFE Model Documentation.

Figure 8-8: Electrified Powertrain Technology Penetration Rates by Model Year

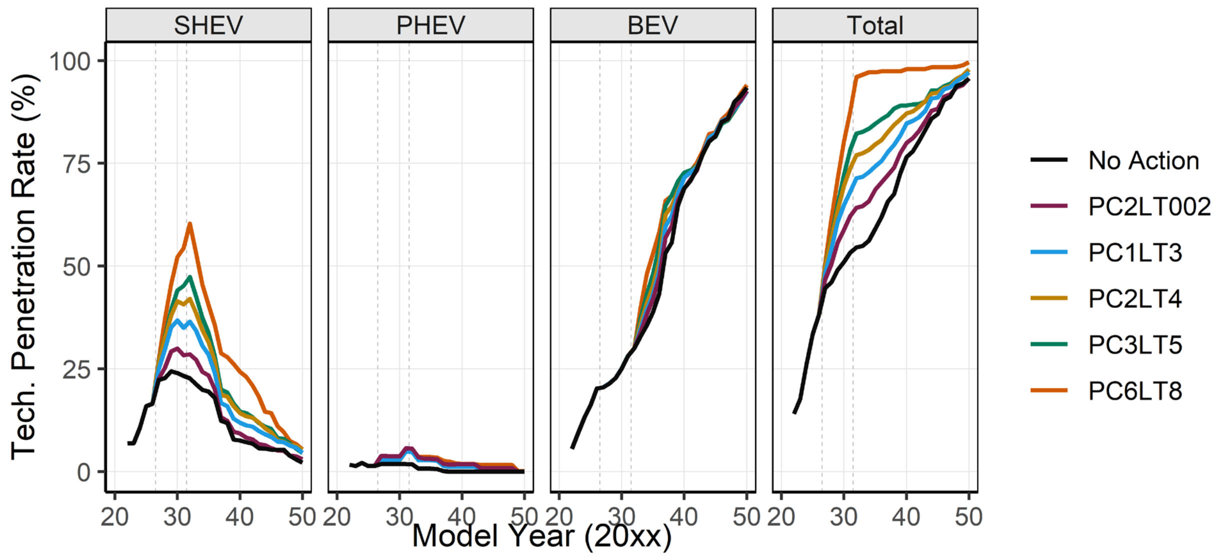
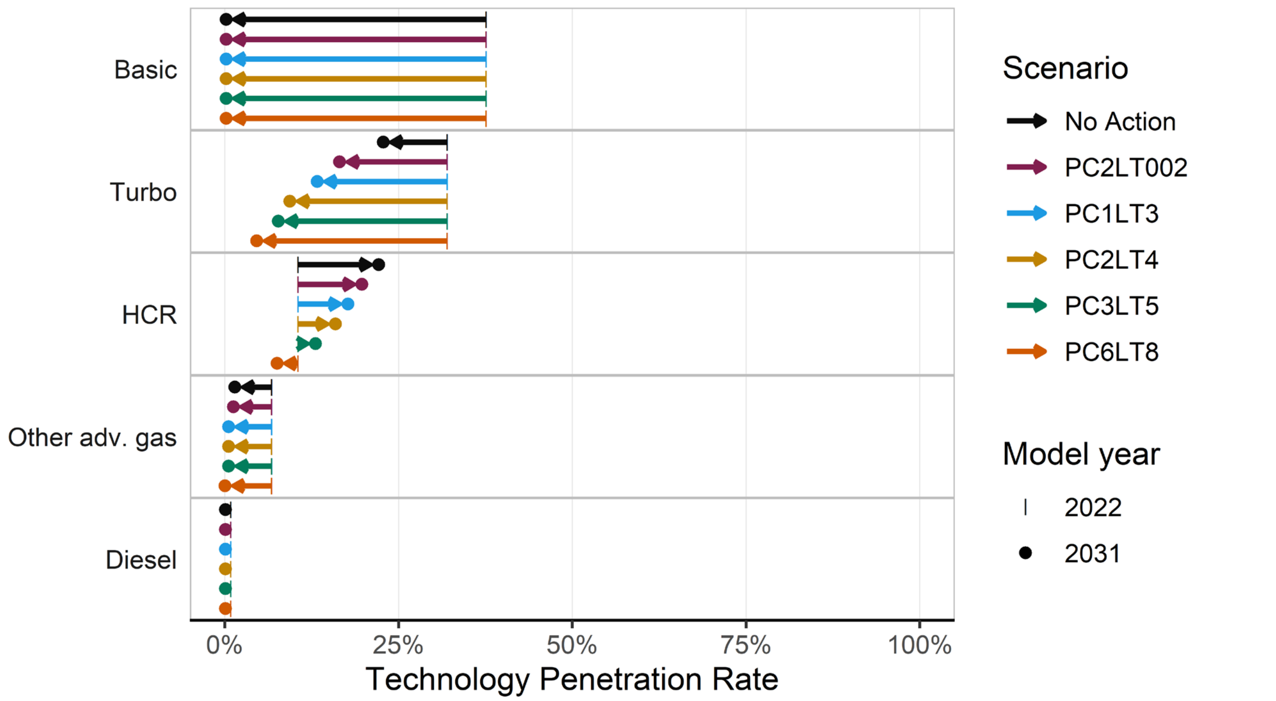


Figure 8-9: Prevalence of Engine Technology in the Fleet Under Different Regulatory Alternatives

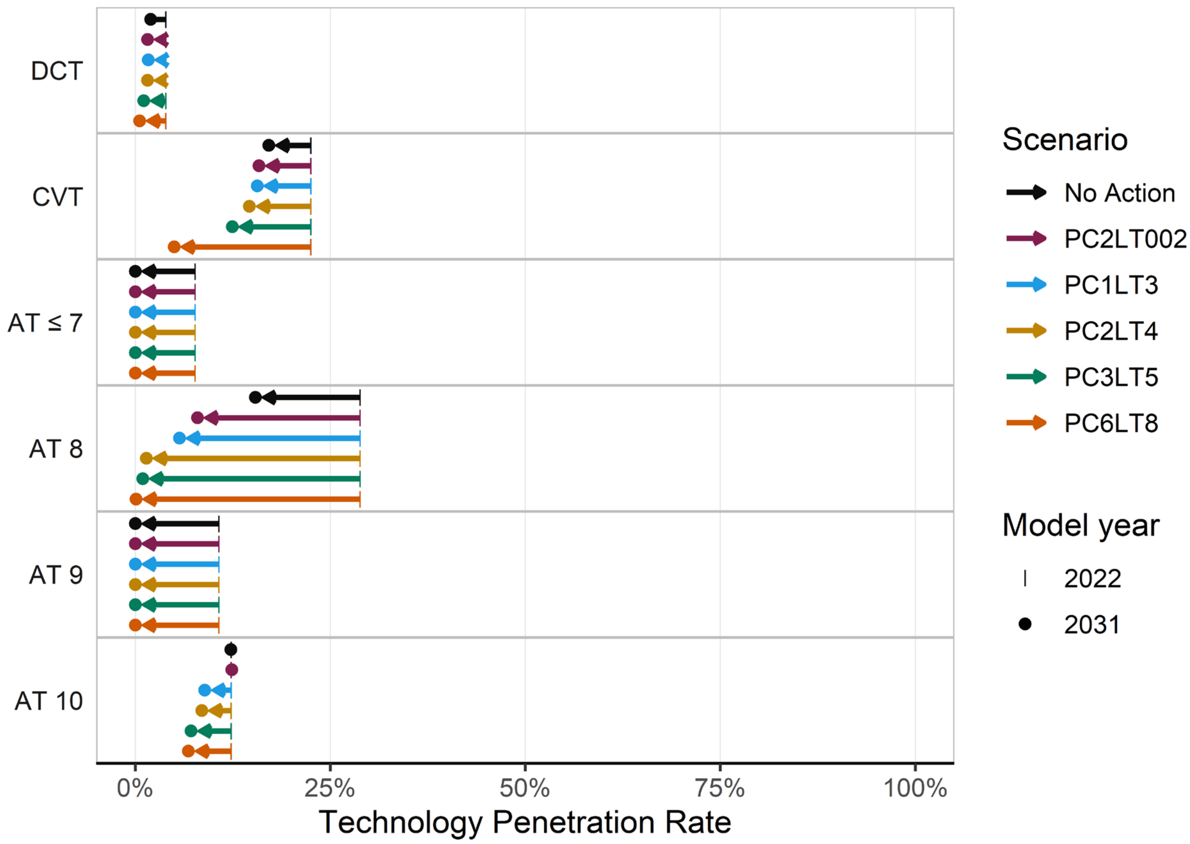


Engine technology (Figure 8-9):

- As the modeled fleet increases penetration of electrified powertrain technology with each subsequent model year (as seen in Figure 8-7 and Figure 8-8), the engine technologies in Figure 8-9 are superseded and thus have decreasing penetration in the fleet. The exception to this is diesel engine technology, which is constant at zero penetration.
- Basic engine technology (including SOHC, Dual Overhead Cam (DOHC), variable valve lift (VVL), cylinder deactivation (DEAC), and stoichiometric gasoline direct injection [SDGI]) decreases to 0% penetration rate between the base MY 2022 fleet and MY 2031 across all alternatives.

- Internal combustion (IC) engine advancements including Turbo and other advanced gas technologies (VCR, variable turbo geometry (VTG), and variable turbo geometry (electric) [VTGE]) all decrease between MY 2022 and MY 2031 in each of the simulated alternatives, though higher stringency alternatives see lower penetration rates by MY 2031.
- Use of High Compression Ratio (HCR) engine technology increases under all scenarios except for the most stringent (PC6LT8). In this case, the modeled increase in SHEVs to meet the higher stringency levels drives this decline in HCR prevalence.
- Diesel engines see limited adoption in all scenarios in MY 2031.

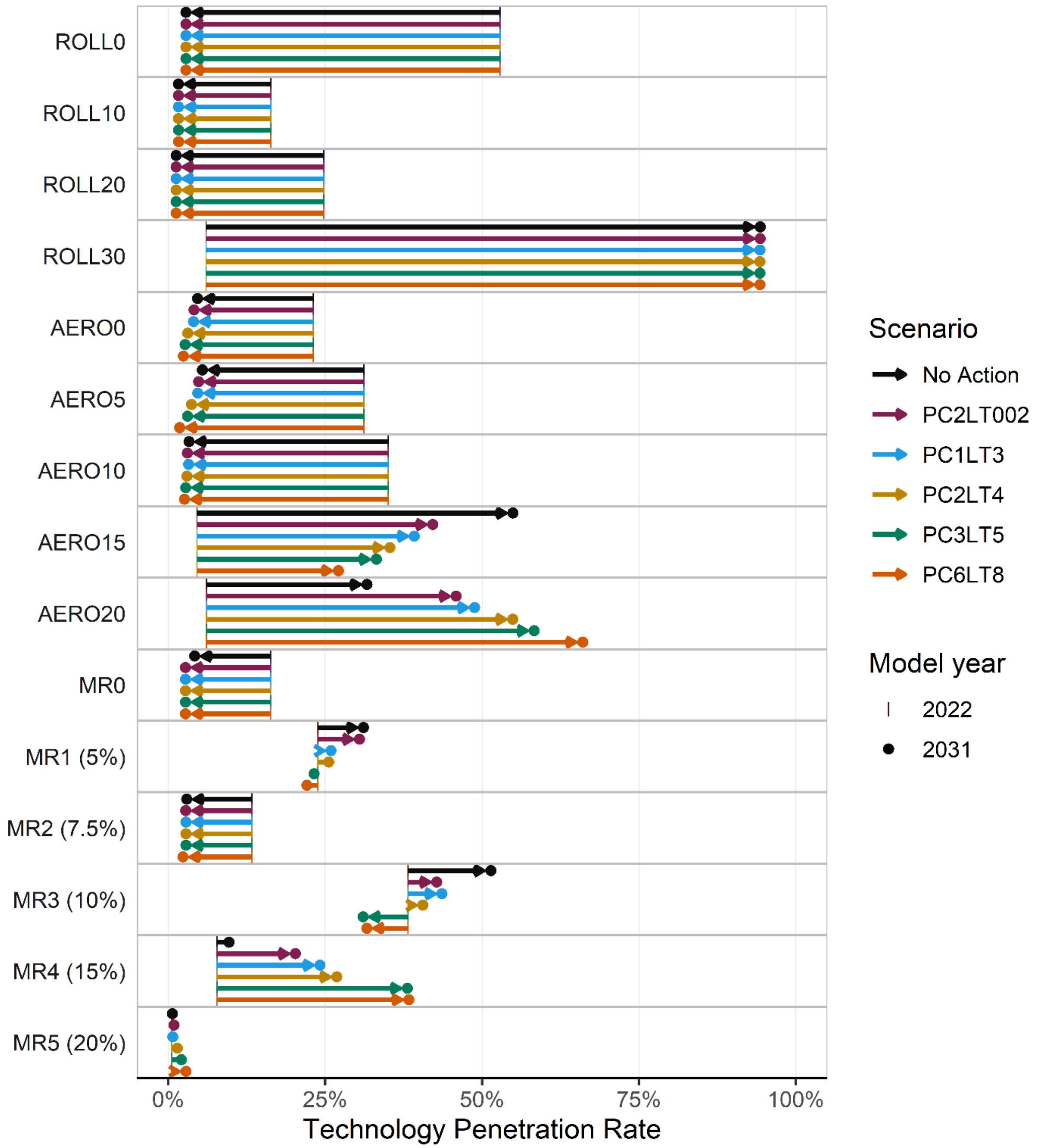
Figure 8-10: Prevalence of Transmission Technology in the Fleet Under Different Regulatory Alternatives



Transmission technology (Figure 8-10):

- All multi-speed transmissions (including continuously variable transmissions (CVTs)) decrease in penetration for all scenarios from MY 2022 until MY 2031. The one exception is AT10, which remains relatively constant in penetration under the No-Action and PC2LT002 scenarios.
- Penetration of Dual-Clutch Transmission (DCT), AT6, AT7, and AT9 decline to near zero percent by MY 2031. Other automatic transmission (AT) options see similar declines in the higher-stringency alternatives (e.g., AT8). This comes as a result of a decline in conventional powertrain technologies and a shift to powertrain technologies that tend to rely more often on CVT or single-speed transmissions.
- Note that the transmission technology in Figure 8-10 represents standalone transmissions. This figure does not account for the penetration rate of these transmission types as a component of strong hybrid powertrains. See Figure 8-7 for electrified powertrain technology penetration.

Figure 8-11: Prevalence of Tire Rolling Resistance, Aerodynamics, and Mass Reduction Technologies in the Fleet Under Different Regulatory Alternatives



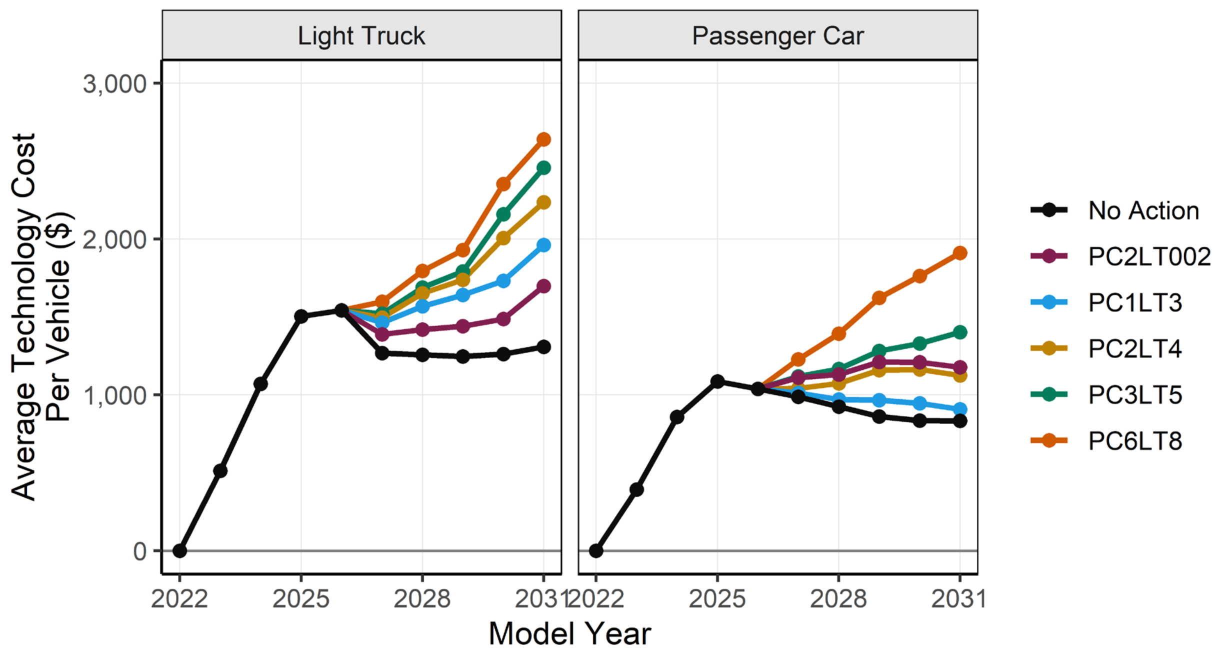
- Rolling Resistance:
  - Results are very similar across scenarios.
  - With few exceptions, ROLL30 is applied to all models by MY 2031.
- Aerodynamics:
  - The amount of AERO0 through AERO10 applied is reduced in favor of applying AERO15 and AERO20.
  - At higher stringency alternatives, aerodynamic improvement technologies are applied more aggressively.

    - Under the most stringent scenario – PC6LT8 – the CAFE model applies AERO20 at a penetration rate over 60%.
- Mass Reduction (MR):
  - The amount of MR0 through MR3 applied is reduced in favor of of MR4 and, to a lesser extent, MR5.
    - MR5 penetration rates are relatively minor but do increase with stricter stringencies.
  - The penetration rates of MR technologies vary across scenarios from MY 2022 until MY 2031.
  - MR greater than or equal to 20 percent is applied sparingly in all scenarios, due in part to modeled cost parameters and limits imposed on application due to feasibility concerns; still, a few manufacturers select MR at this level.

8.2.2.2. Compliance Costs

Manufacturers can comply with CAFE regulations by applying fuel economy-improving technologies and in practice may make up deficits between their target and achieved fuel economies through the use of over-compliance credits (by credit carry-forward, transfer, or trade subject to restrictions).[186] Manufacturers who cannot comply with these flexibilities pay civil penalties.[187] Model outputs report regulatory costs (i.e., the combination of technology costs and total civil penalties across all regulatory classes) as well as technology costs alone; technology costs are a major contributor to regulatory costs. The CAFE Model computes both aggregate and per-vehicle values of these costs. Figure 8-12 reports industry-wide, model year trends in per-vehicle technology costs by vehicle class.

Figure 8-12: Average Per-Vehicle Technology Cost



Per-vehicle technology costs vary widely by manufacturer and across alternatives, in-part, due to estimated technology application choices. Additionally, NHTSA does not allow the model to consider the fuel economy of powertrains fueled by alternative fuels as a compliance strategy to meet the standards, consistent with statutory restrictions. Manufacturers are always free to comply using any technologies they choose, including ones cheaper and more cost-effective than those modeled here.

[186] Additional detail on alternative compliance flexibilities is included in Section VI.B.1.b. and Section VI.B.1.c of the preamble. In the CAFE Modeling framework, the current approach to modeling over-compliance credits allows credit carry forward and credit transfers within a manfaucturer but does not allow trades among manufacturers. These capabilities are disabled during standard-setting model years. For additional detail, see TSD Chapter 2.2.2.3. and the CAFE Model Documentation.
[187] Beginning with MY 2019, civil penalties are adjusted for inflation.

Figure 8-13 presents per-vehicle technology costs for a MY 2031 vehicle in the reference baseline. 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 "No Action" panel. The portions of the bar in color represent the changes in manufacturer technology costs for each action alternative above the reference baseline. For example, average per-vehicle technology costs for Volkswagen Group of America (VWA) in the No Action Alternative are $1,040. Under scenario PC2LT002, these costs increase by $330 per vehicle to $1,370. Under scenario PC1LT3, these costs increase by $430 per vehicle to $1,470. Under scenario PC2LT4, technology costs increase by $520 to $1,560. Manufacturers including Mazda, Hyundai, JLR, and Kia substantially increase per-vehicle technology costs under scenarios PC3LT5 and PC6LT8. Relative to the No Action scenario, PC2LT002 represents an average industry-wide increase in per-vehicle technology costs of $380 – an increase of 33 percent. PC1LT3 represents an average industry-wide increase in per-vehicle technology costs of $540 — an increase of 29 percent. Industry average technology costs increase by $460 in scenario PC1LT3 (40 percent over the No Action Alternative), $710 per vehicle in scenario PC2LT4 (61 percent), $950 in scenario PC3LT5 (83 percent), and $1,240 per vehicle in scenario PC6LT8 (a 108 percent increase).

Figure 8-13: Per-Vehicle Technology Cost, MY 2031 Vehicle

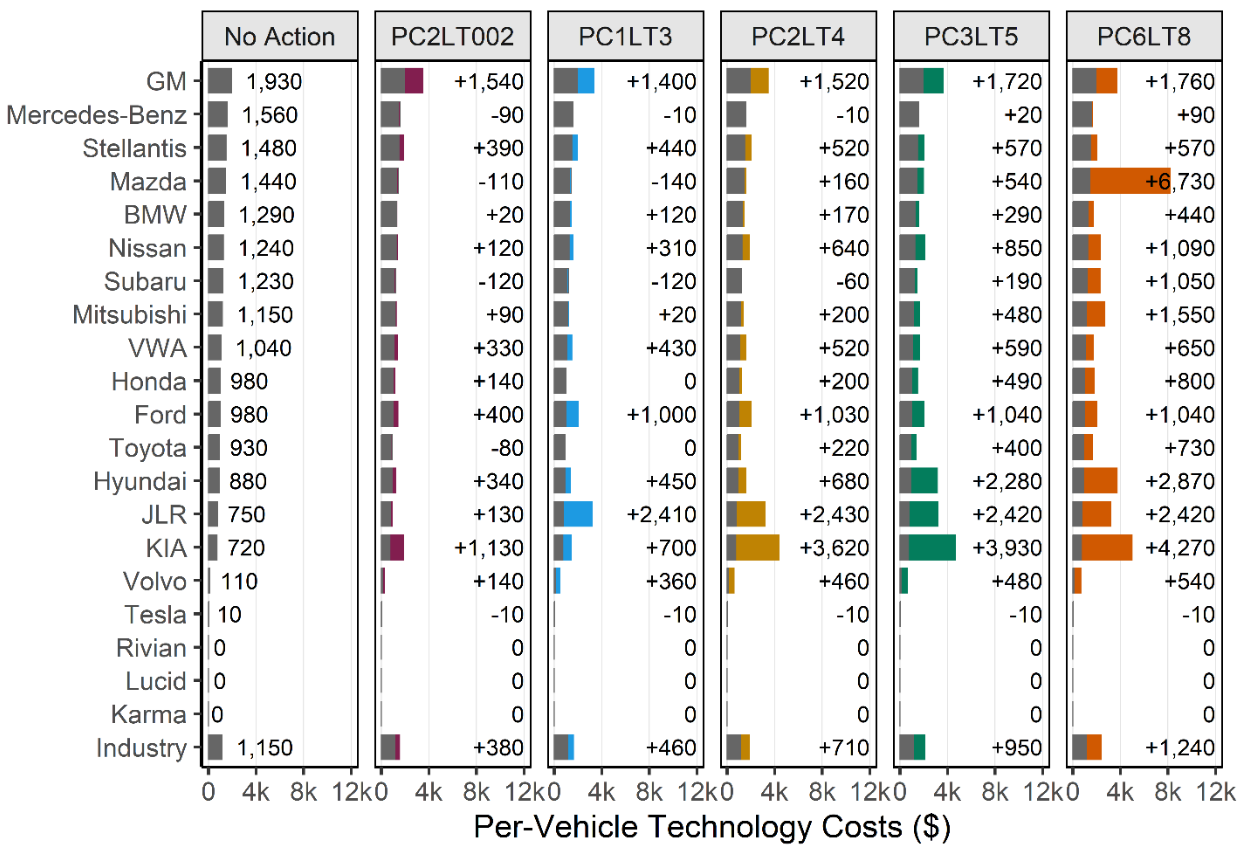
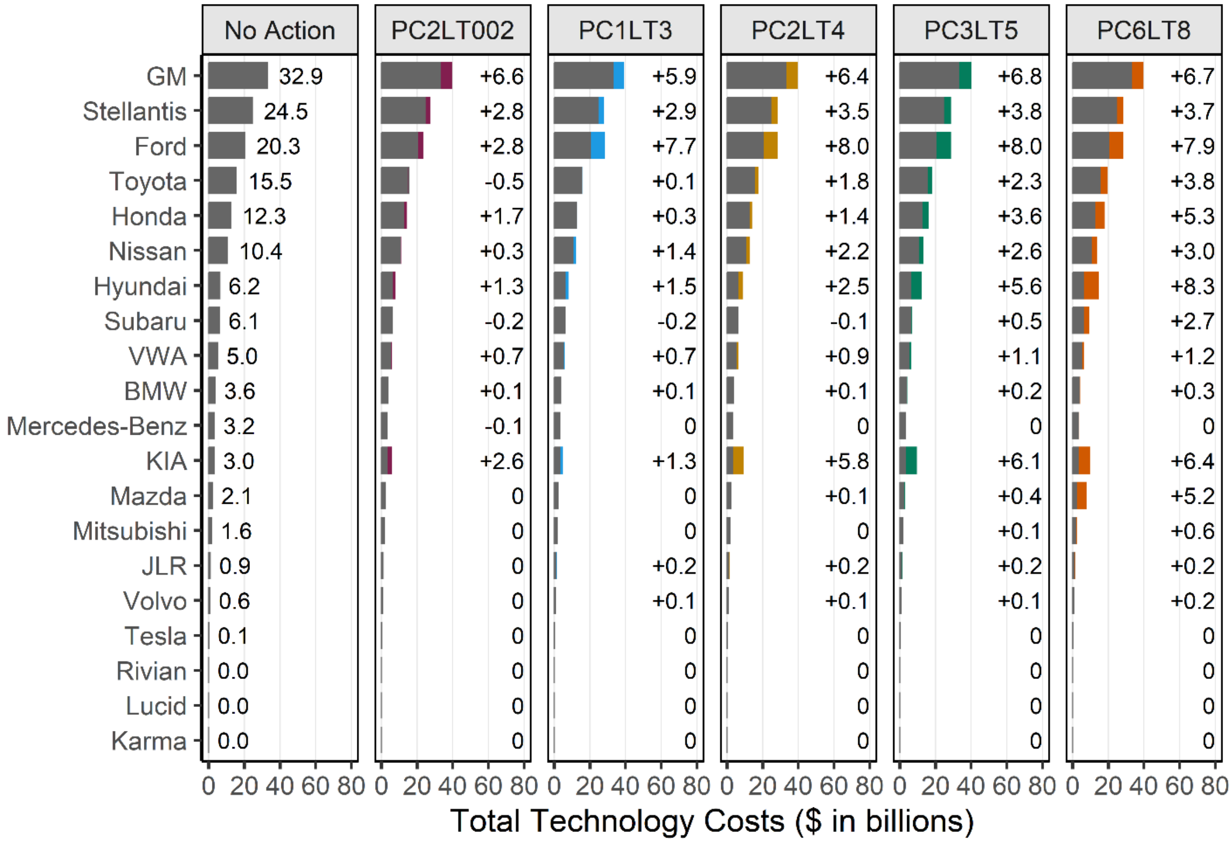


Figure 8-14 reports total technology costs for MYs 2022 through 2031. Gray bars in the figure are costs in the No-Action Alternative. Total No-Action Alternative costs are listed in the data labels in the "No Action" panel. The portions of the bar in color represent the changes in manufacturer technology costs for each action alternative. In most cases, differences in manufacturer rankings between Figure 8-13 and Figure 8-14 are the result of production-scale variation (e.g., and importantly, Ford's large production volumes means it has the third largest total technology cost even though Ford's average per-vehicle costs place it in the middle of the manufacturer ranking in Figure 8-13). 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 the action alternatives and the No-Action Alternative and can be seen by examining technology changes and associated costs for particular manufacturers. For example, Mazda's per vehicle cost increases from $1,330 in PC2LT002 to $1,980 in PC3LT5. Mazda's fleetwide application of high-level

AERO and MR technology (AERO20 and MR5) increase substantially across these alternatives, due to Mazda's high level of platform sharing.[188] Between PC3LT5 and PC6LT8, Mazda's compliance pathway includes additional increases in these technologies as well as a number of PHEV conversions.[189] Cost increases for Hyundai and Kia jump in the higher stringency action alternatives as a result of similar technology application decisions (i.e., high level aero and MR) also coupled to high levels of platform sharing.

Figure 8-14: Technology Costs by Manufacturer, MYs 2022-2031



8.2.2.3. Sales and Employment Impacts

As manufacturers modify their vehicle offerings and utilize fuel economy-improving 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 the additional technology cost in each of the action alternatives exceeds the value of expected fuel savings in the first 30 months, sales decline in each alternative relative to the No-Action Alternative.[190] Figure 8-15 illustrates the magnitude of this effect in the context of total sales. Readers should note that the increase in total sales in MY 2023 represents a recovery from the sales shock caused by the Coronavirus Disease of 2019 (COVID-19) pandemic.

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[188] See TSD Chapter 2 for a discussion on the platform sharing assumptions used in this analysis.
[189] Mazda is one example of a manufacturer with a significant amount of platform sharing and this can result in large movements in technology application. For additional detail, see the discussion of platform sharing and stranded capital in TSD Chapter 2.6.
[190] 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.

Figure 8-15: Industry-Wide Sales

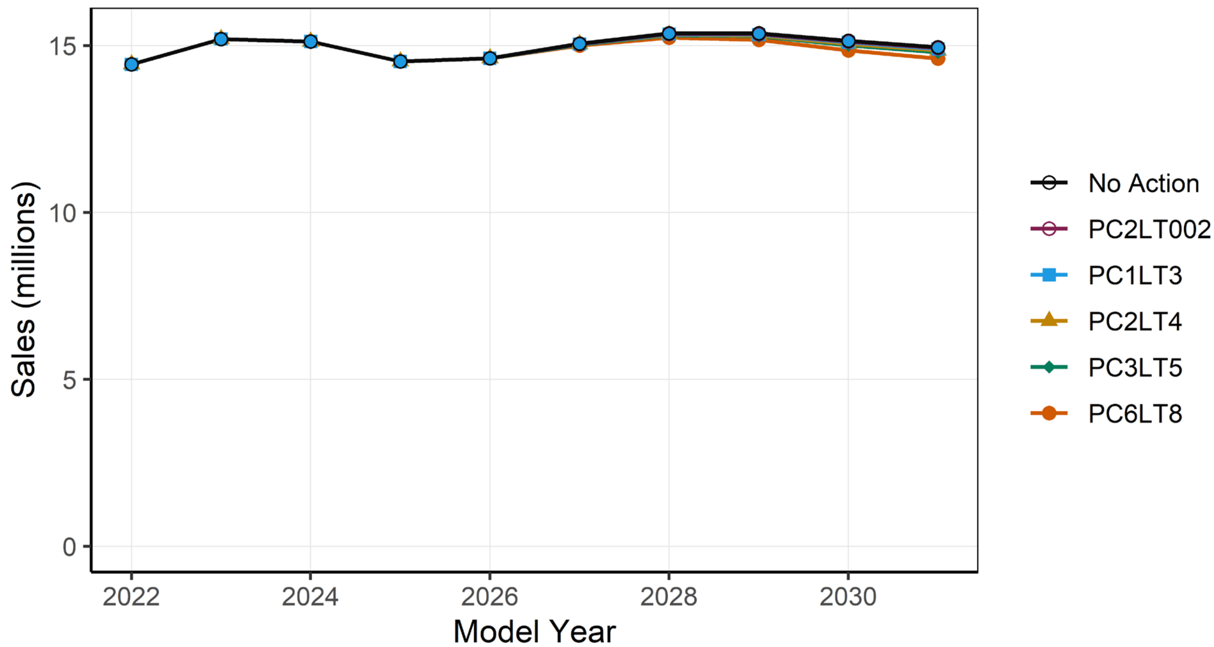


Figure 8-16 shows the simulated sales differences for the current analysis at the industry level across alternatives relative to the reference baseline through MY 2050. For all scenarios, sales stay constant relative to the No-Action scenario through MY 2026, after which the model begins applying technology in response to the action alternatives. Beginning in MY 2027, sales begin to decline in all scenarios compared to the No-Action Alternative. As stringency levels increase across scenarios and technology costs increase, the overall magnitude of the sales response increases as well. Sales declines relative to the No-Action Alternative in the most stringent scenario (PC6LT8) are almost twice the decline in the next most stringent scenario (PC3LT5)), though even the possible 2% decline in sales under the most stringent scenario is within the bounds of annual changes in sales. This initial slight decline in sales moderates beyond the mid-2030s. Excluding the most stringent case, LDV sales differ from the No-Action Alternative by approximately one percent or less through MY 2050.

Figure 8-16: Percentage Change in Sales, by Alternative

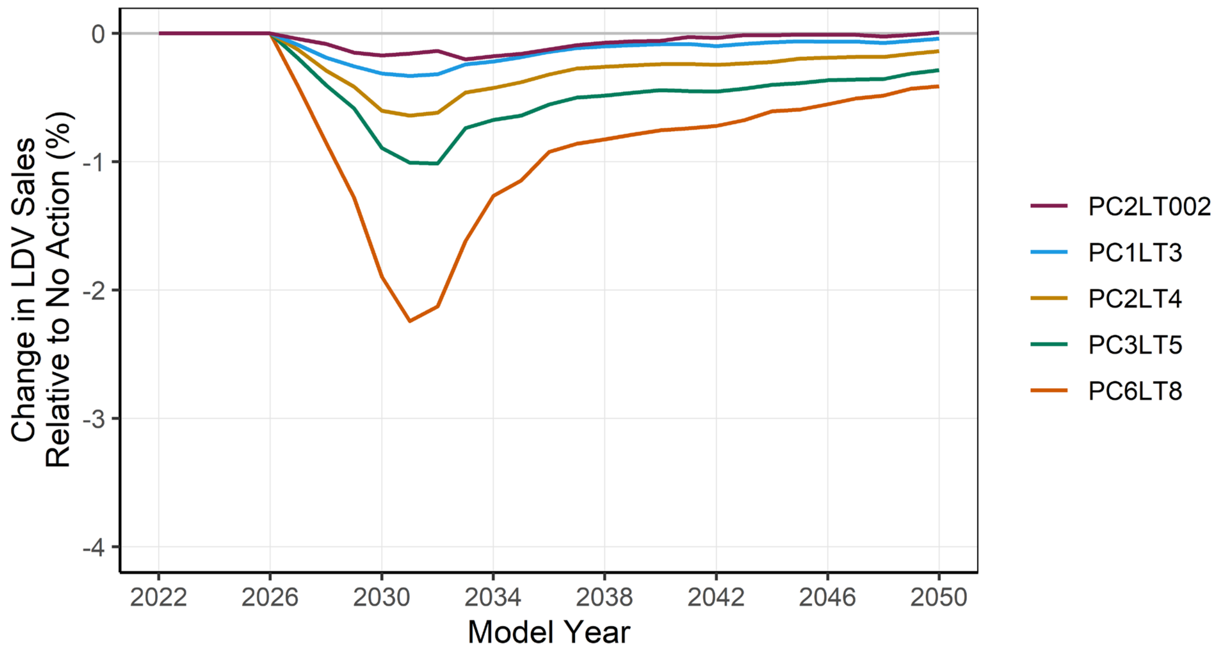
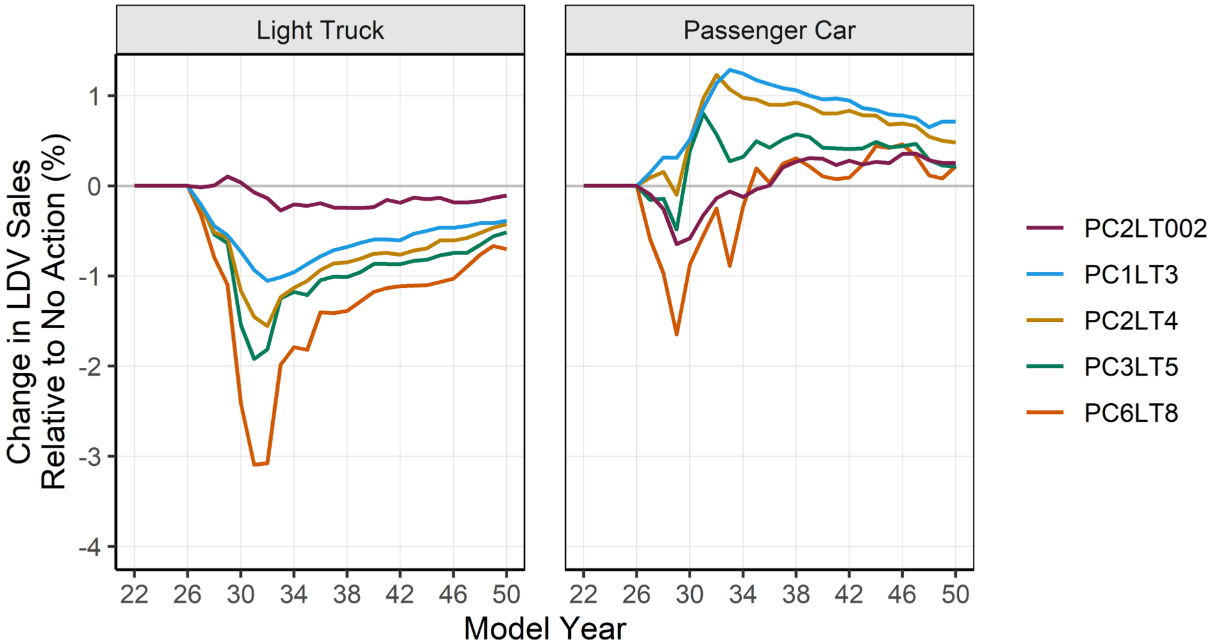


Figure 8-17 presents heterogeneity in sales response across regulatory classes. In the central analysis case presented here, the general trend in sales declines during the standard setting years holds across regulatory alternatives for the LT fleet. The trend in the PC fleet is different.

For scenarios PC1LT3 and PC2LT4, there is a very slight percent increase in PC sales in the initial two years compared to the No-Action Alternative. For regulatory alternatives PC2LT002, PC3LT5, and PC6LT8, we see an initial percent decline in sales relative to the No-Action Alternative. With the exception of the most stringent alternative, these declines are within one percent. Starting after MY 2029, this trend reverses course and by MY 2036 all scenarios show a percent increase in sales relative to the No-Action Alternative. This temporal pattern is driven by two elements of the sales model. First, the initial overall drop in sales relates to how regulatory costs increase relative to the No-Action Alternative as lower-cost technology is applied first, leaving more expensive technologies as the available compliance options in later model years. This increase in vehicle cost (price) interacts with the sales elasticity to initially reduce combined LT and PC aggregate sales. Second, the fleet share elasticity changes sales quantities by regulatory class in response to changes in average vehicle value (where value is defined as costs net of fuel savings and vehicle incentives). The sales elasticity and the variation in stringency (and thus vehicle price) combine to differentiate sales across regulatory alternatives and vehicle class. In terms of comparisons across alternative scenarios, the stringency of PC versus LT impacts the relative cost (net of fuel savings and incentives), and thus the share of PC sales. As LT stringency across alternative increases, we observe a shift in sales towards PC and away from LT, thus accounting for some of the PC sales increase above the No-Action alternative, even with the earlier model years. This can also be seen by observing the LT panel in Figure 8-17, which shows the decrease in sales across alternatives relative to the No-Action alternative is proportional to the LT stringency level. For further discussion of the sales model method and assumptions, see TSD Chapter 4.2. The fleet share elasticity mechanism is isolated in a set of sensitivity analysis included in Chapter 9.

Beyond the standard-setting years, the variation in the LT market share across scenarios decreases, as the trends converge over time but remain slightly below the No-Action Alternative; PC share maintains increases of 0.1 to 1 percent relative to the No-Action Alternative across all scenarios. The relative changes in sales for these two regulatory classes feeds into the analysis of on-road fleet and aggregate vehicle use explored more in detail in Chapter 8.2.5.1.

Figure 8-17: Percentage Change in Sales, by Alternative and Regulatory Class



When fewer vehicles are sold, manufacturers require fewer labor hours to satisfy demand. Hence, the decline in sales shown in Figure 8-16 reduces industry-wide labor hours. However, development and deployment of new fuel economy-improving technologies increases demand for labor. Overall estimated CAFE program impacts on employment utilization depend on the relative magnitude of these two factors. Table 8-1 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, net employment utilization mostly increases until it peaks in 2028 and then declines through 2031, before then increasing again starting in 2033. This mirrors the pattern of total sales in Figure 8-16. Employment utilization increases in each action alternative relative to the No-Action Alternative (with the exception of PC6LT8) but these increases are small relative to their reference baseline levels (within an increase of 0.8 percent). The most stringent scenario, PC6LT8, shows a decrease relative to the No-Action scenario. On average, the third scenario, PC2LT4 sees the greatest increase in labor over the reference baseline.

The fact that overall labor utilization follows the general trend of the No-Action Alternative but increases slightly over the reference baseline in all except the most stringent action alternative indicates that technology effects ultimately outweigh sales effects. The fact that the additional jobs for the first four alternatives (i.e., PC2LT002, PC1LT3, PC2LT4, and PC3LT5) are greater than those for the most stringent alternative (PC6LT8) may indicate that the sales declines in this most stringent alternative would erode some of the labor-related benefits of additional fuel economy-improving technology.

Table 8-1: Industry-Wide Labor Utilization Effects (in Full-Time Equivalent Jobs)

Model Year	No Action Alternative	Difference from No-Action				
		PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
2022	880,265	0	0	0	0	0
2023	937,267	0	0	0	0	0
2024	944,067	0	0	0	0	0
2025	915,149	0	0	0	0	0

2026	922,262	0	0	0	0	0
2027	946,440	2,791	2,221	2,501	2,489	672
2028	965,970	2,984	2,408	2,791	2,451	-526
2029	965,508	3,218	3,292	3,472	2,782	-2,074
2030	951,405	3,391	3,238	5,497	3,925	-3,080
2031	939,739	5,832	5,123	6,985	6,401	-2,137

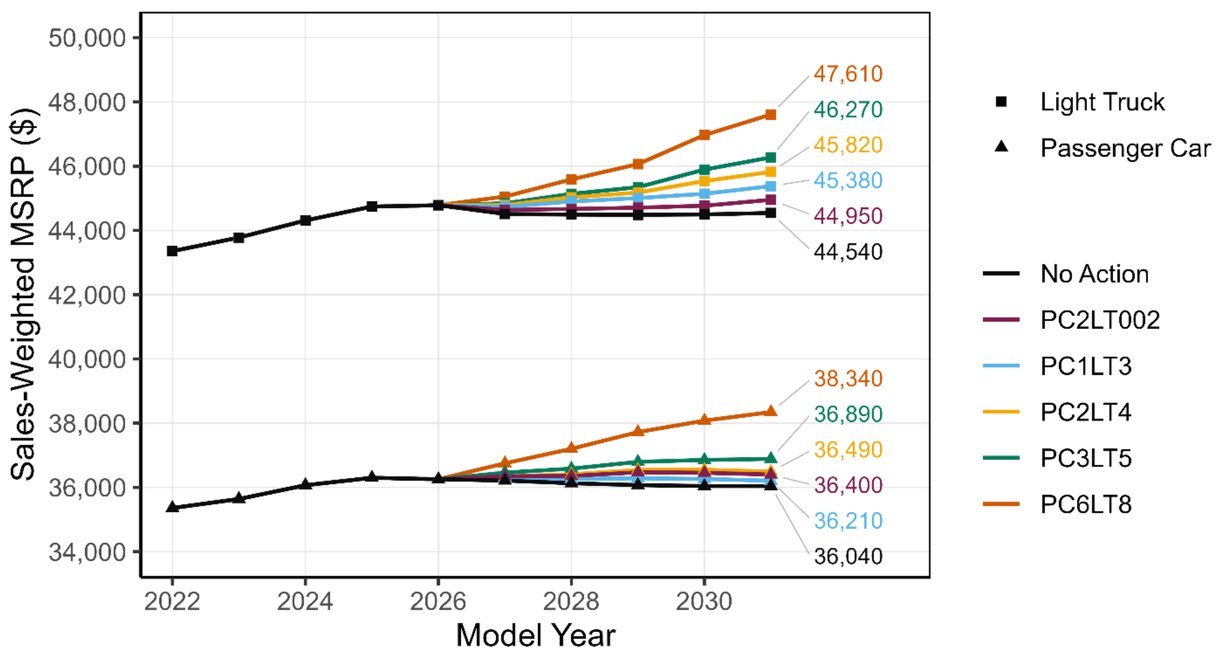
8.2.3. Effects on New Car and Truck Buyers

8.2.3.1. Vehicle Purchasing Price

The CAFE Model uses vehicle-level MSRP values provided in the input fleet as the starting point for modeling light-duty vehicle purchase prices. These initial MSRPs are revised over successive model years to produce final MSRP values that incorporate the regulatory cost of compliance. The prices do not include the effects of EV and battery tax credits passed through to consumers.[191] Figure 8-18 displays trends in these MSRPs for MYs 2022 through 2031 and reports values separately for LTs and PCs. For both regulatory classes, Alternative PC6LT8 produces the largest deviation from the No-Action Alternative, an increase of approximately 4.2 percent on average for MY 2027 through MY 2031 PCs and 3.9 percent for LTs. For Alternative PC2LT002, the deviation is 0.8 percent for PCs and 0.5 percent for LTs. Because these prices are influenced in large part by technology costs, the overall price trends are similar to those found in Chapter 8.3.2, which presents average technology cost per vehicle. After MY 2029, sales-weighted MSRP values for PCs either flatten or decline slightly in the less stringent alternatives. Most manufacturers apply technologies to respond to the CAFE targets in the first few years, and then vehicles retain these technologies. Additionally, the associated costs of these technologies gradually decline over the modeling period due to the model's assumed technology learning rates. The observed MSRP declines in the PC fleet do not carry over to the LT fleet, where the average MSRP increases after 2027 in each alternative. These increases in price in the LT fleet are driven by corresponding increases in cost for technology required to comply with rising standards. In the least stringent alternative, PC2LT002, where standards for LTs only begin to increase in model year 2029, prices only rise very slightly before model year 2031.

[191] While the MSRP reported here does not include the value of tax credits passed through to consumers, these credits are included in the sales model as discussed in Chapter 4 of the TSD.

Figure 8-18: Sales-Weighted MSRP by Regulatory Class



8.2.3.2. Additional Consumer Purchasing Costs and Benefits

In addition to vehicle price effects, the CAFE Model computes various categories of consumer costs and benefits.[192] Table 8-2 summarizes these cost and benefit categories for MY 2031 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.[193] 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 or civil penalties, and therefore increase as alternative stringency increases. As shown in Table 8-2, this regulatory cost component increases by 34 percent over the No-Action Alternative for Alternative PC2LT002 and more than doubles for PC3LT5 in MY 2031.

Estimated consumer benefits include decreased fuel expenditures, time saved due to less frequent fueling, additional value derived from reallocated vehicle miles, realized benefits from rebound travel miles, and any EV tax credits and battery tax credits that are passed on to consumers. As presented in Table 8-2, fuel savings benefits are the largest component of estimated consumer benefits. Estimates for the No-Action Alternative indicate average lifetime retail fuel outlay costs of $14,251 per vehicle in 2031. Fuel cost savings ranged from $639 in PC2LT002, the least stringent alternative, to more than $1,607 per vehicle, around 11 percent of total fuel costs, in the most stringent alternative. Tax credits are highest in the least stringent alternative where PHEVs represent about 1 percent more of the fleet than in the other alternatives. The effect of these vehicles on compliance in the CAFE Model is based on their gasoline fuel economy. Overall, the incremental consumer net benefits are higher in the less stringent alternatives for MY 2031, with the highest consumer net benefits in PC1LT3, followed closely by PC2LT002. This reflects the difficulties that some manufacturers have complying with the most stringent alternatives in the initial years following the changes to CAFE standards, as compliance costs increase by a factor of about 7, while retail fueling benefits to consumers increase by a factor of 2.5. Relative to the No-Action Alternative, net benefits to the consumer in the three least stringent alternatives are positive in MY 2031, while they are negative in the two more stringent alternatives.

[192] This chapter considers only private consumer costs and benefits. Chapter 8.2.4 presents model results for costs and benefits attributable to society as a whole.
[193] Results for additional regulatory fleet aggregations and discount rates are included in Appendix I and II.

Examining consumer benefits and costs by regulatory class, Table 8-3 highlights some of the differences across alternatives between PCs and LTs. PC2LT002 alternative leads to the highest passenger car consumer net benefits, despite being more stringent for cars than PC1LT3, as higher regulatory costs are more than offset by higher fuel cost savings. Net consumer benefits decrease with stringency for passenger cars and become negative in the PC3LT5 alternative. We see here that compared to the preferred alternative, regulatory costs more than quadruple. While fuel savings more than double, the increase is not enough to offset the large increase in costs. For passenger cars, tax credits, which are driven by PHEV sales, are highest in PC2LT002 and generally decrease with stringency. For LTs, consumer net benefits are highest in the PC1LT3 alternative. Apart from this exception, consumer net benefits decrease with stringency, and fall significantly in the most stringent alternative. This reflects regulatory costs not being accompanied by a comparable increase in fuel cost savings, which is attributable to the non-linear relationship between fuel economy and fuel cost-per-mile, leading to (in the absence of technological innovation other than learning) diminishing returns to drivers from the technology applied to these vehicles. This trend is further exacerbated in alternatives where fines are paid as regulatory costs increase with no corresponding consumer benefit to vehicles. Similar to passenger cars, the effect of tax credits on costs to consumers decline with stringency for light trucks as fewer PHEVs are built in the fleet.

Table 8-2: Per-Vehicle Consumer Costs and Benefits, MY 2031 (2021$, 3% Discount Rate)

	No Action	Relative to No Action				
		PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Consumer costs						
Regulatory cost	1,149	392	607	992	1,426	2,802
Insurance cost	3,932	37	54	89	130	260
Ownership taxes/fees	2,276	22	31	52	75	150
Lost consumer surplus	0	0	1	2	6	28
Implicit opportunity cost	0	0	0	0	0	0
Total consumer cost	0	451	693	1,136	1,637	3,241
Consumer benefits						
Fuel savings	−14,251	639	895	1,148	1,343	1,607
EV tax credit	614	80	61	61	61	52
EV battery tax credit	251	11	9	9	9	9
Refueling time benefit	−1,601	37	46	58	66	78
Mobility benefit	553	44	67	89	105	129
Reallocated mileage benefit	0	8	15	27	41	80
Total consumer benefit	0	818	1,092	1,391	1,625	1,954
Net consumer benefit	0	367	399	255	−12	−1,286

Note: Negative retail fuel savings and refueling time benefits represent per-vehicle fuel costs and refueling time costs in the No-Action alternative.

Table 8-3: Per-Vehicle Consumer Costs and Benefits by Regulatory Class, MY 2031 (2021$, 3% Discount Rate)

	Passenger Car						Light Truck					
	No Action	Relative to No Action					No Action	Relative to No Action				
		PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8		PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Consumer costs												
Regulatory cost	834	357	168	450	848	2,303	1,308	409	835	1,277	1,730	3,065
Insurance cost	3,400	34	16	42	80	217	4,201	39	79	120	163	289
Ownership taxes/fees	1,968	20	9	25	46	126	2,432	22	46	70	94	167
Foregone consumer surplus	0	0	1	2	6	28	0	0	1	2	6	28
Implicit opportunity cost	0	0	0	0	0	0	0	0	0	0	0	0
Total consumer cost	0	411	193	519	980	2,674	0	470	960	1,470	1,994	3,550
Consumer benefits												
Fuel savings	−10,306	548	300	503	758	1,321	-16,244	690	1,165	1,434	1,591	1,703
EV tax credit	778	28	−1	−1	0	−1	531	106	91	91	90	77
EV battery tax credit	276	2	0	0	0	0	238	15	13	13	13	13
Refueling time benefit	−1,667	31	16	27	39	65	-1,568	40	62	75	82	86
Mobility benefit	494	41	25	42	62	109	582	45	89	114	128	140
Reallocated mileage benefit	0	5	11	20	30	56	0	9	16	30	47	92
Total consumer benefit	0	656	352	590	889	1,550	0	905	1,436	1,756	1,951	2,111
Net consumer benefit	0	245	158	71	−91	−1,124	0	435	476	286	-43	-1,439
Reg. class share of sales (absolute terms, %)	33.6	33.5	34.0	34.1	34.2	34.1	66.4	66.5	66.0	65.9	65.8	65.9

Note: Negative retail fuel savings and refueling time benefits represent per-vehicle fuel costs and refueling time costs in the No-Action alternative.

Figure 8-19 reports consumer net benefits per vehicle from MY 2022 through MY 2050. Across model years, net consumer benefits vary significantly. In early model years, net consumer benefits are negative in the two most stringent alternatives, as technology application costs of compliance outweigh consumer benefits. As 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 large positive net consumer benefits across alternatives from the model years in the mid-2030s through the early 2040s. However, as costs come down, tech penetration in the No-Action Alternative tends to close the gap and drives incremental net-benefits to consumers down. Chapter 9 of this document explores the sensitivity of these results to alternate modeling assumptions.

Figure 8-19: Private Consumer Net Benefits, Light-Duty Vehicles, 3% Social Discount Rate

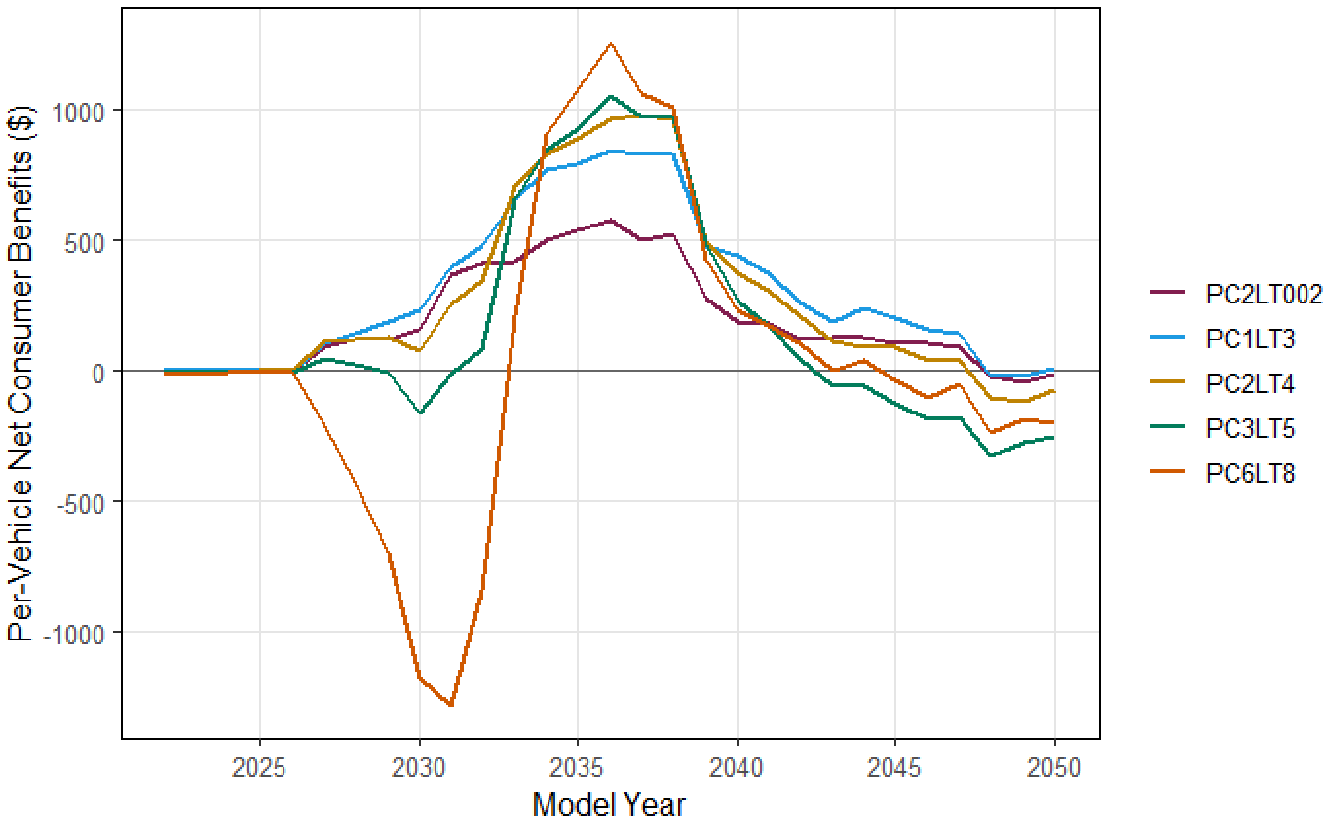


Figure 8-20 plots trends in each of the consumer cost components that are directly tied to vehicle MSRP. As expected, patterns of these costs track each other and MSRP trends (i.e., sharp initial increases followed by more gradual increases in later years for the less stringent alternatives, and steadier increases throughout the time period for the more stringent alternatives). Figure 8-21 breaks out the other cost and benefit components of the consumer net benefit calculation. Fluctuations in foregone consumer surplus from reduced sales, refueling time cost, mobility benefits, and reallocated value are relatively small compared to the retail fuel savings. As expected, retail fuel savings and mobility benefits move with one another over time, retail fuel savings increasing with more efficient fleets and mobility benefits increasing with a larger number of rebound miles traveled. Note, as above, private consumer benefits due to avoided retail fuel costs are substantial across all the alternatives, however in later years these savings are somewhat higher in the most stringent scenario as manufacturers must continue to apply additional technology to comply with higher standards.

Figure 8-20: Light-Duty Vehicles MSRP-Based Incremental Consumer Costs, 3% Social Discount Rate

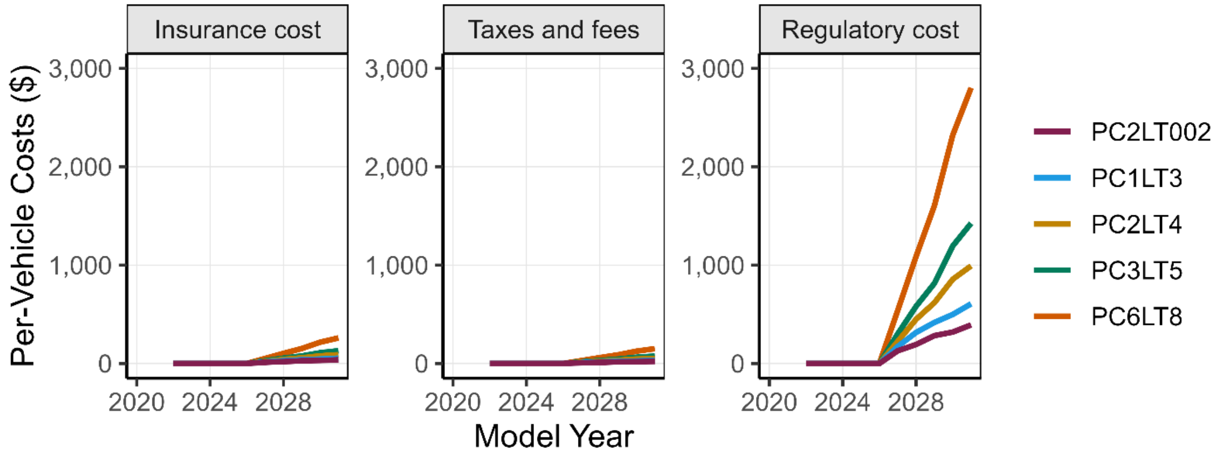
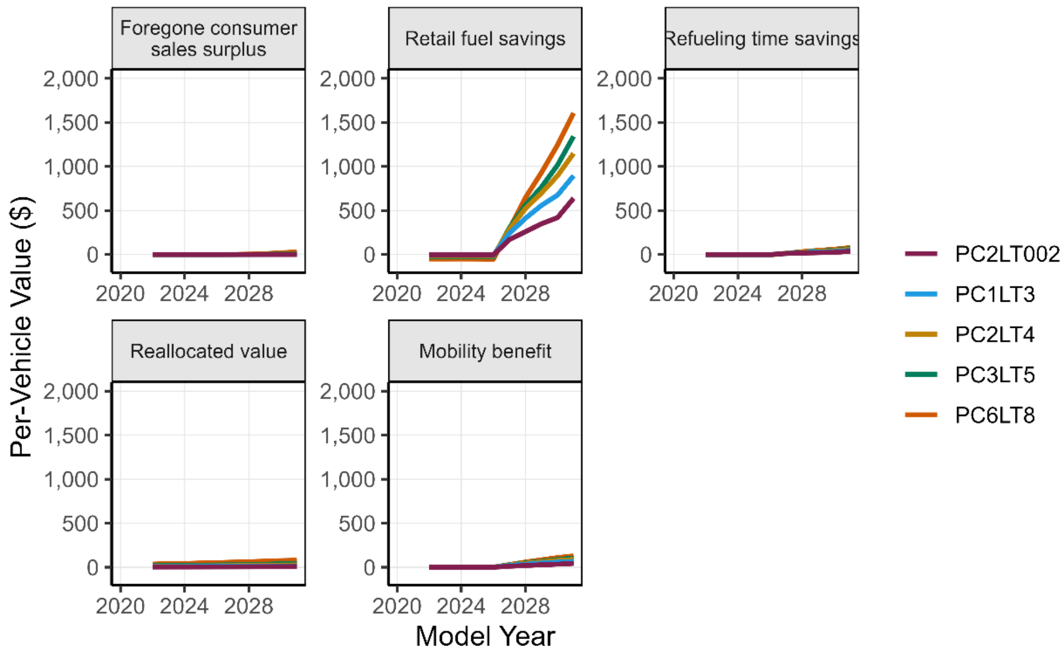


Figure 8-21: Light-Duty Vehicle Incremental Consumer Costs and Benefits, 3% Social Discount Rate



8.2.3.3. Total Cost of Ownership Payback Period

An alternative metric for evaluating relative costs and benefits of fuel economy 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 net of any tax credits passed through to consumers. It then compares these to a running total of undiscounted 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.[194] The vehicle age at which estimated consumer benefits outweigh estimated costs is the payback period. Figure 8-22 illustrates the distribution of payback periods across all modeled vehicle sales.

[194] The "initial state" of each vehicle is based on the vehicle's technology status in MY 2022.

Figure 8-22: Light-Duty Vehicle Distribution of Vehicle TCO Payback, MY 2031

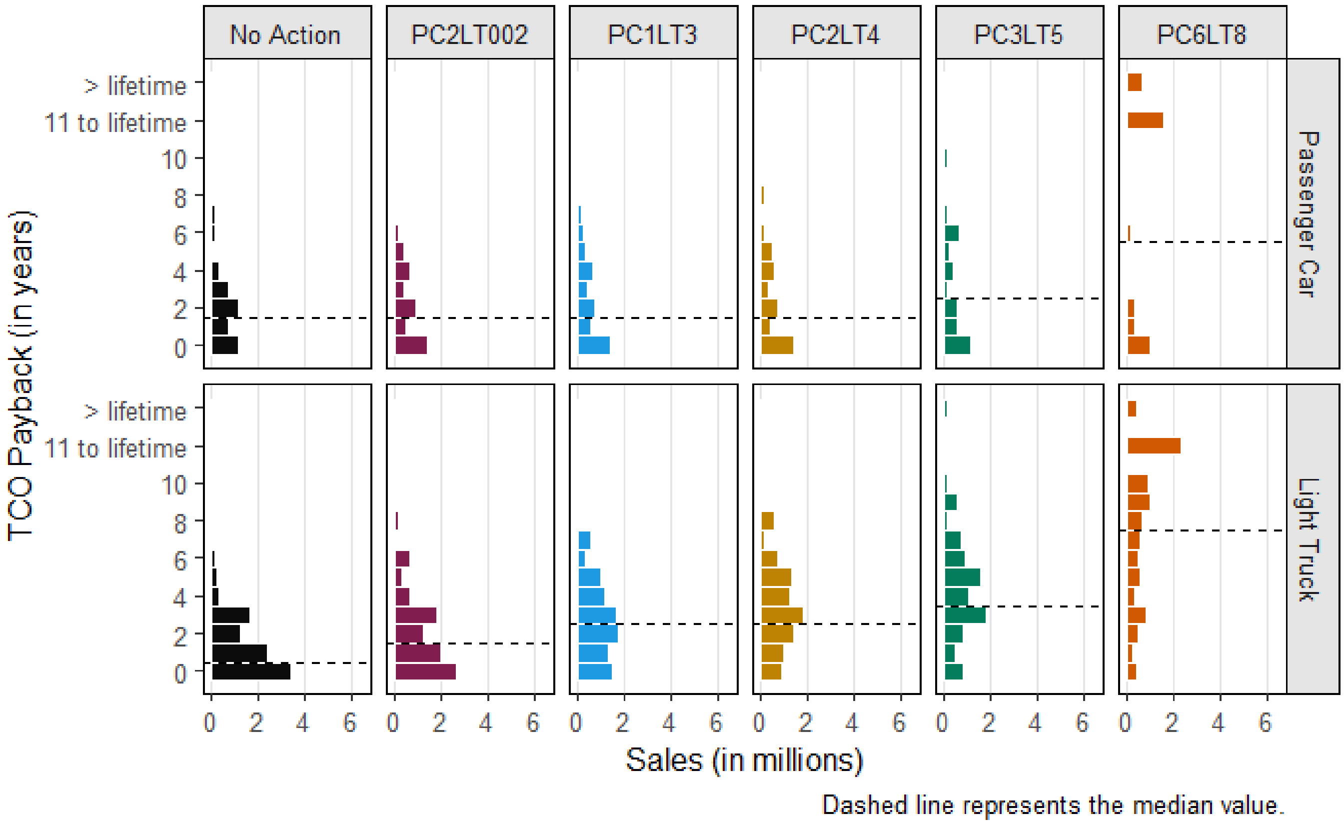


Figure 8-22 summarizes payback periods for undiscounted costs from the CAFE Model's vehicles report.[195] With the exception of PC2LT002 and PC6LT8, the average PC payback periods are slightly shorter than LT payback periods in the regulatory alternatives in MY 2031. In PC2LT002 stringency increases more slowly, helping to keep payback periods shorter on average for trucks, while in the most stringent alternative the required technology adoption for both fleets is significant and the payback periods become close. For passenger cars, payback periods in the three least stringent alternatives are all centered around one year with the longest payback periods falling between 5 and 8 years. For the two most stringent alternatives we see that some passenger cars do not payback until 10 or more years after purchase, and in the case of PC6LT8, some vehicles do not payback over the course of their lifetime. For light trucks, the three least stringent alternatives generally payback within the first three years. As in the case of passenger cars, there are some vehicles that do not payback in the two most stringent alternatives. In the most stringent alternative just over two million trucks payback more than 11 years after purchase. Table 8 summarizes these results and shows that in the No-Action Alternative LTs tend to take less time to pay back the costs of applied technology and fines. In the regulatory alternatives, at the mean, the total payback time for cars is longer than that of trucks only in the least stringent alternative for LTs, when increases on stringency for light trucks do not take place in the first two standard setting years, and the most stringent alternative. As stringency increases, the median payback time for trucks overtakes passenger cars.

Table 8-4: Light-Duty Vehicle Incremental Payback Times, MY 2031 by Regulatory Class (in Years)

		Incremental Payback

[195] 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 8-4. As presented in Figure 8-22, 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 increases payback periods. For example, for MY 2031 PCs, the baseline average TCO payback period is 3.0 years and increases to over 20 years in Alternative PC6LT8. As this payback value is censored at 99 years, average and median payback periods presented above underestimate true fleet-wide payback, though outside of PC6LT8, the fraction of total vehicles with long payback periods is small.

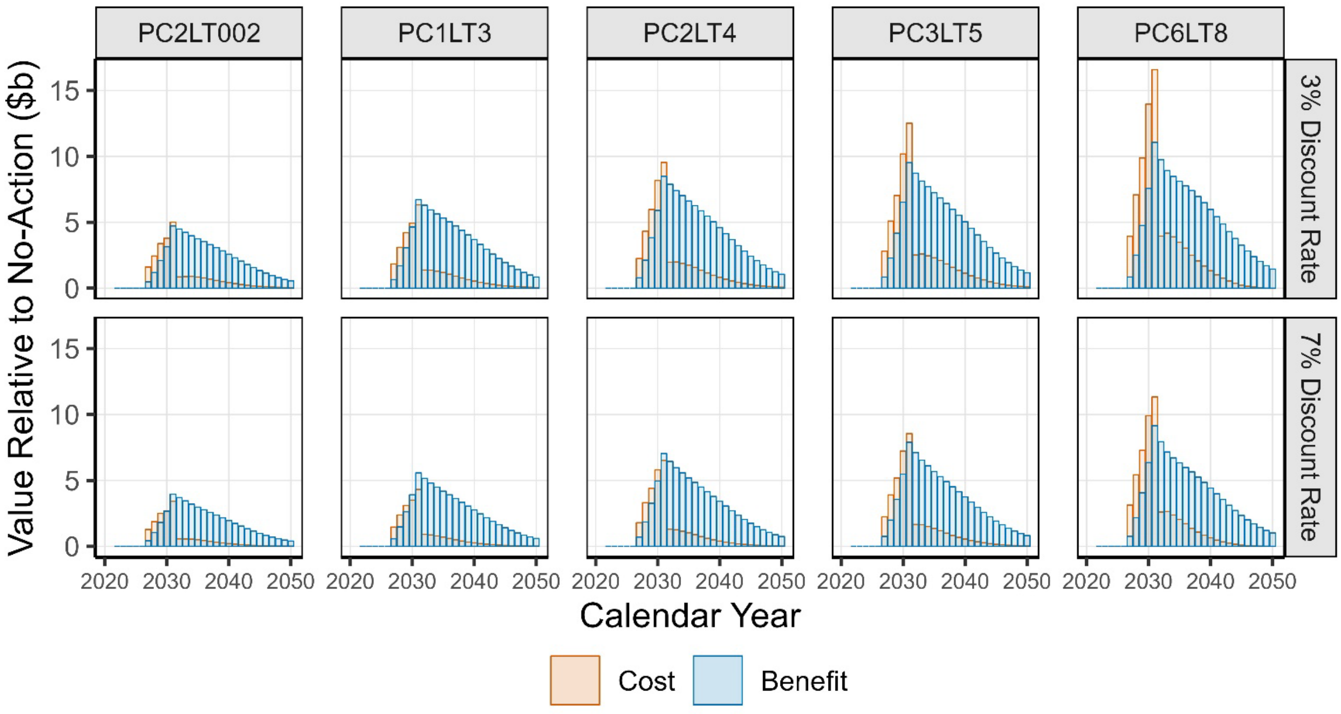
	No Action	PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
	Mean TCO Payback					
Passenger Car	2.2	0.2	0.3	0.7	1.4	5.8
Light Truck	1.6	0.5	1.3	1.9	2.7	6.0
	Median TCO Payback					
Passenger Car	1.5	0.0	0.0	0.0	1.0	4.0
Light Truck	0.5	1.0	2.0	2.0	3.0	7.0

8.2.4. 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 (8.2.4.1 through 8.2.4.6) discuss the external effects to society. Chapter 8.2.4.6 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 manufacturers and consumers described in Chapter 8.2.2 and Chapter 8.2.3.

The CAFE Model records costs and benefits by MYs 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 8-23 displays values for MYs 1983 through 2031 vehicles over their lifetimes, for all costs, including both private and social/external. Across all alternatives and both discount rates, for CY 2031 and earlier, costs exceed benefits, driven mostly by costs for applying efficiency-improving technologies. From 2032 onward, benefits exceed costs. The costs values increase as the alternatives become more stringent, with the highest costs occurring under Alternative PC6LT8, which also accrues the most benefits.

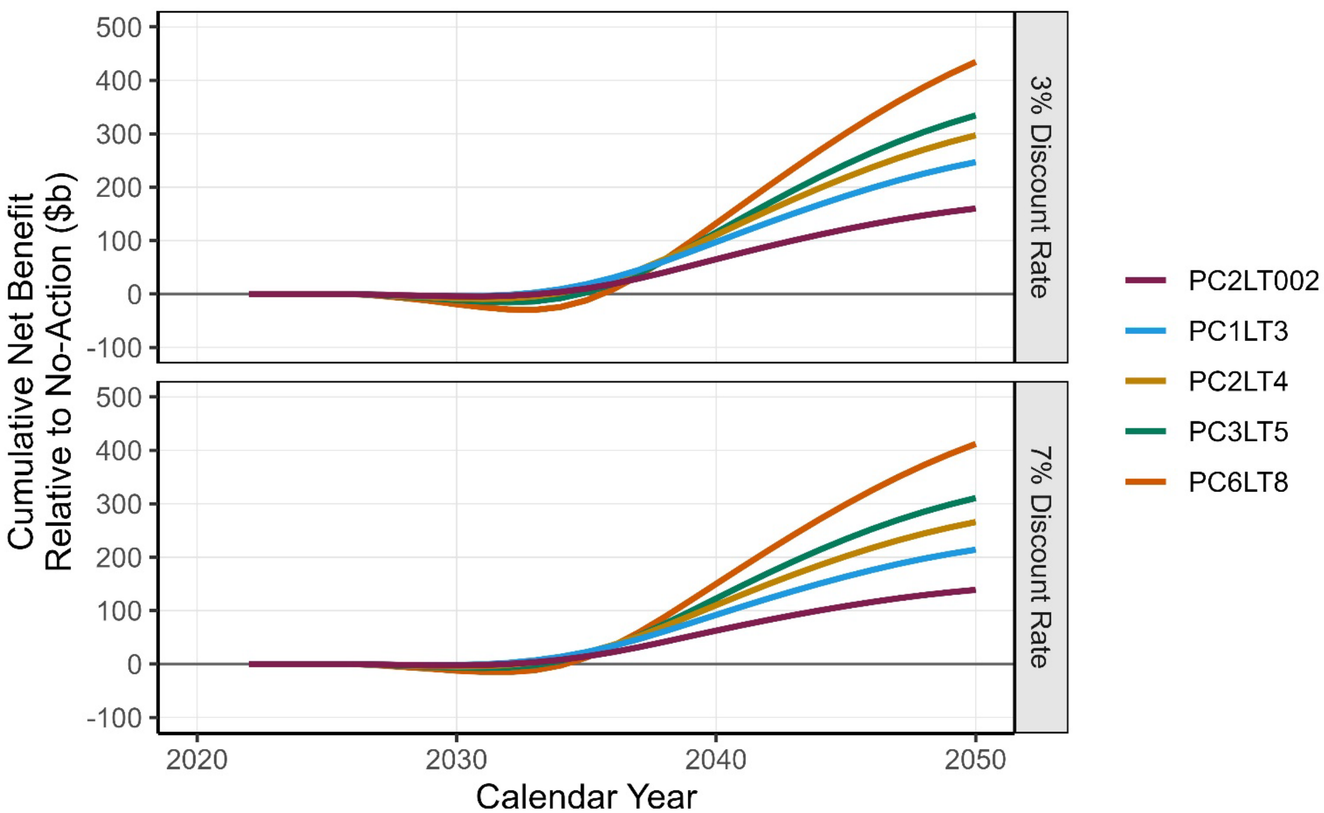
Figure 8-23: Annual Costs and Benefits of MYs 1983-2031 (Total Fleet), on a CY Basis[196]



[196] For exposition, the figure truncates costs and benefits at 2050. Some costs and benefits accrue out to 2071, though these values are relatively small.

This chapter 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.[197] Figure 8-24 aggregates annual cost and benefit streams to produce cumulative net benefits, by CY, for the five modeled alternatives. Estimated program compliance and outcomes indicate the industry reaches cumulative positive net benefits for Alternatives PC2LT002 and PC1LT3 in 2034 using a 3 percent discount rate (as well as PC2LT4 using a 7 percent discount rate). Using the 3 percent discount rate, Alternative PC2LT4 reaches this threshold in 2035, Alternative PC3LT5 in 2037, and Alternative PC6LT8 in 2038 (2036 for PC3LT5 and 2037 for PC6LT8 at the 7 percent discount rate). As shown in Figure 8-23 net benefits first become positive around CY 2031. In Figure 8-24 this can be seen by the change in slope from negative to positive for cumulative net benefits in the early 2030s. While the depth of the decline in cumulative net benefits is greater for Alternative PC6LT8 than any of the others, the net benefits also grow at a faster rate once they turn positive. The cumulative net benefits are highest under the more stringent alternatives, under both the 3% and 7% discount rates. This figure illustrates the prior note regarding the CY accounting perspective; the earlier years closest to the action years have different costs and benefits from the later years, but those later years can be sufficient to dominate the calculation of net benefits.

Figure 8-24: Cumulative Net Benefits, CY 2022-2050



The graphs in this chapter present certain effects in absolute terms, while others show incremental costs and benefits relative to the No-Action Alternative. Both model year and calendar year perspectives are used in this chapter depending on the effects discussed. Unless otherwise stated, the model year perspective includes MYs 1983-2031 and the calendar years that correspond to the full lifetimes of models produced in those model years (through calendar year 2070), while the calendar year perspective measures effects that accrue to the on-road fleet in CYs 2022-2050 only.

[197] See Chapter 5.3 of this FRIA for the differences between calendar year and model year reporting.

8.2.4.1. Social Benefits of Reducing GHG Emissions

NHTSA estimates the monetary value of climate effects using the values published by the EPA in late 2023.[198] See Chapter 6.2.1 in the TSD for discussion of how these values were integrated into the CAFE Model inputs. Section III.G.2.d.1 of the preamble details the reasoning behind NHTSA's decision to use these values.

For each of the three GHGs considered (CO_2, CH_4, and nitrous oxide (N_2O), the CAFE Model multiplies the cost per ton of emissions by the quantity emitted. Chapter 5 of the TSD describes the calculation of total emissions, from both upstream and downstream 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 2021 dollars. Table 8-5 lists the total costs of GHG emissions by alternative, for MYs 1983-2031, based on the three different SC-GHG discount rates. All values in Table 8-5 are in absolute terms, monetizing the incurred costs of emissions. Social costs associated with GHG emissions in the analysis decrease for all three GHGs (CO_2, CH_4, N_2O) as stringency increases across the alternatives.[199] Chapter 5 in the TSD also discusses the different pollutants included in our analysis.

Table 8-5: Total Costs of GHG Emissions Across Alternatives (2021$, in Billions, MYs 1983-2031)

	No Action (Reference Baseline)	PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
	2.5% SC-GHG discount rate[200]					
CO_2	2771.0	2753.2	2746.4	2740.5	2737.7	2732.6
CH_4	50.4	50.1	49.9	49.8	49.8	49.7
N_2O	34.9	34.7	34.7	34.6	34.6	34.6
	2% SC-GHG discount rate					
CO_2	4631.8	4601.7	4590.1	4580.3	4575.5	4566.9
CH_4	66.3	65.8	65.6	65.5	65.4	65.3
N_2O	54.4	54.1	54.0	54.0	53.9	53.9
	1.5% SC-GHG discount rate					
CO_2	8116.1	8062.8	8042.3	8024.9	8016.4	8001.2
CH_4	91.9	91.3	91.0	90.8	90.7	90.5
N_2O	88.6	88.1	88.0	87.9	87.9	87.8

Figure 8-25 and Figure 8-26 show the total social costs of GHG emissions in the No-Action Alternative for CYs 2022-2050, illustrating the relative magnitudes of each pollutant's monetized damages. 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 8.2.5), 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 SC-GHG estimate (discounted at 1.5 percent), damage costs due to GHG emissions peak at over $1 trillion dollars per year and then decline from there. In contrast, using the lowest estimates (discounted at 2.5 percent), damage costs amount to slightly over $350 billion dollars per year at their highest point, and then decline in future years.

[198] See p. 154 of 2023 EPA SC-GHG Report.
[199] Climate benefits are based on changes (reductions) in CO2, CH4, and N2O emissions and are calculated using three different estimates of the SCC, SC-CH4, and SC-N2O. Each estimate assumes a different discount rate (1.5 percent, 2 percent, and 2.5 percent). For simplicity, most tables throughout this analysis pair the 3 percent and 7 percent social discount rates of non-GHG related effects with a 2 percent discount rate for the social costs of GHGs. For comparison to NPRM values, Chapter 9includes results using the various discount rates and interim SC-GHGs estimates from the IWG that were used in the PRIA.

Figure 8-25: Social Costs of CO_2, CH_4, and N_2O Under the No-Action Alternative for CYs 2022-2050, 2.5% Discount Rate (2021$, Billions)

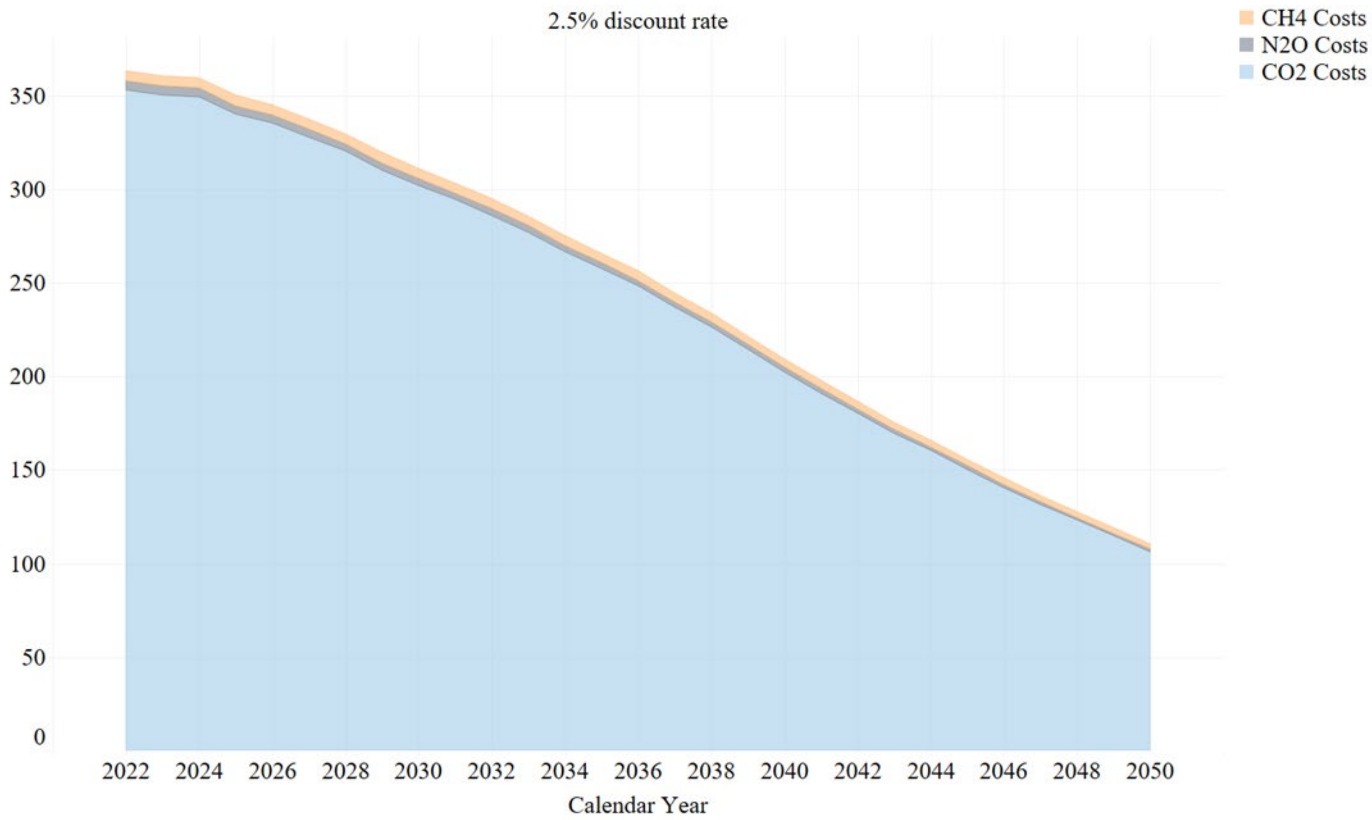


Figure 8-26: Social Costs of CO_2, CH_4, and N_2O Under the No-Action Alternative for CYs 2022-2050, 2% and 1.5% Discount Rates (2021$, Billions)

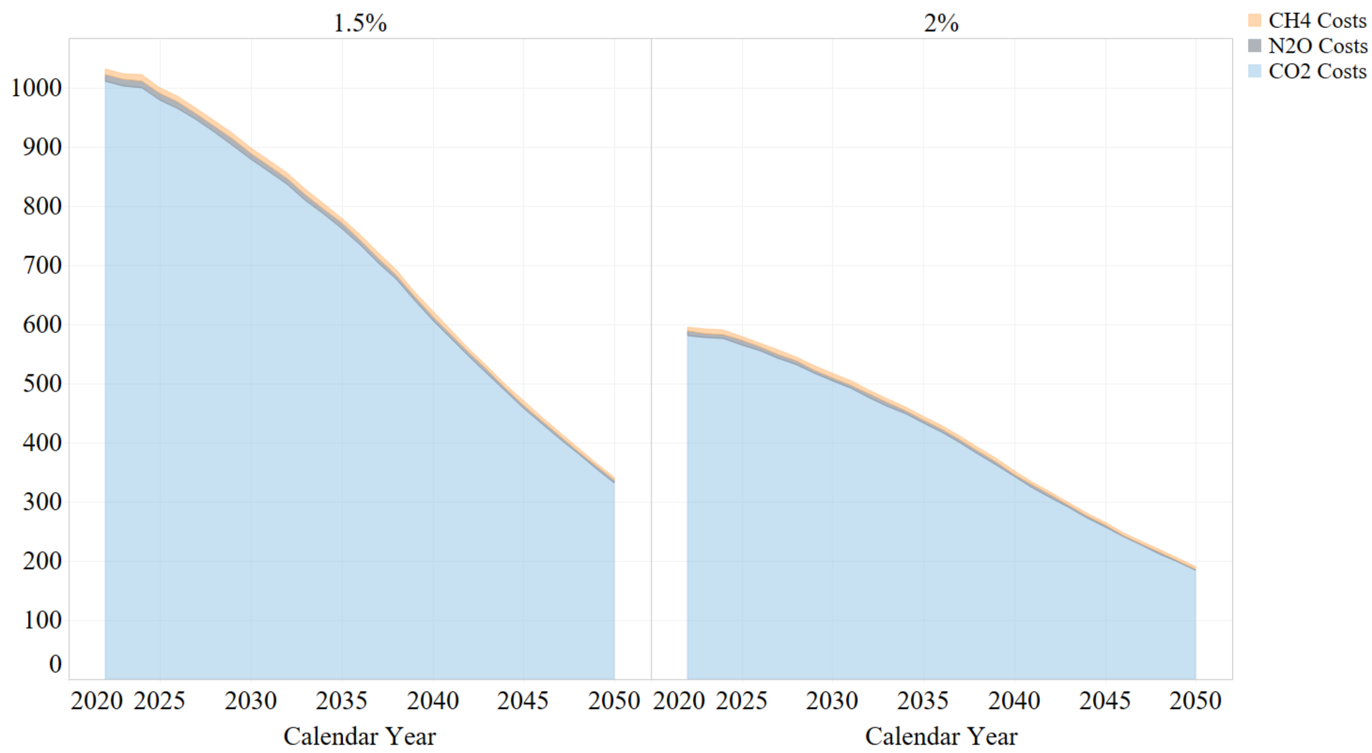


Table 8-6 presents the social costs of GHG emissions in terms of incurred costs.[201] This table reports GHG costs by SC-GHG discount rate. The GHG emission costs in the reference baseline are shown in absolutes, while the costs in each alternative are shown in terms of incremental reduced costs relative to the reference baseline. For instance, using the 2 percent discount rate, Alternative PC1LT3 reduces costs by approximately $42.7 billion relative to the No-Action levels (about 0.9 percent of the reference baseline total), while Alternative PC6LT8 reduces costs by $66.5 billion from the No-Action Alternative levels (approximately 1.4 percent of the total reference baseline costs). Alternative PC2LT4 reduces costs by approximately $52.8 billion.

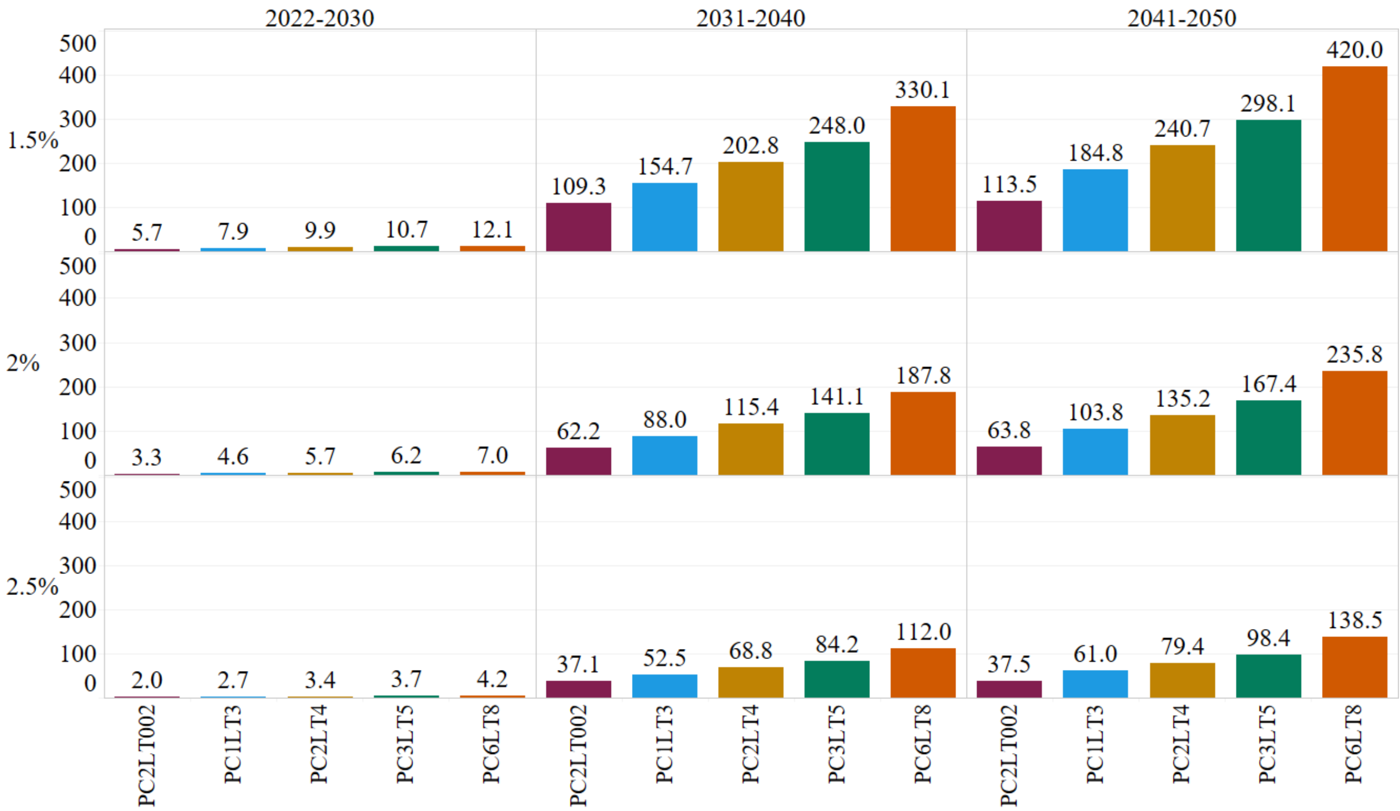
Table 8-6: Total GHG Costs in the Baseline and Avoided GHG Costs by Alternative (Relative to Baseline), by SC-GHG Discount Rate for MYs 1983-2031 (2021$, Billions)

SC-GHG Discount Rate	No Action (Baseline)	Relative to No Action				
		PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
2.5 percent	2,856.4	-18.3	-25.4	-31.4	-34.3	-39.5
2 percent	4,752.5	-30.9	-42.7	-52.8	-57.7	-66.5
1.5 percent	8,296.6	-54.4	-75.3	-93.0	-101.6	-117.2

Figure 8-27 and Figure 8-28 focus on these reduced costs relative to the reference baseline, presenting them as benefits in positive terms (avoided costs). Unlike in the previous graphs, this figure shows the distribution of GHG benefits across CYs, dividing the benefits into three decades: 2022-2030, 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.

[201] Negative incurred costs relative to the baseline are GHG costs that are avoided due to the action alternatives (i.e., reduced fuel consumption reduces GHG emissions). These avoided costs appear in figures and tables later in this chapter as positive values, as they enter the cost-benefit analysis as external social benefits.

Figure 8-27: Avoided GHG Costs Relative to the No-Action Alternative (2021$, Billions, 2.5%, 2%, and 1.5% Discount Rates, CYs 2022-2050)



8.2.4.2. Social Benefits of Reducing Criteria Pollutant Emissions

The criteria pollutant emissions computed by the CAFE Model—the contributions of nitrogen oxides (NO_X) and sulfur oxides (SO_X) to the formation of particulate matter 2.5 microns or less in diameter ($PM_{2.5}$),[202] and directly-emitted $PM_{2.5}$—are linked to various health impacts (see TSD Chapter 5.4).[203] 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 Output Files. For further information pertaining to these criteria pollutant emissions, see also Chapter 4 in the Final EIS.

Table 8-7: Total and Incremental Costs of Criteria Pollutants, by Alternative and Social Discount Rate, MYs 1983-2031 (2021$, Billions)

	No Action (Total)	PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
3% Social Discount Rate						
NO_X	46.6	-0.02	-0.04	-0.04	-0.04	-0.01
SO_X	62.6	-0.13	-0.30	-0.39	-0.43	-0.50
$PM_{2.5}$	299.2	-0.58	-0.42	-0.36	-0.25	-0.03

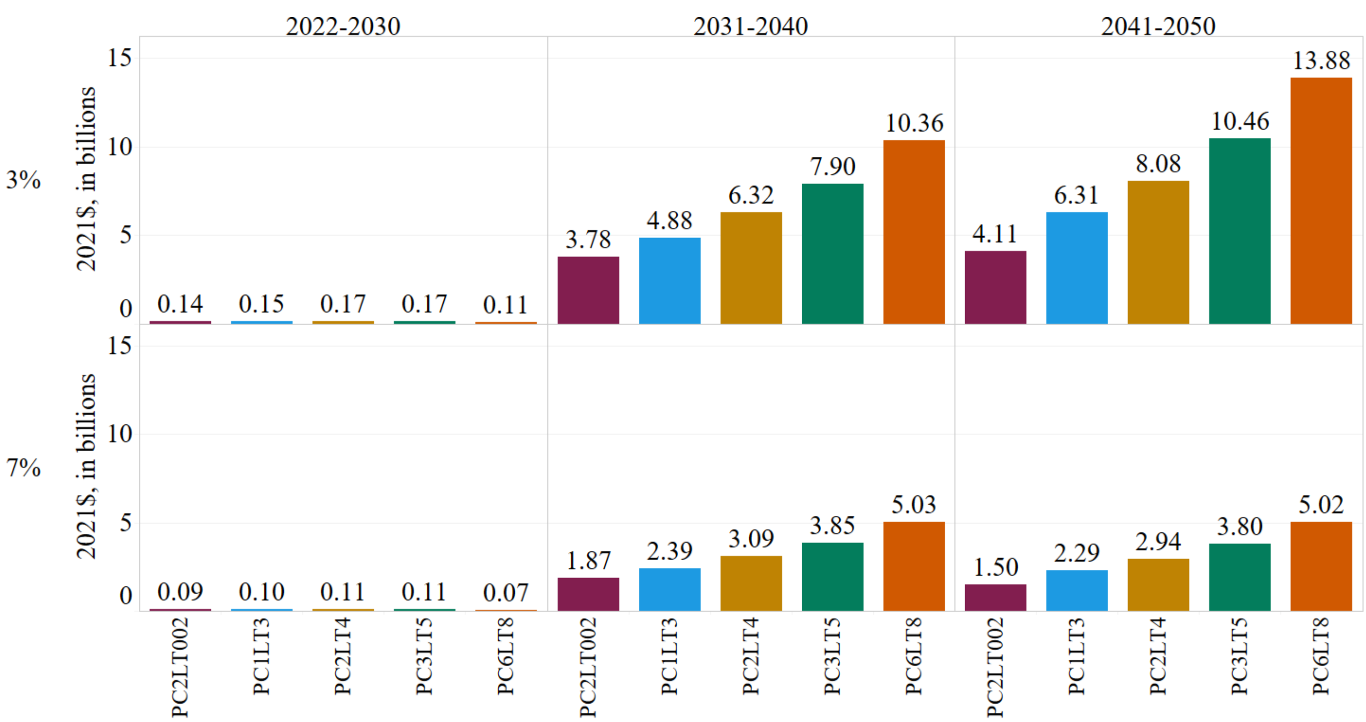
202 Although the health impacts of NO_x and SO_2 are associated with their contribution to secondarily-formed PM2.5, we refer to these as NOx and SOx health impacts throughout this chapter for simplicity and to show the origin of the pollution impacts.
203 The morbidity health impacts included in the 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.

7% Social Discount Rate						
NO_X	32.6	-0.01	-0.02	-0.02	-0.02	0.00
SO_X	41.2	-0.06	-0.15	-0.20	-0.22	-0.26
$PM_{2.5}$	194.2	-0.29	-0.20	-0.17	-0.11	0.02

Table 8-7 shows the total and incremental health costs attributable to the three criteria pollutants under each rulemaking alternative, using the model year perspective (MYs 1983-2031), discounted at 3 and 7 percent. In the No-Action Alternative column, we present these costs in absolute terms. Incremental costs are presented relative to the reference baseline in each action alternative. These social costs decrease slightly for all pollutants across all alternatives. In the model year perspective, social costs of SO_X decrease across all alternatives, with the magnitude of the decrease corresponding positively to the stringency of the alternative. Social costs of NO_x decrease across all alternatives, with the larger decreases in alternatives PC1LT3 through PC3LT5. Social costs of $PM_{2.5}$ decrease across all alternatives as well (with the exception of PC6LT8 using a 7% discount rate), but the magnitude of those decreases shrinks in more stringent alternatives. Chapter 8.2.5.3, which describes the changes in the pollutants themselves across alternatives, rather than the changes in costs, includes further explanation of these effects on a calendar year basis.

Figure 8-28 shows increased benefits from avoided criteria pollutants with increasing stringency and across calendar year cohorts, as opposed to across model year lifetimes. Although the reference baseline levels of all of the pollutants decrease across calendar years, and in terms of tons NO_x has the highest magnitude of emissions, the bulk of the reduction in criteria pollutant costs in the preferred alternative in dollar terms is due to decreasing PM levels, which have more health costs per ton associated with them than NO_x and sulfur dioxide (SO_2). In other alternatives, benefits associated with the reduction of SO_x are larger. As seen in the figure, the calendar year perspective allows us to see that most of these benefits accrue in later years, from 2031 and beyond.

Figure 8-28: Benefit from Avoided Criteria Pollutants Relative to the No-Action Alternative (2021$, Billions, 3% and 7% Discount Rates, CYs 2022-2050)



8.2.4.3. Social Costs of Changes to Congestion and Road Noise

Table 8-8 and Table 8-9 report the incremental social costs of congestion and noise relative to the totals in the reference baseline across alternatives on a model year basis. Congestion and noise are functions of VMT, and therefore the increases in these costs relate directly to increases in VMT, across MY and alternatives (see Chapter 8.2.5). 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.

Table 8-8: Social Costs of Congestion and Noise Across Alternatives for MYs 1983-2031 (2021$, in Billions), Discounted at 3%

		Relative to Alternative 0				
	No Action (Total)	PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Congestion	4743.89	2.04	3.01	4.68	6.45	8.32
Noise	43.25	0.02	0.03	0.04	0.06	0.08

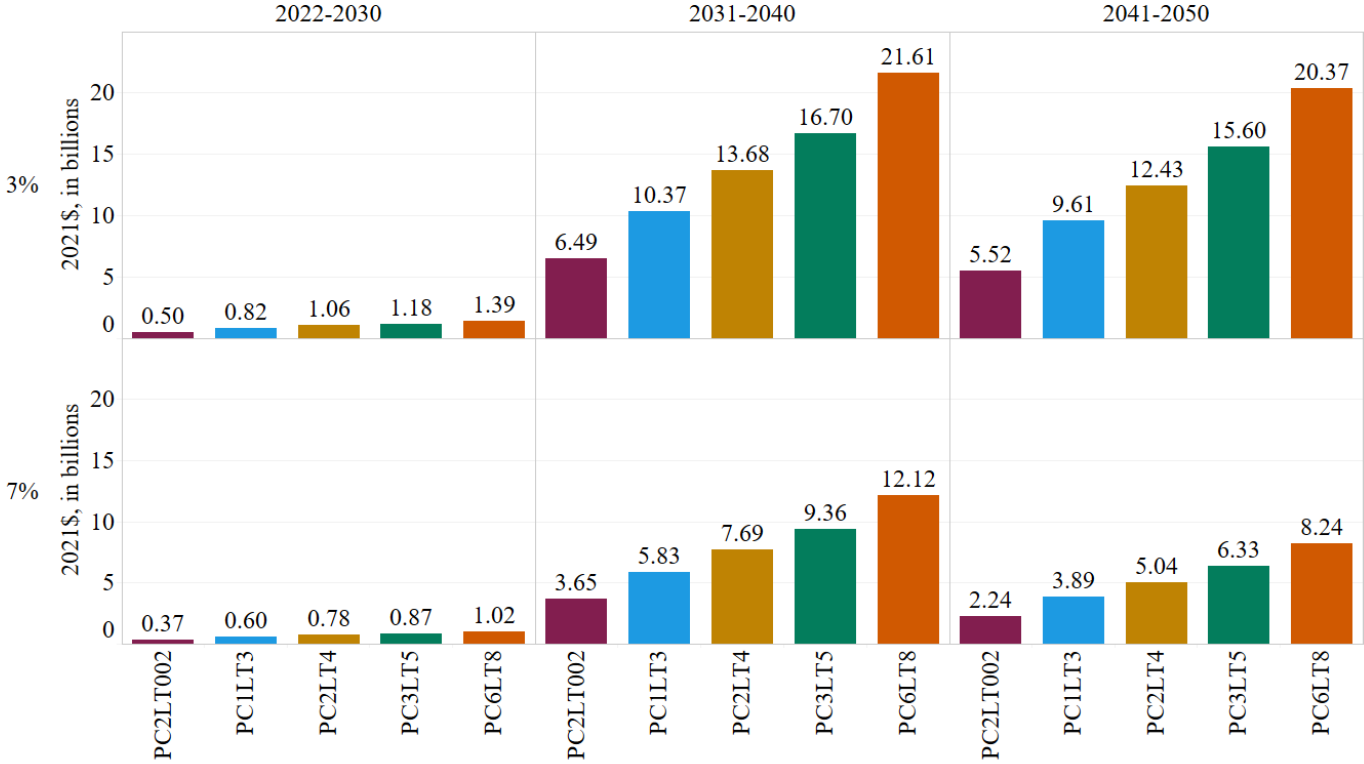
Table 8-9: Social Costs of Congestion and Noise Across Alternatives for MYs 1983-2031 (2021$, in Billions), Discounted at 7%

		Relative to Alternative 0				
	No Action (Total)	PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Congestion	3379.06	1.20	1.79	2.73	3.69	4.95
Noise	30.79	0.01	0.02	0.02	0.03	0.04

Figure 8-29 focuses on these differences in costs between the alternatives relative to the reference baseline. 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 Figure 8-29 (corresponding to the 3 percent discount rate), the bar corresponding to Alternative PC6LT8 in the period from 2041-2050 represents a $20.37 billion increase in congestion and noise costs relative to the reference baseline totals. Most of the incremental costs are incurred during the second decade, 2031-2040.

It is important to note that the incremental costs presented in Figure 8-29, even at their highest, are equal in value to a relatively small portion of the total congestion and noise costs incurred in the No-Action alternative. For instance, under Alternative PC6LT8, using a 3 percent discount rate, the incremental costs arising from noise and congestion between 2041-2050 were equal in magnitude to about 0.4 percent of the total congestion and noise reference baseline costs.

Figure 8-29: Congestion and Noise Costs Relative to the No-Action Alternative, CYs 2022-2050 (2021$, Billions)



8.2.4.4. 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 internalized by consumers through long-run equilibrium gasoline 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.

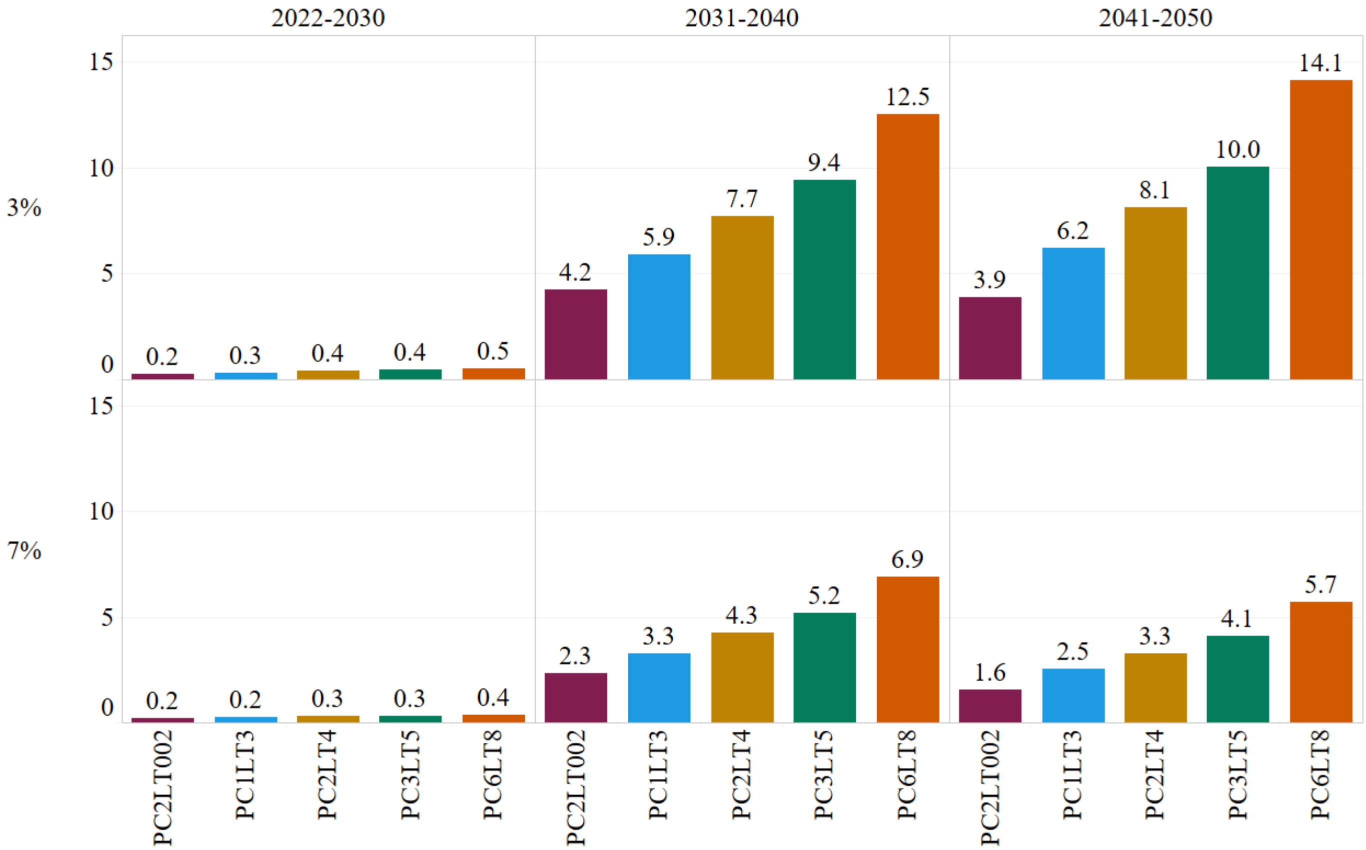
As seen in Table 8-10, social costs of petroleum market externalities decrease (or the benefits of increased energy security increase) in all alternatives, and the magnitudes of the decreases become greater as the alternatives become more stringent. The scope of these changes is relatively small; using the 3 percent discount rate, the largest benefits (avoided incremental energy security costs) are approximately equal to 1.3 percent of the total petroleum market externality costs in the No-Action Alternative.

Table 8-10: Social Costs of Increased Energy Security Relative to the No-Action Alternative, MYs 1983-2031 (2021$, Billions)

	No Action	PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
3% discount rate	159.8	-1.03	-1.38	-1.69	-1.85	-2.11
7% discount rate	114.6	-0.57	-0.76	-0.94	-1.02	-1.16

Figure 8-30 shows the distribution of these avoided costs (positive benefits) across CY 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 reference baseline.

Figure 8-30: Avoided Costs of Petroleum Externalities Relative to the No-Action Alternative, CYs 2022-2050 (2021$, Billions)



8.2.4.5. Safety Effects of Changing Standards

Table 8-11 through Table 8-13 summarize the safety impacts of each alternative broken down by safety factor. These impacts are summarized over CYs 2022-2050, for all light passenger vehicles (including PCs and LTs). Economic impacts are shown separately under both 3 and 7 percent discount rates. Discounting is applied to CY cost impacts. Fatality, non-fatal injury, and Property Damage-Only (PDO) counts are undiscounted.

As noted previously, safety impacts are expected to be driven by changes in vehicle mass resulting from vehicles having mass reduction applied to improve fuel economy, through increased exposure from rebound miles driven in response to reduced driving costs that result from improved fuel economy, 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 PCs compared to LTs.

Generally, the improved fuel efficiency required by higher CAFE standards triggers greater use of mass reduction and the resulting reductions in driving costs produce more rebound driving. Higher prices resulting from higher CAFE requirements slow the turnover of the vehicle fleet. As standards become more stringent, the additional cost of attaining those standards increases the price of new vehicles. This results in fewer new vehicles being sold and more miles being driven on older vehicles without improved safety features and technologies of newer vehicles. In addition, changes in the relative prices of cars and trucks result in changes in the sales of each through the CAFE Model's fleet share adjustment. Constrained non-rebound VMT is then reallocated between fleets, resulting in changes in the incremental safety effects for cars and trucks. Since this is largely a function of reference baseline VMT being transferred between regulatory classes, much of the effect nets out at the light duty fleet level.

Across alternatives, except for PC6LT8, mass changes relative to the reference baseline result in small reductions in overall fatalities, injuries, and property damage. For less stringent standards, mass reduction is predominantly applied to LTs and results in a net increase in safety. Under PC6LT8, mass reduction is applied increasingly to PCs and this PC mass reduction negatively affects safety in aggregate (although the effects of mass reduction on safety are not statistically distinguishable from zero). Furthermore, the change in the model's predicted fleet share of LTs relative to PCs plays a meaningful role in the mass-safety outcome. It is important to note, as discussed in TSD Ch. 7.3.3, the mass-safety parameters estimated from statistical models used in the CAFE analysis are statistically indistinguishable from zero. Rebound and scrappage effects increase fatalities as policy alternatives become more stringent. The total societal crash costs range from $11.2 ($5.6) billion to $43.4 ($22.2) billion across alternatives with a 3% (7%) discount rate.

Table 8-13 illustrates the cumulative impact of each alternative on the number of fatalities, nonfatal injuries, and vehicles sustaining property damage during CYs 2022 through 2050. For context, during this same period, reference baseline fatalities are expected to total somewhat less than 600,000, or an annual average of about 20,000. The PDO costs for sales/scrappage are shown as a benefit. This is a result of sale/scrappage effects being estimated as total PDO crashes minus rebound and mass attributed PDO crashes. The model calculates PDO using a separate model from non-fatal and fatal crashes and then we account for rebound and mass-safety effects separately. Sales/scrappage PDO crashes are deemed to be the difference between total PDO crashes minus PDS crashes attributable to either rebound driving or mass changes.[204]

Table 8-11: Change in Safety Parameters from Alternative 0 (Reference Baseline) for CY 2022-2050 for Total Fleet, 3% Discount Rate, by Alternative

Change in Safety Parameters from Alternative 0 (Reference Baseline) for CY 2022-2050 for Total Fleet, 3% Discount Rate, by Alternative					
Alternative	**PC2LT002**	**PC1LT3**	**PC2LT4**	**PC3LT5**	**PC6LT8**
Fatality Costs ($b)					
Fatality Costs from Mass Changes	0.0	-0.2	-0.3	-0.4	0.4
Fatality Costs from Rebound Effect	2.9	4.7	6.2	7.6	9.9
Fatality Costs from Sales/Scrappage	0.2	0.3	0.6	1.1	2.2
Total - Fatality Costs	3.1	4.8	6.6	8.4	12.6
Non-Fatal Crash Costs ($b)					
Non-Fatal Crash Costs from Mass Changes	0.0	-0.4	-0.6	-0.9	1.0
Non-Fatal Crash Costs from Rebound Effect	6.8	11.1	14.6	18.0	23.6
Non-Fatal Crash Costs from Sales/Scrappage	0.2	0.3	0.8	1.5	2.9
Total - Non-Fatal Crash Costs	7.1	10.9	14.8	18.6	27.4
Property Damage Costs ($b)					
Property Damage Costs from Mass Changes	0.0	-0.1	-0.1	-0.1	0.2
Property Damage Costs from Rebound Effect	1.1	1.8	2.3	2.8	3.7
Property Damage Costs from Sales/Scrappage	0.0	-0.1	-0.2	-0.3	-0.5
Total - Property Damage Costs	1.0	1.6	2.0	2.4	3.4
Societal Crash Costs ($b)					
Crash Costs from Mass Changes	0.0	-0.7	-1.0	-1.4	1.5
Crash Costs from Rebound Effect	10.8	17.6	23.1	28.5	37.3
Crash Costs from Sales/Scrappage	0.4	0.4	1.2	2.3	4.6

[204] See TSD Chapter 7.5.

Total - Societal Crash Costs	11.2	17.3	23.3	29.4	43.4

Table 8-12: Change in Safety Parameters from Alternative 0 (Reference Baseline) for CY 2022-2050 for Total Fleet, 7% Discount Rate, by Alternative

Change in Safety Parameters from Alternative 0 (Reference Baseline) for CY 2022-2050 for Total Fleet, 7% Discount Rate, by Alternative					
Alternative	**PC2LT002**	**PC1LT3**	**PC2LT4**	**PC3LT5**	**PC6LT8**
Fatality Costs ($b)					
Fatality Costs from Mass Changes	0.0	-0.1	-0.1	-0.2	0.2
Fatality Costs from Rebound Effect	1.4	2.3	3.0	3.7	4.8
Fatality Costs from Sales/Scrappage	0.1	0.2	0.5	0.8	1.6
Total - Fatality Costs	1.5	2.4	3.4	4.3	6.6
Non-Fatal Crash Costs ($b)					
Non-Fatal Crash Costs from Mass Changes	0.0	-0.2	-0.3	-0.4	0.4
Non-Fatal Crash Costs from Rebound Effect	3.3	5.4	7.1	8.7	11.3
Non-Fatal Crash Costs from Sales/Scrappage	0.2	0.3	0.7	1.2	2.3
Total - Non-Fatal Crash Costs	3.5	5.5	7.5	9.5	14.0
Property Damage Costs ($b)					
Property Damage Costs from Mass Changes	0.0	0.0	0.0	-0.1	0.1
Property Damage Costs from Rebound Effect	0.5	0.9	1.1	1.4	1.8
Property Damage Costs from Sales/Scrappage	0.0	-0.1	-0.1	-0.2	-0.3
Total - Property Damage Costs	0.5	0.8	1.0	1.2	1.6
Societal Crash Costs ($b)					
Crash Costs from Mass Changes	0.0	-0.3	-0.4	-0.6	0.6
Crash Costs from Rebound Effect	5.3	8.5	11.2	13.8	17.9
Crash Costs from Sales/Scrappage	0.3	0.5	1.1	1.8	3.7
Total - Societal Crash Costs	5.6	8.7	11.8	15.0	22.2

Table 8-13: Change in Fatalities, Non-Fatal Injuries, and PDO from Alternative 0 (Reference Baseline) for CY 2022-2050 for Total Fleet, by Alternative

Change in Safety Parameters from Alternative 0 (Reference Baseline) for CY 2022-2050 by Alternative					
Alternative	**PC2LT002**	**PC1LT3**	**PC2LT4**	**PC3LT5**	**PC6LT8**
Fatalities					
Fatalities From Mass Changes	0	-30	-40	-60	65
Fatalities from Rebound Effect	426	698	915	1,133	1,484
Fatalities from Sales/Scrappage	16	20	60	116	215
Total Changes in Fatalities	442	688	935	1,189	1,764
Non-Fatal Crashes					

Non-Fatal Crash from Mass Changes	-17	-4,721	-6,437	-9,560	10,517
Non-Fatal Crash from Rebound Effect	67,888	111,123	145,705	180,463	236,560
Non-Fatal Crash from Sales/Scrappage	998	291	3,668	8,781	15,943
Total - Non-Fatal Crash	68,869	106,692	142,935	179,683	263,020
Property Damaged Vehicles					
Property Damage Vehicles from Mass Changes	770	-15,964	-21,594	-32,168	38,593
Property Damage Vehicles from Rebound Effect	226,067	371,536	486,205	602,874	792,940
Property Damage Vehicles from Sales/Scrappage	-8,313	-20,236	-36,412	-55,721	-93,846
Total - Property Damage Vehicles	218,524	335,336	428,200	514,985	737,686

8.2.4.6. Summary of Social Benefits and Costs

Table 8-14 and Table 8-15 describe the costs and benefits of increasing CAFE standards in each alternative, as well as the party to which they accrue, from the model year and calendar year perspective, respectively. See Chapter 8.1 for a discussion of the differences between these two perspectives, which cause variation in the magnitudes of the resulting costs and benefits. 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, civil penalties that are paid to the U.S. Treasury to cover shortfalls fund the general business of government. As such, they are a transfer from new vehicle buyers (through manufacturers) 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 central analysis. They are difficult to estimate for emerging technologies but represent real costs (and real benefits in the case of AFVs 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). See Chapter 7 in the TSD for further discussion.

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 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 social costs.[205] Of these social costs, the largest is the loss in fuel tax revenue that occurs as a result of falling fuel consumption.[206] Buyers of new cars

[205] 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.
[206] 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.

and light trucks produced in model years subject to increasing CAFE standards save on fuel purchases that include Federal, state, and sometimes local or Tribal 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 revenue represents a social cost.[207] 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 an 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. These tables show the different social net benefits 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 majority of costs are private costs that accrue to buyers of new cars and trucks, but the majority of benefits stem from external welfare changes that affect society more generally. These external benefits are driven mainly by the benefits from reducing GHGs.

The choice of discount rate social discount rate also affects the resulting benefits and costs. As the tables show, net social benefits are positive for all alternative, but have higher magnitudes when climate benefits are discounted using lower discount rates lower discount rates. Totals in the following table may not sum perfectly due to rounding.

Table 8-14: Incremental Benefits and Costs Over the Lifetimes of Total Fleet Produced Through 2031 (2021$ Billions), by Alternative

	3% Discount Rate					7% Discount Rate				
	PC2 LT002	**PC1 LT3**	**PC2 LT4**	**PC3 LT5**	**PC6 LT8**	**PC2 LT002**	**PC1 LT3**	**PC2 LT4**	**PC3 LT5**	**PC6 LT8**
Private Costs										
Technology Costs to Increase Fuel Economy	14.0	16.9	25.6	32.0	43.0	10.2	12.3	18.5	23.1	31.1
Increased Maintenance and Repair Costs*	-	-	-	-	-	-	-	-	-	-
Sacrifice in Other Vehicle Attributes*	-	-	-	-	-	-	-	-	-	-
Consumer Surplus Loss from Reduced New Vehicle Sales	0.0	0.0	0.1	0.2	0.7	0.0	0.0	0.0	0.1	0.5
Safety Costs Internalized by Drivers	2.7	4.3	5.7	6.5	8.0	1.5	2.4	3.2	3.6	4.5
Subtotal - Private Costs	16.8	21.3	31.3	38.7	51.7	11.7	14.7	21.7	26.9	36.0
Social Costs										
Congestion and Noise Costs from Rebound-Effect Driving	2.1	3.0	4.7	6.5	8.4	1.2	1.8	2.8	3.7	5.0
Safety Costs Not Internalized by Drivers	1.4	1.8	4.0	7.2	11.9	0.9	1.3	2.6	4.5	7.9
Loss in Fuel Tax Revenue	4.2	5.7	7.0	7.6	8.7	2.4	3.2	4.0	4.3	4.9
Subtotal - Social Costs	7.7	10.5	15.7	21.4	29.0	4.5	6.3	9.3	12.5	17.8
Total Societal Costs (incl. private)	24.5	31.8	47.1	60.1	80.8	16.2	21.0	31.0	39.4	53.8

[207] 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	21.4	32.3	40.7	44.8	52.0	12.0	18.1	22.8	25.0	28.9
Benefits from Additional Driving	4.3	6.9	9.0	10.3	12.4	2.4	3.9	5.1	5.8	6.9
Less Frequent Refueling	1.3	1.7	2.2	2.5	3.1	0.8	1.0	1.2	1.4	1.8
Subtotal - Private Benefits	27.0	41.0	51.9	57.6	67.5	15.2	22.9	29.1	32.2	37.5
External Benefits										
Reduction in Petroleum Market Externality	1.0	1.4	1.7	1.8	2.1	0.6	0.8	0.9	1.0	1.2
Reduced Health Damages	0.7	0.8	0.8	0.7	0.6	0.4	0.4	0.4	0.3	0.2
Reduced Climate Damages										
SC-GHG at 2.5% DR[208]	18.3	25.4	31.4	34.3	39.5	18.3	25.4	31.4	34.3	39.5
SC-GHG at 2.0% DR	30.9	42.7	52.8	57.7	66.5	30.9	42.7	52.8	57.7	66.5
SC-GHG at 1.5% DR	54.4	75.3	93.0	101.6	117.2	54.4	75.3	93.0	101.6	117.2
Total Societal Benefits (incl. private)										
SC-GHG at 2.5% DR	47.1	68.5	85.7	94.4	109.6	34.5	49.4	61.7	67.9	78.4
SC-GHG at 2.0% DR	59.7	85.8	107.2	117.8	136.6	47.0	66.8	83.1	91.3	105.4
SC-GHG at 1.5% DR	83.2	118.4	147.4	161.8	187.3	70.5	99.3	123.4	135.2	156.1
Net Social Benefits										
SC-GHG at 2.5% DR	22.7	36.7	38.7	34.3	28.8	18.2	28.4	30.7	28.5	24.6
SC-GHG at 2.0% DR	35.2	54.0	60.1	57.7	55.8	30.8	45.8	52.1	51.9	51.6
SC-GHG at 1.5% DR	58.7	86.6	100.3	101.7	106.6	54.3	78.3	92.3	95.8	102.3

* The costs of increased maintenance and repair and sacrifices to other vehicle attributes are not estimated.

Table 8-15: Incremental Benefits and Costs for the On-Road Fleet CY 2022-2050 (2021$ Billions), by Alternative

	3% Discount Rate					7% Discount Rate				
	PC2L T002	PC1 LT3	PC2 LT4	PC3 LT5	PC6 LT8	PC2L T002	PC1 LT3	PC2 LT4	PC3 LT5	PC6 LT8
Private Costs										
Technology Costs to Increase Fuel Economy	43.1	63.4	107.3	158.4	233.9	26.7	37.6	62.1	89.6	131.1
Increased Maintenance and Repair Costs*	-	-	-	-	-	-	-	-	-	-
Sacrifice in Other Vehicle Attributes*	-	-	-	-	-	-	-	-	-	-
Consumer Surplus Loss from Reduced New Vehicle Sales	0.0	0.0	0.2	0.4	1.6	0.0	0.0	0.1	0.3	1.0
Safety Costs Internalized by Drivers	9.7	15.8	20.8	25.6	33.5	4.8	7.7	10.1	12.4	16.1

208 We discount the benefits of reduced GHG emissiosn at different rates than the other costs and benefits. For instance, this row shows the monetized benefits from reducing GHGs constructed with a 2.5% near-term Ramsey discount rate, which are discounted from year of emission to present value at 2.5%.

Subtotal - Private Costs	52.9	79.3	128.3	184.4	269.0	31.5	45.3	72.3	102.2	148.2
Social Costs										
Congestion and Noise Costs from Rebound-Effect Driving	6.3	10.4	13.6	16.7	21.7	3.1	5.2	6.8	8.3	10.7
Safety Costs Not Internalized by Drivers	1.4	1.5	2.6	3.8	9.8	0.8	1.0	1.7	2.6	6.1
Loss in Fuel Tax Revenue	16.2	24.1	31.4	38.5	52.4	8.1	11.9	15.5	18.8	25.4
Subtotal - Social Costs	23.9	36.0	47.6	59.0	83.9	12.1	18.1	24.0	29.7	42.2
Total Societal Costs (incl. private)	76.8	115.3	175.8	243.4	352.9	43.6	63.4	96.3	131.9	190.4
Private Benefits										
Reduced Fuel Costs	82.0	129.5	169.5	207.0	280.7	40.6	63.5	83.0	100.9	135.5
Benefits from Additional Driving	15.2	24.9	32.5	39.6	50.9	7.5	12.1	15.9	19.3	24.6
Less Frequent Refueling	2.3	-0.4	-0.6	-2.7	-0.5	1.3	0.0	0.0	-0.9	0.1
Subtotal - Private Benefits	99.5	154.0	201.3	243.9	331.1	49.4	75.6	98.8	119.3	160.3
External Benefits										
Reduction in Petroleum Market Externality	4.2	6.2	8.1	9.9	13.6	2.1	3.0	3.9	4.8	6.5
Reduced Health Damages	4.0	5.7	7.3	9.3	12.2	1.7	2.4	3.1	3.9	5.1
Reduced Climate Damages										
SC-GHG at 2.5% DR	76.5	116.2	151.6	186.2	254.6	76.5	116.2	151.6	186.2	254.6
SC-GHG at 2% DR	129.2	196.4	256.3	314.8	430.6	129.2	196.4	256.3	314.8	430.6
SC-GHG at 1.5% DR	228.5	347.4	453.4	556.9	762.2	228.5	347.4	453.4	556.9	762.2
Total Societal Benefits (incl. private)										
SC-GHG at 2.5% DR	184.2	282.0	368.4	449.3	611.5	129.7	197.2	257.5	314.2	426.5
SC-GHG at 2% DR	236.9	362.2	473.0	577.9	787.5	182.4	277.4	362.1	442.7	602.5
SC-GHG at 1.5% DR	336.2	513.3	670.1	820.0	1,119.1	281.6	428.5	559.2	684.8	934.0
Net Social Benefits										
SC-GHG at 2.5% DR	107.4	166.8	192.5	205.9	258.6	86.1	133.9	161.2	182.2	236.1
SC-GHG at 2% DR	160.1	247.0	297.1	334.4	434.6	138.8	214.1	265.8	310.7	412.1
SC-GHG at 1.5% DR	259.3	398.0	494.2	576.5	766.2	238.0	365.1	462.9	552.9	743.6

* The costs of increased maintenance and repair and sacrifices to other vehicle attributes are not estimated.

8.2.5. Physical and Environmental Effects

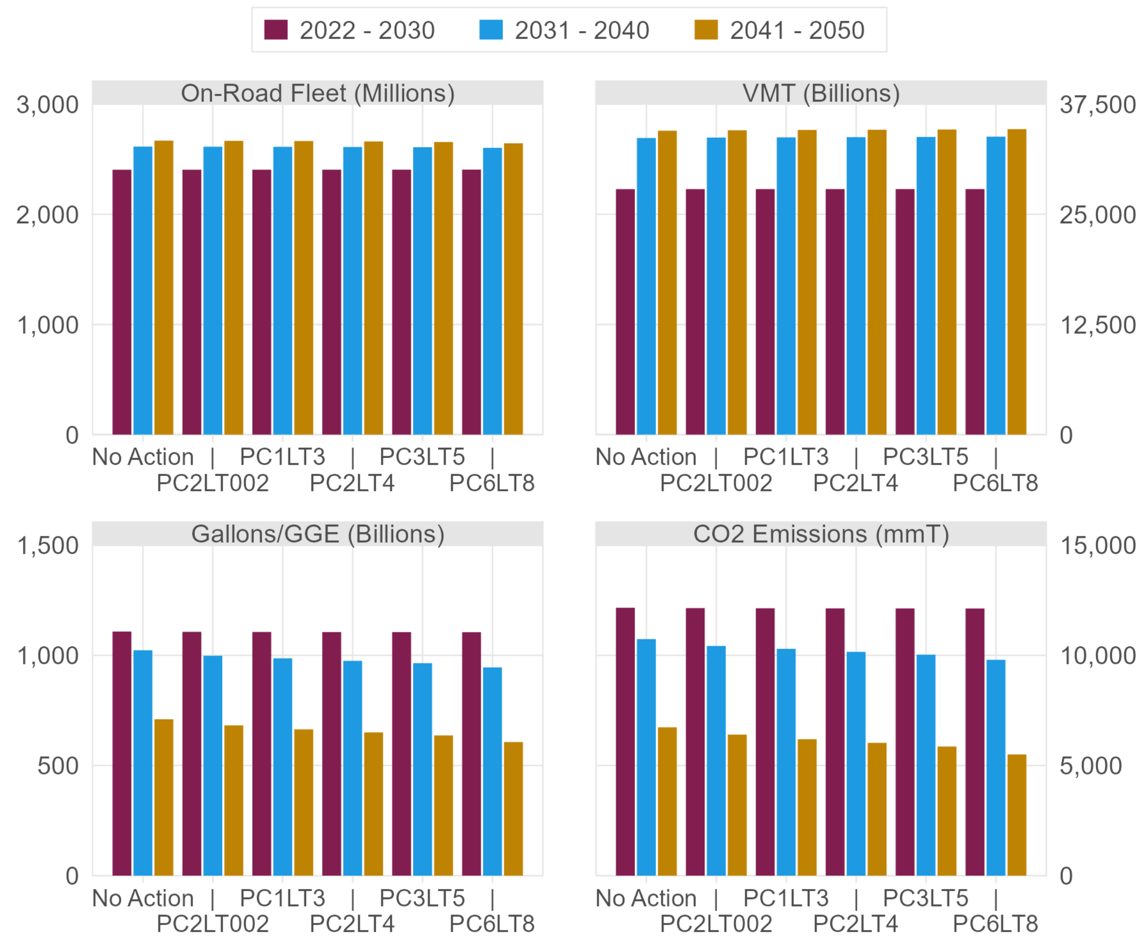
Since improvements in vehicle fuel economy typically add costs to those vehicles, and since added cost often results in higher prices, the sale of new vehicle models may be impacted as consumers prefer to hold on to their existing vehicles for longer if they perceive that the value of fuel savings is less than the increase in purchase price. Over time, the cumulative change in new vehicle sales and retirement of older vehicles will impact 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 reference baseline scenario (the No-Action Alternative) in the out years. 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, thereby increasing the total demand for travel. As a consequence of reduced 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. Since the first model year evaluated in this analysis is MY 2022, the first aggregation period in the table and figure cover the range of CYs between CYs 2022 and 2030, while each of the latter two encompass effects over a full decade. As such, the values shown for the first calendar year grouping are marginally lower (by comparison) than what they would have been if the entire ten-year horizon was available. Nevertheless, the cumulative impacts are presented in such a way to provide a reader with a snapshot of the overall results of the analysis, while also demonstrating the relative differences between calendar year groups. Later chapters present this information in a disaggregated manner, by focusing on the effects during individual CYs.

Table 8-16: Cumulative Physical and Environmental Effects for All Alternatives

	No-Action	PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
	On-Road Fleet (Million Units)					
2022 - 2030	2,404	2,404	2,404	2,404	2,404	2,405
2031 - 2040	2,614	2,613	2,612	2,610	2,609	2,603
2041 - 2050	2,668	2,666	2,664	2,660	2,655	2,644
	Vehicle Miles Traveled (Billion Miles)					
2022 - 2030	27,853	27,855	27,857	27,858	27,859	27,860
2031 - 2040	33,656	33,702	33,728	33,751	33,773	33,808
2041 - 2050	34,480	34,530	34,566	34,591	34,621	34,666
	Fuel Consumption (Billion Gallons/GGE)					
2022 - 2030	1,108	1,107	1,106	1,105	1,105	1,105
2031 - 2040	1,023	998	986	975	964	945
2041 - 2050	710	682	664	650	636	606
	CO_2 Emissions (mmT)					
2022 - 2030	12,159	12,143	12,137	12,132	12,129	12,126
2031 - 2040	10,736	10,425	10,295	10,158	10,029	9,795
2041 - 2050	6,733	6,401	6,192	6,028	5,860	5,503

Figure 8-31: Cumulative Physical and Environmental Effects for All Alternatives



As Table 8-16 and Figure 8-31 show, 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. At the same time, while the cumulative on-road fleet and VMT grow moderately between the decades, fuel consumption and CO_2 emissions see a drastic decline during the last decade (covering CY 2041 to 2050). The chapters that follow provide additional detail of the aforementioned effects, while comparing the outcomes of the action and No-Action alternatives.

8.2.5.1. Changes to On-Road Fleet and Vehicle Miles Traveled

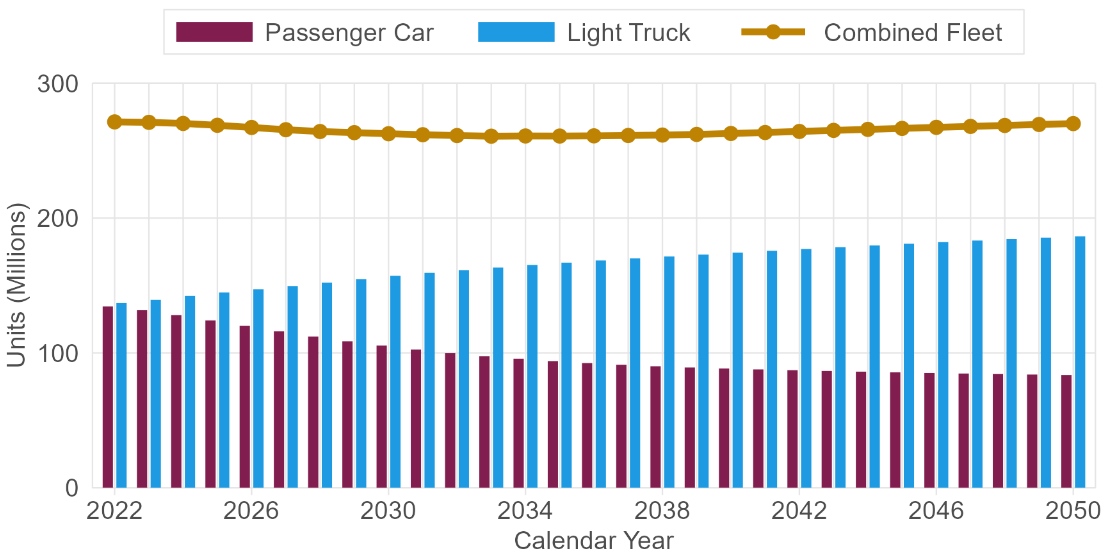
The CAFE Model simulates the consumer response to increases in vehicle prices and fuel economy imposed by action alternatives, including the effect on new vehicle sales as well as the ancillary impacts these changes pose to the existing vehicle fleet. As CAFE standards become more stringent, the cost of new vehicles would rise, which would cause a decline in new vehicle sales—if consumers perceive that the present value of fuel savings do 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 if vehicle retirement rates remain relatively constant. Introducing more fuel-efficient options into the vehicle population is assumed to have the opposite effect on the amount of miles traveled, marginally increasing the total VMT as the cost of travel becomes cheaper. To capture these effects on VMT, the CAFE Model estimates fleet-wide VMT first through a bottom-up approach (i.e., multiplying annual VMT by fleet size by vehicle age and type) and then constrains the resulting non-rebound VMT to a reference baseline VMT derived from external modeling.[209] After determining the level of non-rebound VMT, the model applies a rebound elasticity to the per-mile costs from each modeled scenario to estimate total,

[209] See TSD Section 4.3 for a description of the VMT algorithm and base VMT forecast coefficients derived from FHWA VMT Forecast modeling.

fleet-wide VMT. This approach incorporates the effect of new sales, changing retirement rates, and rebound effects in the estimation of fleet composition and use.

Figure 8-32 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 PC and LT fleets independently, while the line above the bars plots the size of the combined fleet. As demonstrated by Figure 8-32, the overall fleet undergoes a moderate decline during the first half of the analysis, while regaining most of the lost vehicle population during the second half. This decline is attributed entirely to the declining sales of PCs. The subsequent resurgence in the later years is ascribed to continual annual growth of the LT fleet paired with a slowing in the decline of PCs.

Figure 8-32: Total On-Road Fleet in the Reference Baseline Scenario



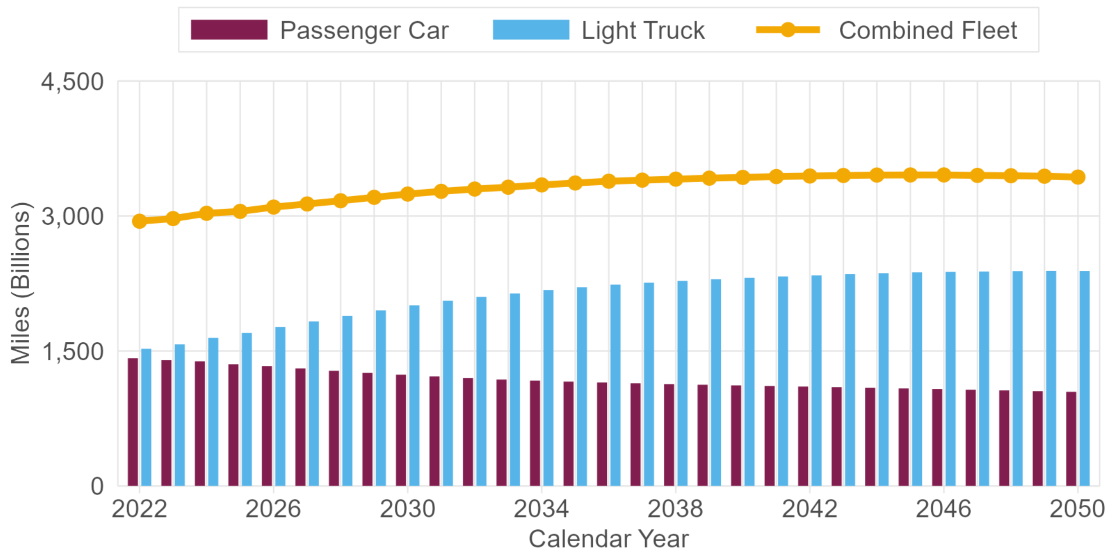
For the initial fleet (MY 2022), the production of LTs (8.96m units) exceeds that of PCs (5.48m units) by over 60 percent. To project vehicle sales in future years, NHTSA utilizes a macroeconomic model to estimate the production volumes of the overall light-duty fleet, and the 2023 Annual Energy Outlook (AEO) projections were adapted to estimate the individual shares of new car and truck sales.[210] The AEO projections show a shift from PCs toward LTs, and as a result, by the end of the analysis (MY 2050), the volume of new LTs sold (10.95m units) is estimated to be more than double the volume of PCs (5.04m units). The surplus of light truck sales, coupled with the accompanying decline in car shares, leads to a sharp shift of the on-road fleet from passenger cars to light trucks throughout the future CYs, as aging vehicles are retired in favor of newer models. The outcome of this behavior is visualized by Figure 8-32.

While the on-road fleet declines somewhat in the No-Action Alternative, the total amount of VMT increases steadily year over year, as illustrated in Figure 8-33. Around CY 2046, the total fleet-wide VMT peaks, and remains steady thereafter (with only imperceivable fluctuations).[211] The VMT projections for both PC and LT fleets follow similar patterns that were observed for the on-road fleet, showing a decrease in the total VMT for the car fleet, and an increase for the light truck fleet. By the end of the analysis (in MY 2050), the share of total miles traveled by the LT fleet is over twice as high as that of the passenger car fleet.

[210] Refer to TSD Chapters 4.2.1.2 and 4.2.1.3 for more detail on the way NHTSA has modeled projections to sales and fleet-mix changes during the future years under the baseline (No-Action) and the action alternatives.

[211] The agency breaks VMT into two components: "non-rebound VMT" and "rebound VMT." Non-rebound VMT is assumed to be unaffected by the standards as much of the demand of travel is presumed to be inelastic, and therefore is the same across all regualtory scenarios. Rebound VMT is the direct measurement of how demand for VMT will respond to decreases in vehicle operating costs. See TSD Chapter 4.3. Since non-rebound VMT is fixed across alternatives, rebound VMT is responsible for the changes in VMT across alternatives.

Figure 8-33: Total VMT in the No-Action Alternative



With the increases in stringency that the action alternatives represent, the number of new vehicles produced and sold during future model years declines when compared to the No-Action Alternative.[212] This reduction generally translates to a cumulative decrease in the on-road population of the combined fleet relative to the No-Action Alternative beyond CY 2033, as can be seen in Figure 8-34. This figure presents the change in fleet size relative to the No-Action Alternative, for each action alternative evaluated as part of this rulemaking. Higher CAFE standards, such as Alternative PC6LT8, lead to greater reductions in on-road fleet size in later CYs as compared to the alternatives with smaller stringency increases. Prior to CY 2033, the on-road fleet is slightly larger in the action alternatives than in the reference baseline due to a reduction in scrappage rates that dominates the reduction in new vehicle sales. The smaller fleet sizes in the more stringent alternatives beyond CY 2033 are driven by reductions in the LT fleet. In the more stringent action alternatives, LTs become relatively more expensive than PCs, causing a relative decrease in sales of new LTs that begins to outpace the slowing scrappage rates. Note that the axis limits of the figure panels vary to better illustrate the differences across alternatives.

[212] New vehicle sales in the action alternatives decline by up 3.1% depending on the fleet, model year, and alternative. For the PC fleet, however, some of the action alterantives show a slight increase in sales by up to 1.3% in a few of the later model years.

Figure 8-34: Changes in On-Road Fleet Compared to Reference Baseline

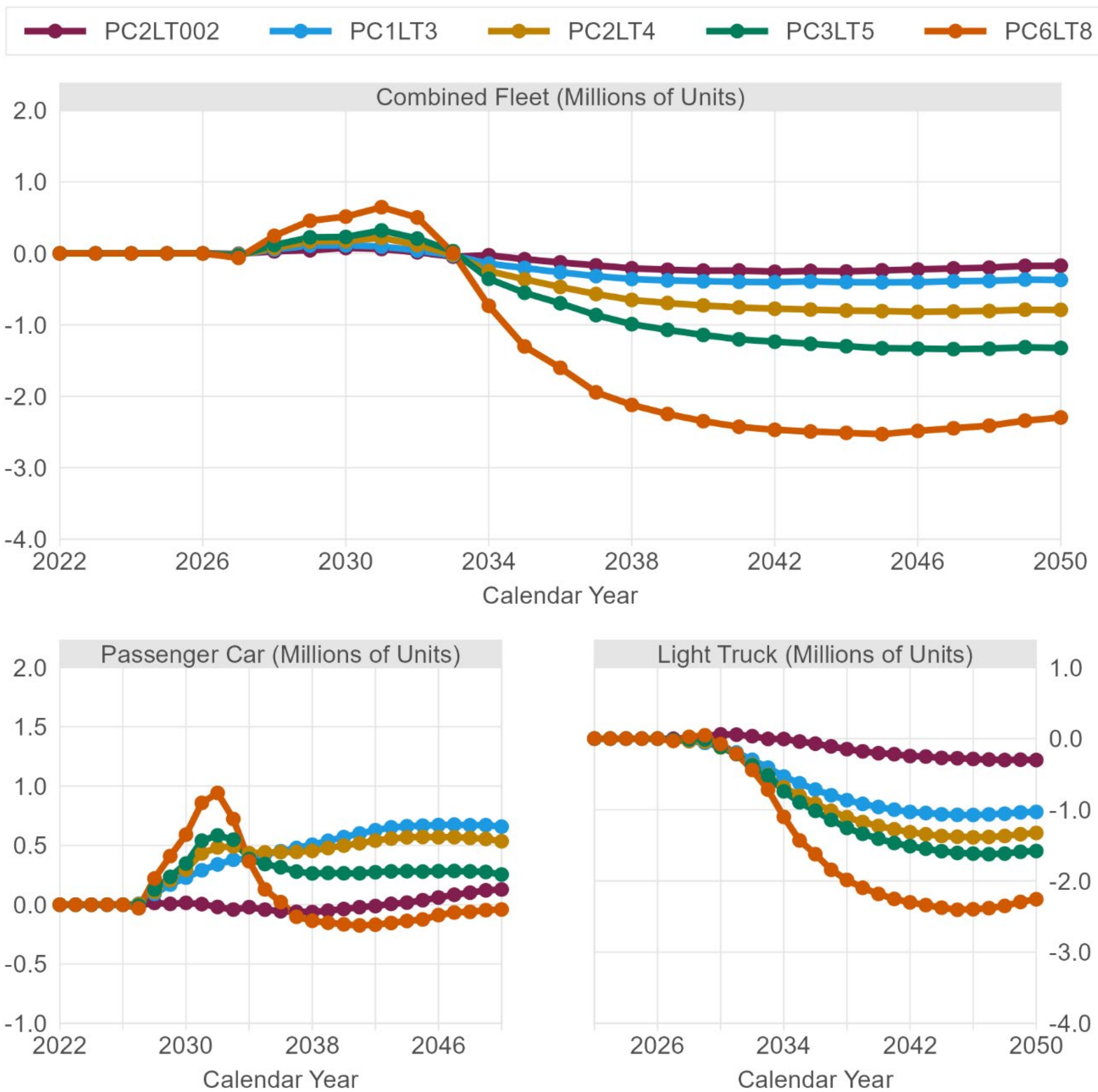
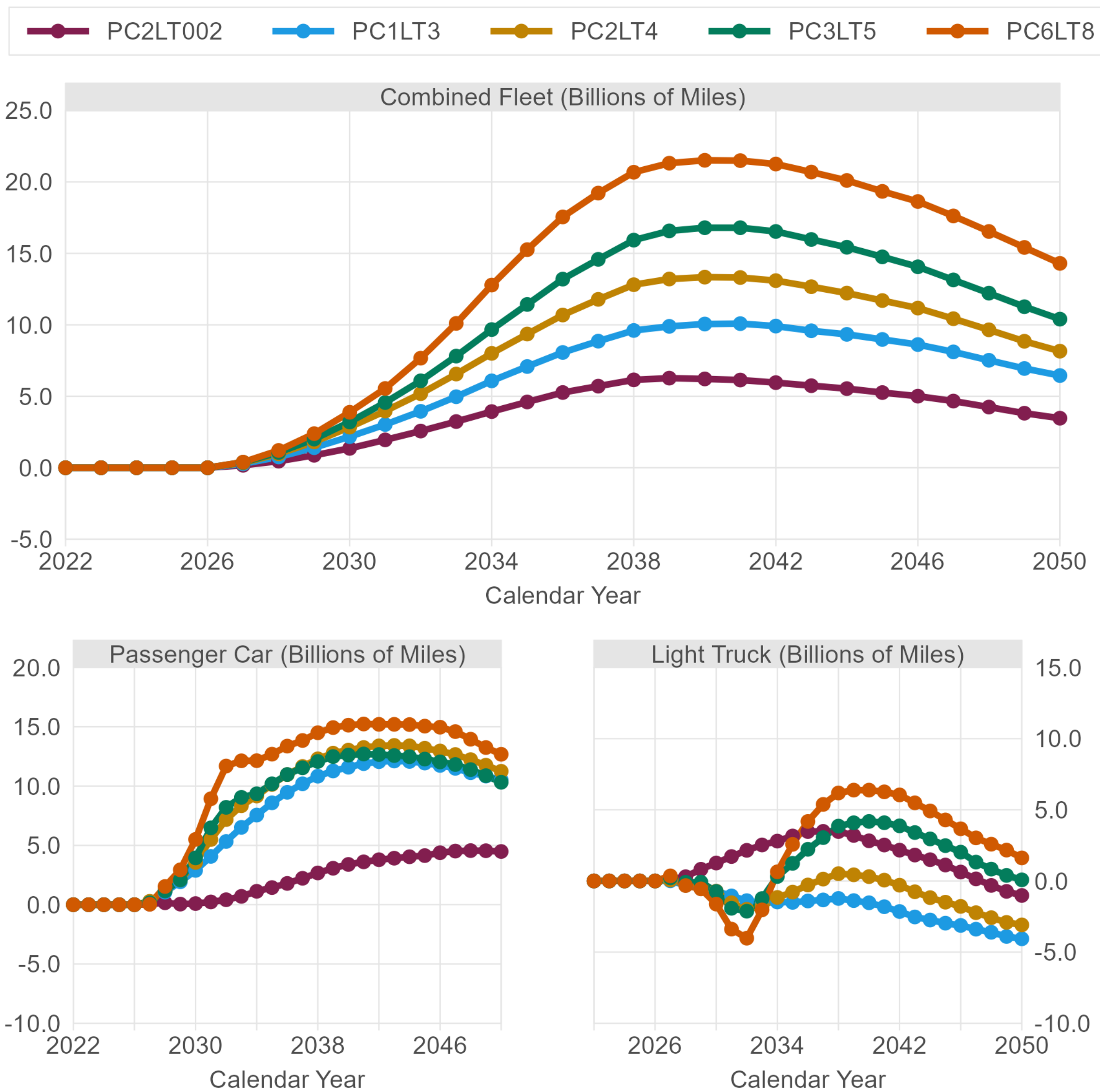


Figure 8-34 shows the incremental differences in the on-road fleet by CY. During the standard setting years, the fleet grows, as a reduction in the scrappage of used vehicles dominates the reduction in sales of new vehicles. Sales and scrappage are expected to be lower than in the No-Action Alternative due to the effect of greater technology adoption costs on the prices for new vehicles. In later years the effect on sales dominates the scrappage effect and the on-road fleet becomes smaller in the action alternatives. 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 8-35 illustrates the incremental differences in VMT for each CY between the action alternatives and the reference baseline scenario.

Figure 8-35: Changes in VMT Compared to Reference Baseline

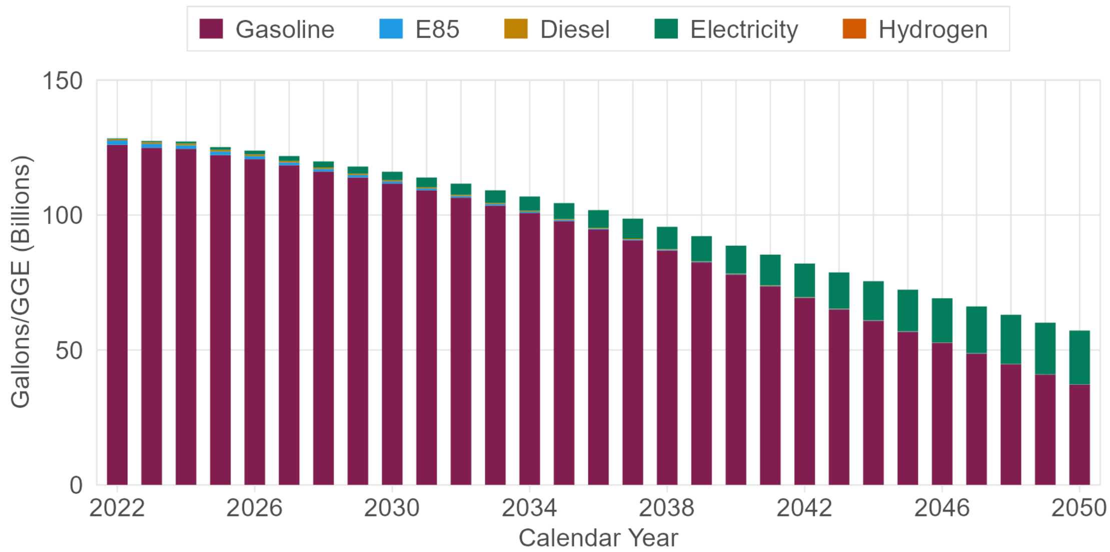


A growing PC fleet drives all growth in the combined on-road fleet during the standard setting years. This growing PC fleet, coupled with a per-vehicle VMT increase due to the rebound effect, causes PC VMT to increase substantially during the standard setting years, relative to the No-Action alternative. This growth eventually slows down in the later years as the rate of growth in the PC fleet begins to decrease. This trend occurs across most alternatives considered; the most stringent alternative considered, PC6LT8, results in a decrease in the PC fleet, however, this alternative still sees the largest increase in PC VMT due to the significantly improved fuel economy, and thus larger rebound effect. The opposite is seen in the LT fleet, which decreases moderately throughout the standard setting years, and most later years, before leveling out around 2045. LT VMT decreases respectively at the beginning of the analysis period, but the rebound effect begins to dominate the decrease in the LT fleet around 2032, causing rapid gains in LT VMT beyond this point. This occurs because incremental improvements from fuel saving 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, making the rebound effect stronger for these vehicles. However, during the last decade of the analysis, per-vehicle VMT increases are no longer enough to offset the impacts of the declining on-road LT fleet, resulting in a moderate reduction in light-truck VMT in the least stringent alternatives, and a marginal change in the most stringent alternatives.

8.2.5.2. Changes to Fuel Consumption and Emissions of GHGs

Increases in CAFE standards reduce the total amount of fuel consumed, as more fuel-efficient vehicles enter the market, displacing older and less efficient models. With the existing fleet gradually turning over with each subsequent CY, the benefits of higher standards enforced during earlier MYs become even more apparent, as the annual fuel consumption of the U.S. vehicle fleet declines further. Moreover, with the rise of AFVs, specifically BEVs being added in the No-Action Alternative, the use of gasoline within the light-duty fleet is gradually supplanted by electricity. At the same time, increased production of SHEVs during earlier to middle MYs leads to further decline of gasoline use. Figure 8-36 presents the consumption of various fuel types in each CY for the No-Action Alternative. In Figure 8-36, the consumption of gasoline, E85, and diesel are denominated in gallons, while electricity and hydrogen are specified in gasoline gallon equivalent (GGE).

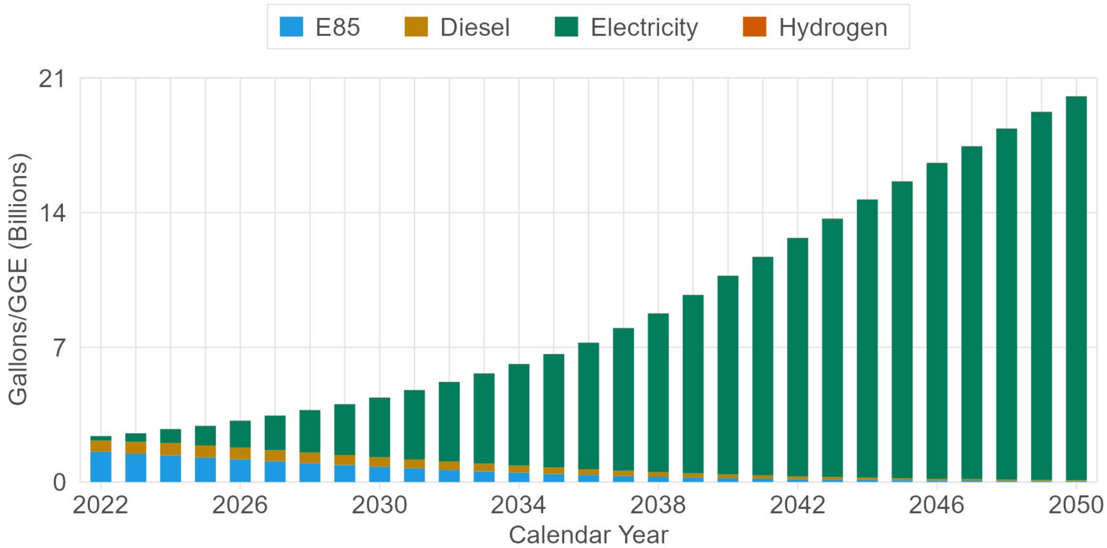
Figure 8-36: Fuel Consumption in the Reference Baseline Scenario



As illustrated by Figure 8-36, gasoline remains the main source of fuel well into the future under the No-Action Alternative. However, with increasing fuel economy ratings and large-scale conversion to SHEVs and BEVs, the use of gasoline greatly diminishes during the later years; a similar trend is seen in the use of E85 for the same reasons. Conversely, electricity consumption rapidly increases year over year, culminating in about one third of the total amount of fuel consumed (on GGE basis) being attributed to electricity by CY 2050. Meanwhile, the collective sum of all the other alternative fuel types used by the on-road fleet is only a fraction of the total energy consumed during each CY.[213] Figure 8-37 provides a closer look at the consumption of non-gasoline fuels. This figure shows electricity with the strongest annual growth, while over the same timeframe, the use of E85 and diesel steadily declines.

[213] In CY 2022, the total amount of E85, diesel, and hydrogen fuels consumed by the on-road fleet is 1.7 percent in the No-Action Alternative. By CY 2050, that number declines to 0.2 percent.

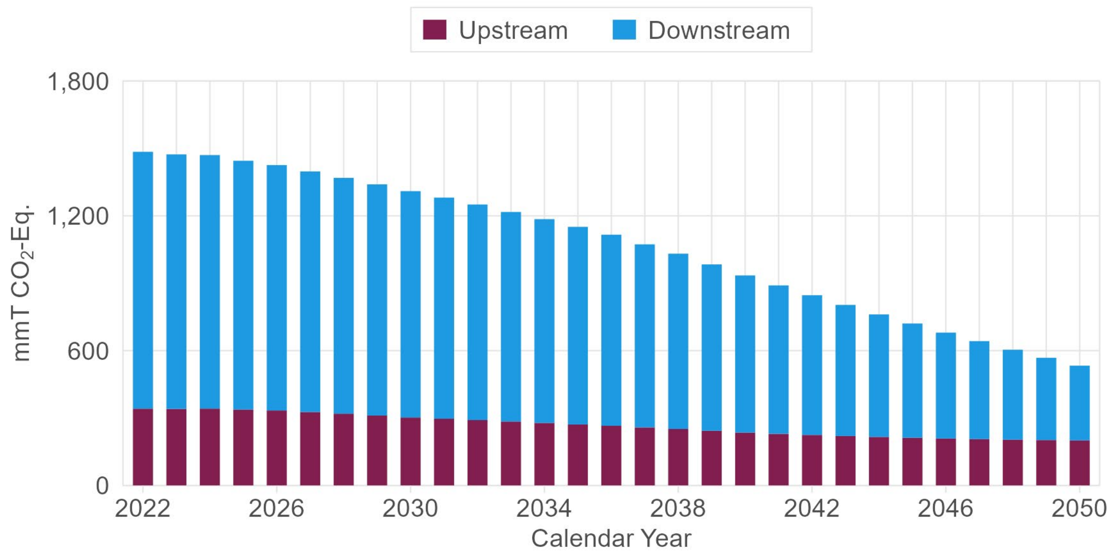
Figure 8-37: Consumption of Non-Gasoline Fuels in the Reference Baseline Scenario



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 8-38 displays the amount of annual GHG emissions generated by the light-duty fleet under 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 GWP multipliers of 25 and 298 respectively,[214] and are denominated using mmT of CO_2 equivalent emissions. However, CO_2 remains the predominant contributor of GHGs, making up approximately 99.3 percent of total GHG upstream emissions and 99.9 percent of GHG vehicle-based emissions.[215] This analysis does not include HFC emissions from vehicles. As shown in Figure 8-38, 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, as the effects of increased electricity generation offset the reduction in emissions from the production, storage, and distribution of motor fuels. The downstream emissions, which occur during vehicle operation, see a large declining trend similar to what was observed for the overall annual consumption of fuel.

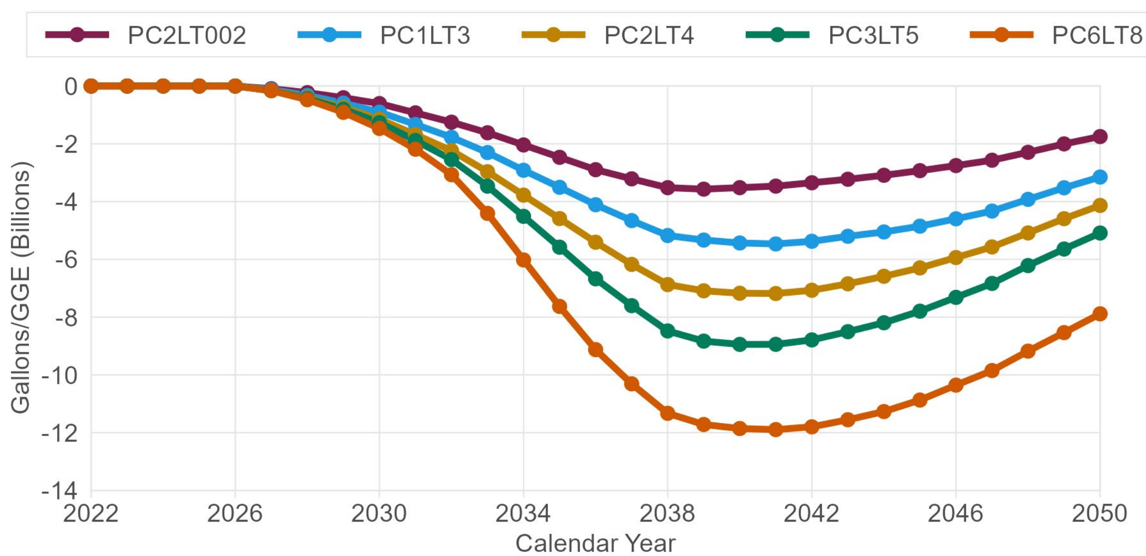
[214] GWP multipliers here are derived from the 4th IPCC Report; NHTSA is aware that the 5th IPCC report changes these values slightly, but tentatively concludes that the difference is not meaningful for purposes of Figure 8-38. NHTSA calculates emissions of CH_4 and N_2O directly in terms of tons emitted for benefits purposes.
[215] Depending on CY being considered, the CO_2 share of GHG upstream emissions varies by up to 2 percent, while the share of downstream emissions varies less than 0.1 percent.

Figure 8-38: Emissions of GHG in the Reference Baseline Scenario



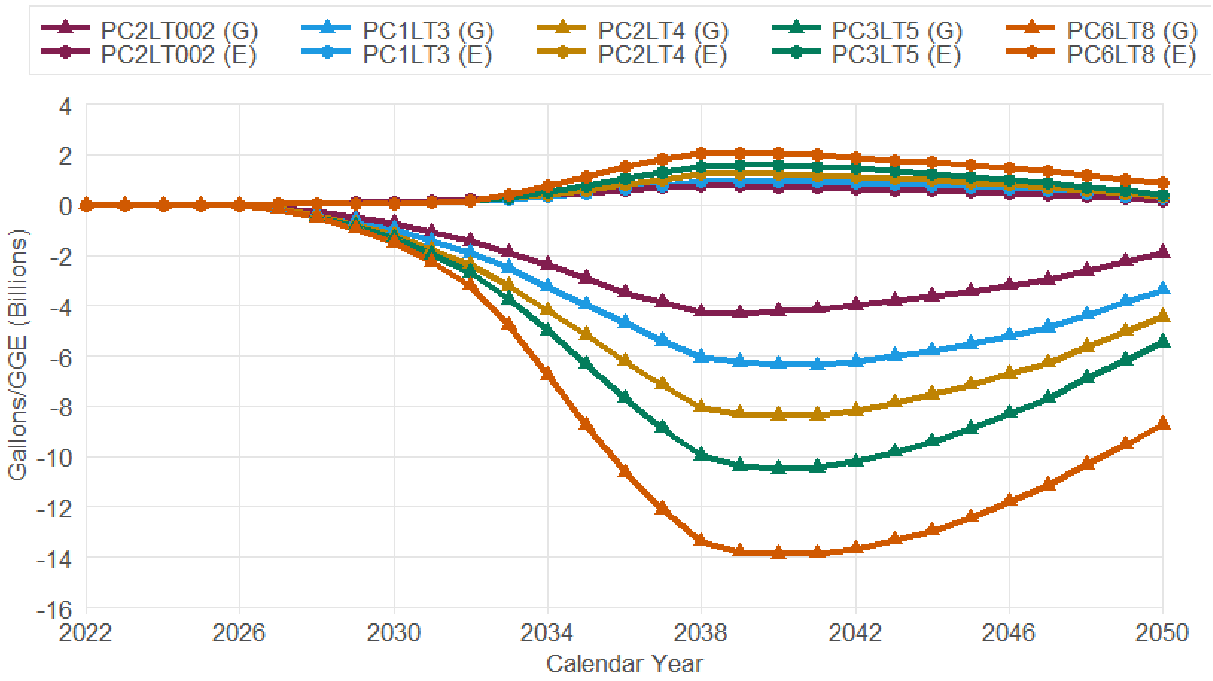
Fleet-wide fuel consumption and GHG emissions continue to decline further under the action alternatives in response to higher CAFE standards. Figure 8-39 presents the incremental differences to overall energy consumption, as compared to the reference baseline scenario, for each action alternative. As shown in the figure, the outcome of the progressively increasing stringency defined by each action alternative is a greater reduction to the amount of fuel consumed by the on-road light-duty fleet.

Figure 8-39: Changes in Fuel Consumption Compared to Reference Baseline



As was the case under the No-Action Alternative, gasoline remains the dominant source of fuel for the light-duty fleet in all CYs, and for all action alternatives. However, as was noted above for the No-Action Alternative, gasoline consumption rapidly decreases with each passing year, while electricity use undergoes a rapid growth. This trend continues under the action alternatives as well, and with more stringent standards, gasoline consumption falls by even larger margins, while the annual use of electricity increases further. Figure 8-40 separates and presents the incremental changes of gasoline and electricity use, as those had the largest observable difference over the reference baseline. The differences observed between the action and the No-Action Alternatives for all other fuels were inconsequential and are omitted from the figure.

Figure 8-40: Changes in Gasoline and Electricity Consumption Compared to Reference 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. Figure 8-41 presents the incremental changes to emissions of GHG as compared to the No-Action Alternative. The larger chart at the top presents the overall emissions of GHG, while the left and right portions at the bottom provide deconstructed views of upstream and downstream components, respectively. In each case, the incremental emissions of GHGs decrease at a greater rate as the standards defined by the action alternatives increase in stringency. Hence, the highest CAFE standards, defined by Alternative PC6LT8, lead to the greatest reduction of upstream, downstream, and overall emissions of GHG.

Figure 8-41: Changes in GHG Emissions Compared to Reference Baseline

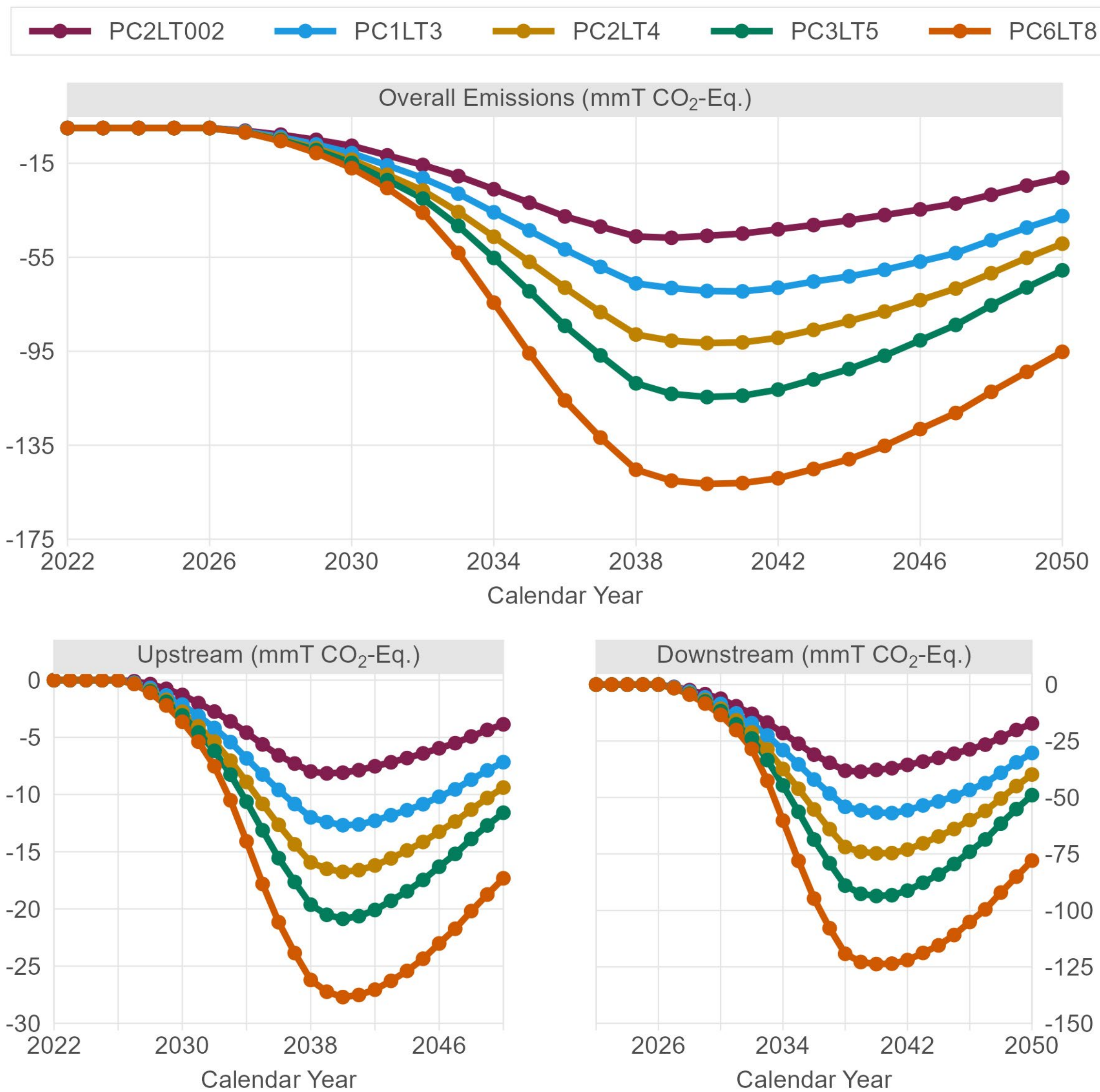
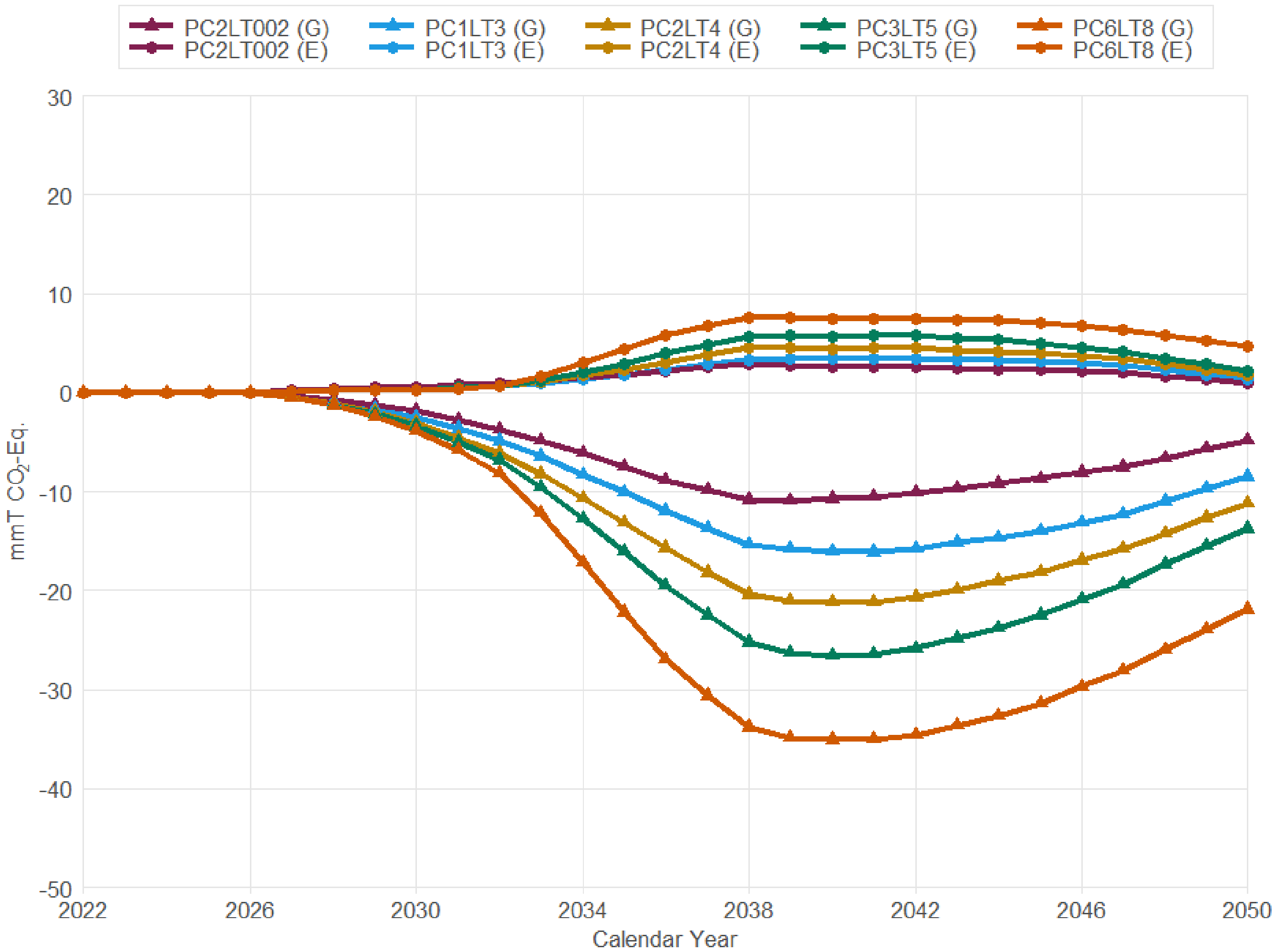


Figure 8-42 displays the incremental GHG upstream emissions for gasoline and electricity for each action alternative relative to the No-Action alternative. As with fuel consumption, the other fuel types do not differ meaningfully here, and are therefore omitted. The figure shows increasing emissions relative to the reference baseline from growing electricity demand, especially beyond CY 2034. These net emissions increases are outpaced by the emission reductions brought on by decreasing gasoline consumption. This trend continues to about 2040, when the differences in BEV adoption for these alternatives relative to the reference baseline decline.

Figure 8-42: Changes in Upstream Gasoline and Electricity GHG Emissions Compared to Reference Baseline



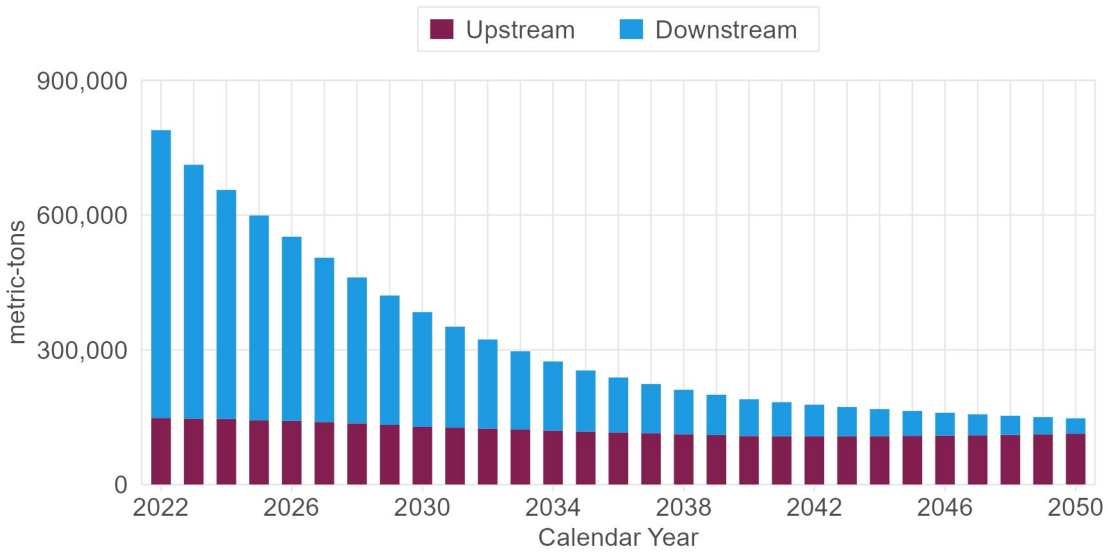
8.2.5.3. Changes to Emission of Criteria Air Pollutants

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). The 2022 Standard Scenarios forecast developed by the National Renewable Energy Laboratory (NREL) predicts electricity production will initially be more polluting than gasoline production in the early years of this analysis. However, the NREL forecast expects significant decarbonization of the electricity grid (see TSD Chapter 5.2) bringing the emission associated with electricity production to parity with that of gasoline production, on a grams/BTU basis around 2030; the NREL forecast expects this trend to continue, making electricity production cleaner than gasoline production in the years after 2030, for most pollutants. While differences in emissions of criteria pollutants during the standard setting years is minimal across alternatives, the introduction of additional BEVs and PHEVs into the on-road fleet after the standard setting years due to reduced battery costs ultimately reduces *upstream* emissions in the later years as these vehicles are reliant on a cleaner form of energy than their gasoline counterparts. Similarly, the improved fuel-efficiency associated with each alternative and the introduction of BEVs and PHEVs greatly reduces the amount of *downstream* pollutants that are emitted into the atmosphere from vehicle operation as gasoline consumption decreases, and BEVs do not emit tailpipe criteria pollutants. This chapter 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 8.2.5.4.

Figure 8-43 and Figure 8-44 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. In the case of $PM_{2.5}$, downstream emissions are split and presented separately for emissions related to brake and tire wear (BTW) and vehicular emissions originating at a vehicle's exhaust.[216] As 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. Given that vehicles operating on electricity do not emit criteria pollutants at the exhaust, the increased presence of BEVs within the No-Action Alternative further contribute to the accelerated reduction of downstream emissions shown in the figures. However, since the BTW emissions are defined at a constant rate, rather than varying by vehicle production year and age, downstream BTW emission of $PM_{2.5}$ are shown to increase proportionally as the demand for travel goes up.

The relative impacts on upstream emissions for both pollutants are comparatively less pronounced, however, showing some fluctuation in the No-Action Alternative, but ultimately resulting in a marginal decrease. This change in upstream emissions correlates with the higher demand for electricity, as more vehicles are gradually converted to BEVs during each subsequent year (as was presented by Figure 8-36 and Figure 8-37), and is thus determined by the distribution of criteria pollutants associated with electricity production. No-Action As such, Figure 8-43 and Figure 8-44 show a marginal annual decrease to the upstream emissions of NO_X and $PM_{2.5}$.

Figure 8-43: Emissions of NO_X in the Reference Baseline Scenario



[216] NHTSA has introduced separate accounting of $PM_{2.5}$ brake and tire wear (BTW) emissions into the analysis for the current rulemaking.

Figure 8-44: Emissions of $PM_{2.5}$ in the Reference Baseline Scenario

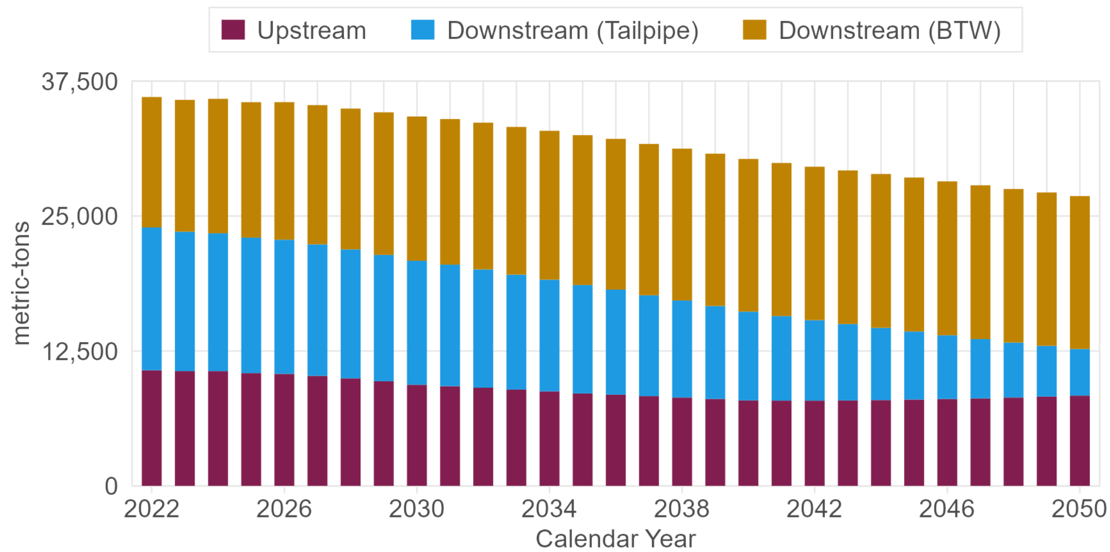
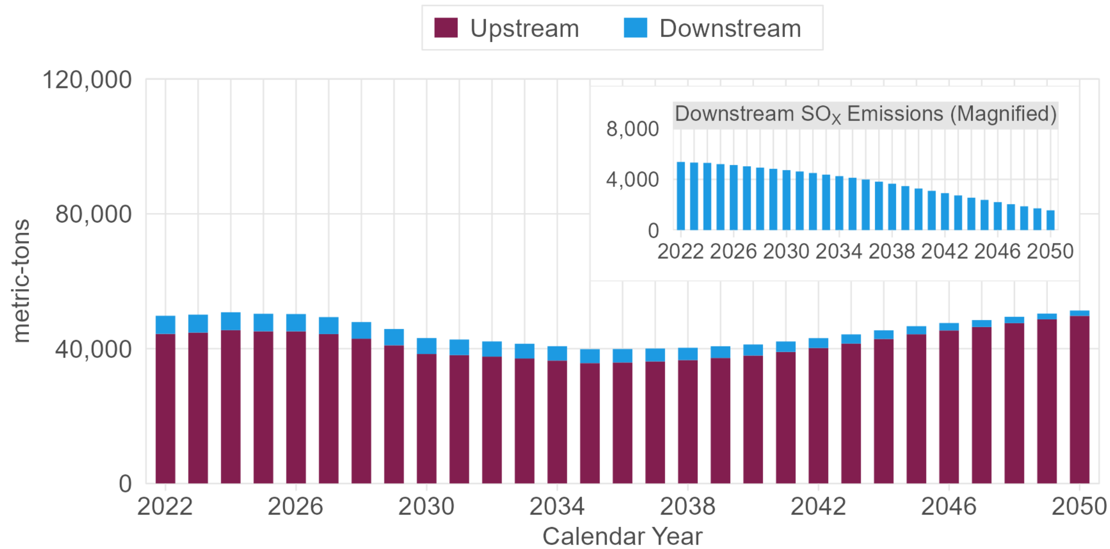


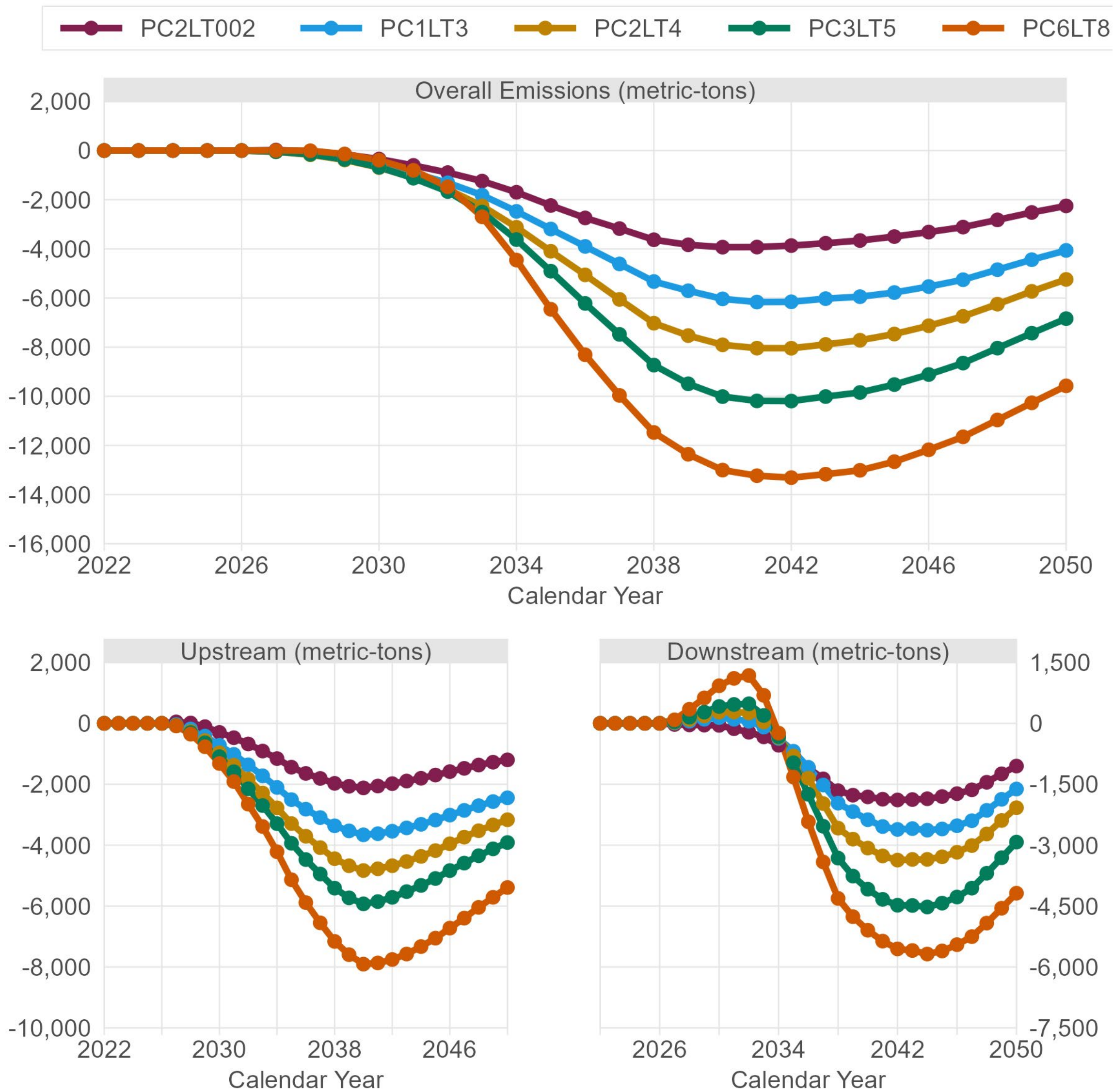
Figure 8-45 shows the annual SO_X emissions for the on-road fleet under the No-Action Alternative. Contrary to the previous two pollutants, downstream emissions of SO_X are measured based on the consumption of fuel, rather than on a per-mile basis dictated by the vehicle emissions standards. Hence, SO_X emissions are influenced directly by changes to the amount of fuel consumed, rather than the total miles traveled by the light-duty fleet. Figure 8-45 shows 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 top-right corner of the figure presents a magnified view of downstream SO_X emissions for clarity. The upstream SO_X emissions see a mostly similar pattern as was observed for NO_X and $PM_{2.5}$ pollutants. Here, emissions fluctuate over the analysis period as the fleet share of PHEVs and BEVs increases. In the later years displayed in the plot overall SO_X upstream emissions show a marginal increase.

Figure 8-45: Emissions of SO_X in the Reference Baseline Scenario



As demonstrated in the next several figures, increases in CAFE standards generally lead to decreases in both upstream and downstream emissions of NO_X and $PM_{2.5}$ for all alternatives evaluated. The same increase in standards generally leads to reduced downstream SO_X emissions; however, upstream SO_X emissions see little change across alternatives. The net changes to emissions, though, depend on the alternative, CY, and pollutant being presented, where overall values may show an increase or a decrease in total emissions generated. Figure 8-46 shows the incremental changes to NO_X emissions in the action alternatives versus the reference 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. This shows that NO_x emissions generally decrease with increasing CAFE standards. The upstream emissions for the most stringent alternative (PC6LT8) show a rapid decrease over the reference baseline beginning in the standard setting years, as the demand for gasoline is reduced; additionally, the introduction of BEVs and PHEVs occurs sooner under PC6LT8, causing gasoline production to be supplanted by electricity production, which emits relatively less NO_X, earlier in the analysis period. This pattern is consistent across alternatives and varies depending on the overall reduction in the demand for gasoline, and the introduction of BEVs and PHEVs into the on-road fleet.

Figure 8-46: Changes in NO_X Emissions Compared to Reference Baseline



The downstream emissions in Figure 8-46 show an increase in the earlier years under all action alternatives as compared to the reference 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,[217] 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 quickly begin to fall, declining to below reference baseline levels.

Figure 8-47 presents the incremental changes to $PM_{2.5}$ emissions in the action alternatives as compared to the reference 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. In the case of $PM_{2.5}$, however, the downstream portion represents a combination of vehicle exhaust and BTW emissions.

Figure 8-47: Changes in $PM_{2.5}$ Emissions Compared to Reference Baseline

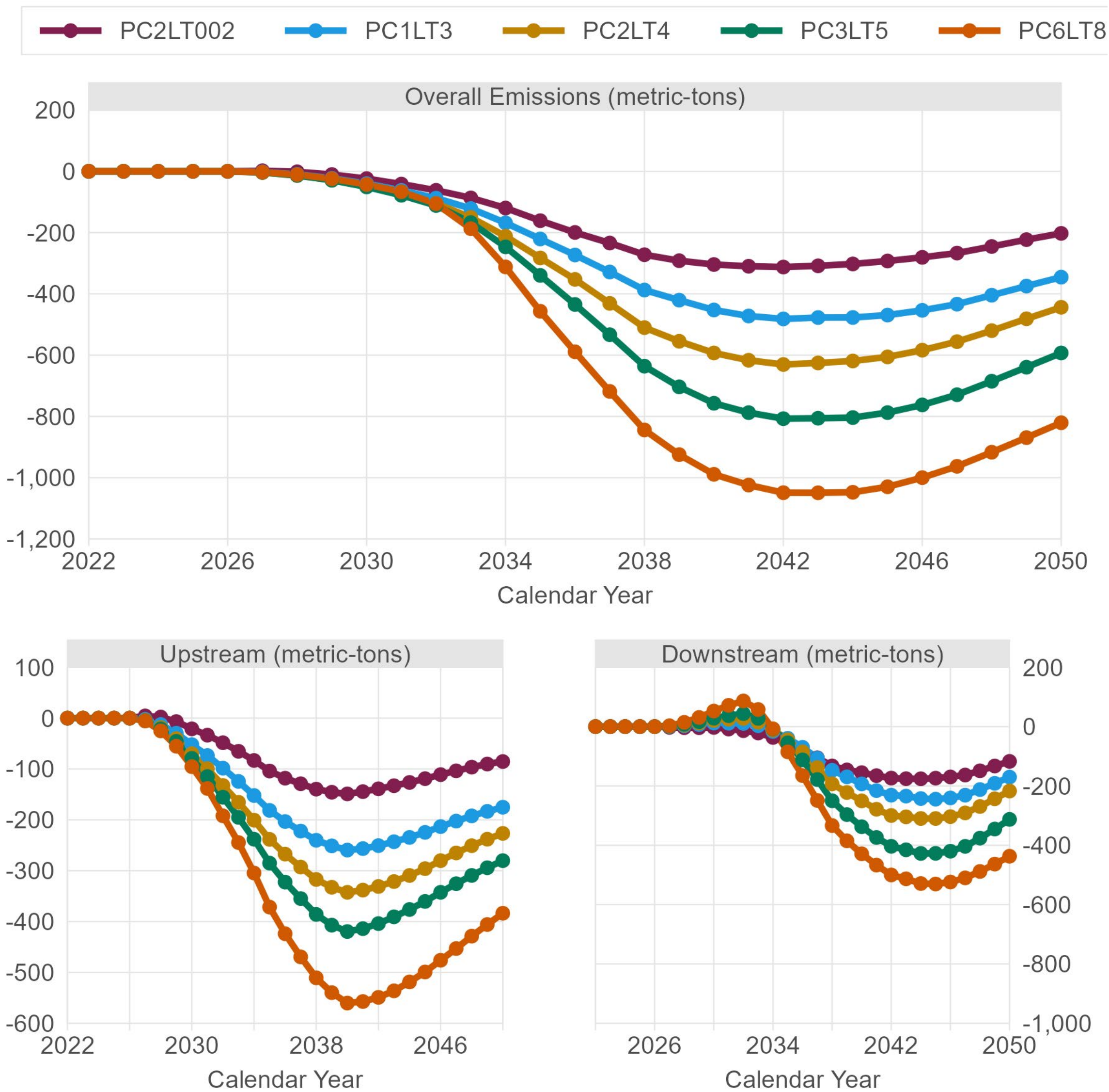
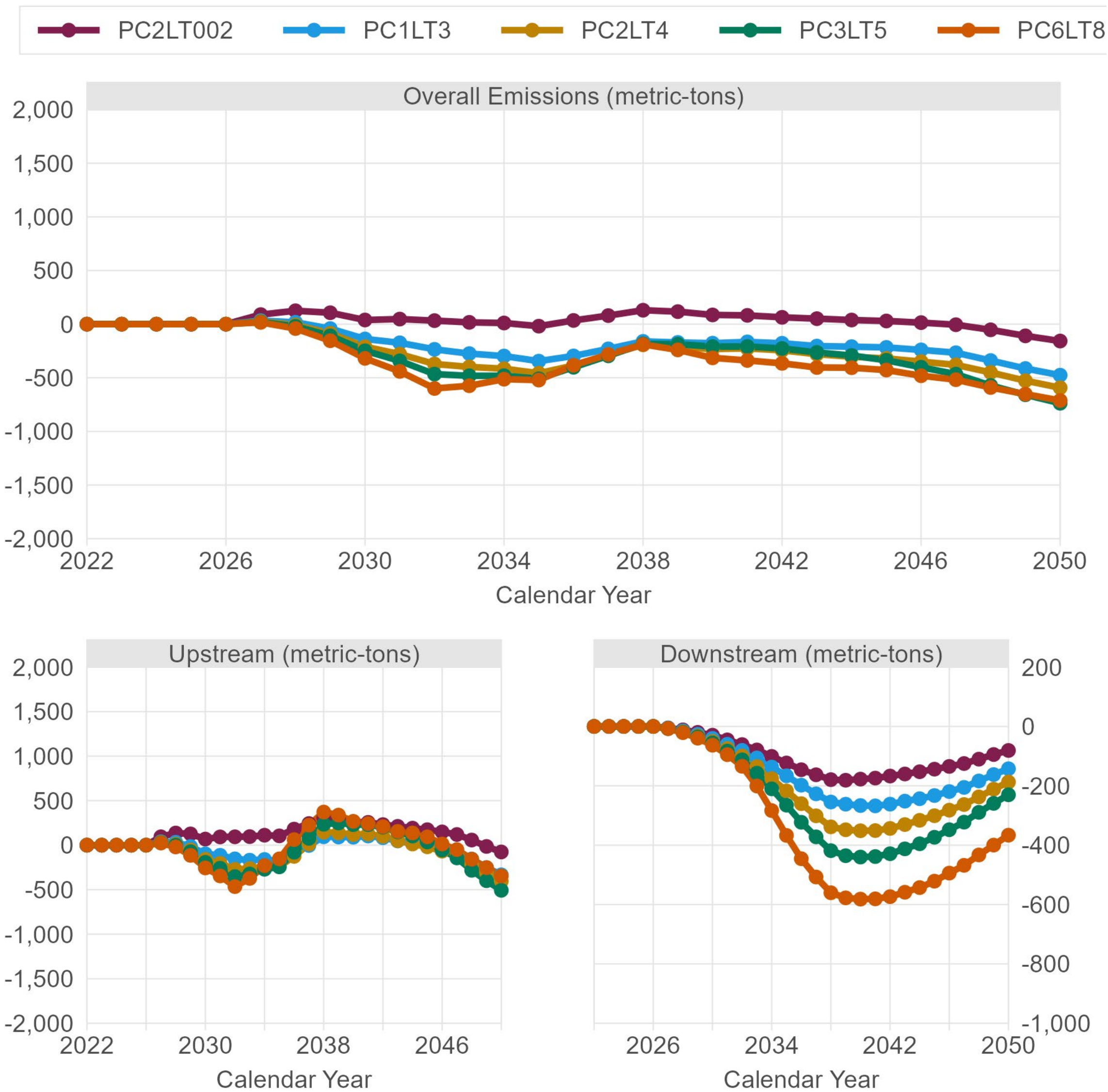


Figure 8-48 illustrates the incremental emission changes for SO_X for the action alternatives versus the reference baseline. As was noted earlier, the SO_X downstream emissions are measured based on the total consumption of fuel, rather than on a per-mile basis (see TSD 5.3.3.2). Thus, the reduction 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 see only marginal changes relative to the reference baseline due to the slightly higher SO_X emission rates associated electricity production than with gasoline production, particularly

[217] Readers should refer to the Parameters Input File for the current assumptions of the annual downstream emission inputs for various pollutants.

in the early years. Upstream SO_X emissions make up a significantly larger portion of total SO_X emissions, therefore, total SO_X emissions follow a similar pattern, and see only a marginal decrease relative to the reference baseline across action alternatives.

Figure 8-48: Changes in SO_X Emissions Compared to Reference Baseline



As demonstrated in this chapter, relative levels of all criteria pollutants, except for SO_X, decrease across action alternatives. The magnitude of change depends on the pollutant being considered. In the case of SO_X, emissions decline in each alternative except for PC2LT002 where it remains very near to No-Action alternative levels. These results are a direct consequence of the input assumptions used for this analysis and are subject to the usual caveats that accompany uncertainty in input assumptions.[218] When estimating the upstream emissions, the CAFE Model relies on the upstream emission rates provided by the GREET 2023 Model for liquid fuels and the NREL 2022 grid mix forecast for upstream electricity emissions. These input emission rates may change over time (and between rulemaking analyses) depending on the version of the GREET Model used and the associated assumptions about emissions rates, grid mix, and the production and distribution of various petroleum-based feedstocks.

[218] See FRIA 9.2.4.1 – sensitivity section on upstream and downstream sensitivities plus docket memo the memo on electricity grid forecasts for additional detail on inputs, especially the upstream grid mix forecast.

When estimating the downstream emissions, the CAFE Model relies on the emission rates provided by the MOVES4 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 CYs under the more stringent alternatives.

8.2.5.4. 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 CYs and with increased alternative stringency. Table 8-17 presents the number of incidents and proportions for each of the various emission health impacts, which are considered in this rulemaking. Since CY 2022 corresponds to the initial year evaluated for this analysis (MY 2022), and since the CAFE Model does not apply any fuel saving technologies during that initial year, the health impacts shown in the table are the same across all alternatives at the beginning of the analysis. For more information on how emission health impacts are determined, see TSD Chapter 5.4.

Table 8-17: Emission Health Impacts in CY 2022

	Incidents (Units)	Share of Total Incidents
High Incident Counts		
Minor Restricted Activity Days	2,460,350	78.6%
Work Loss Days	418,629	13.4%
Asthma Exacerbation	97,011	3.1%
Upper Respiratory Symptoms	82,706	2.6%
Lower Respiratory Symptoms	58,209	1.9%
Low Incident Counts		
Acute Bronchitis	4,571	0.15%
Non-Fatal Heart Attacks (Peters)	3,248	0.10%
Premature Deaths	3,147	0.10%
Respiratory Emergency Room Visits	1,753	0.06%
Respiratory Hospital Admissions	783	0.03%
Cardiovascular Hospital Admissions	826	0.03%
Non-Fatal Heart Attacks (All Others)	350	0.01%

As demonstrated by Table 8-17 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 the least significantly affected by exposure to emissions from criteria air pollutants. Throughout the analysis of all alternatives, the proportion of each category remains mostly the same during each CY, the nominal number of incidences moderately decline with each subsequent year.

The emission health impacts attributed to the No-Action Alternative for the remainder of the CYs are presented as cumulative impacts over the next three decades in Figure 8-49 and Figure 8-50.[219] The figures are split into subsets of major incident counts (above ten thousand per year) and minor incident counts (below

[219] As discussed at the introduction to Chapter 8.2.5, the first decade in all figures presented by this chapter cover the range of CYs between CYs 2022 and 2030, while the latter two encompass effects over the full ten-year period. While this marginally reduces the magnitude of cumulative incidents occurring during the first decade (as compared to the following ones), the figures still demonstrate the relative differences and a declining trend between the decades.

ten thousand) to aid with interpretation. The figures show that the health-related outcomes in every category follow a significant downward trend between the decades in response to significantly declining overall emissions of the NO_X pollutant and decreases to the $PM_{2.5}$ pollutant (discussed in Chapter 8.2.5.3).

Figure 8-49: Cumulative Emission Health Impacts in the Reference Baseline Scenario (Part 1)

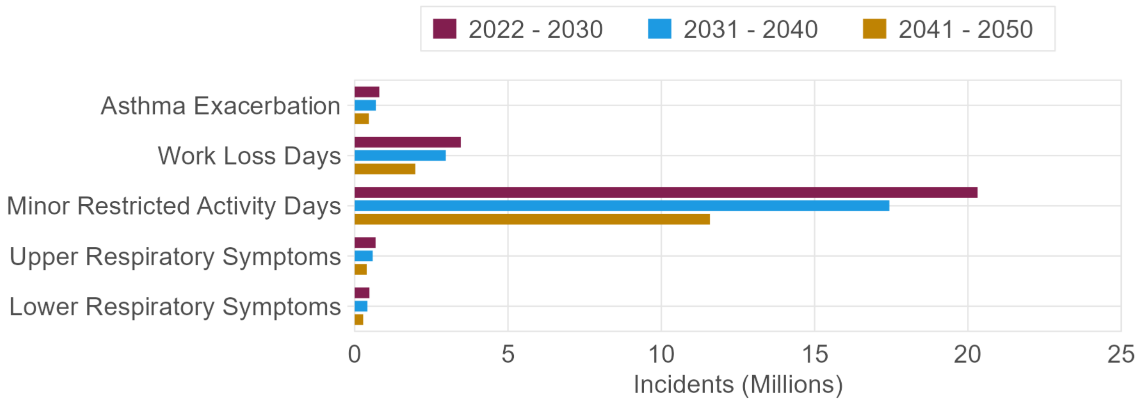
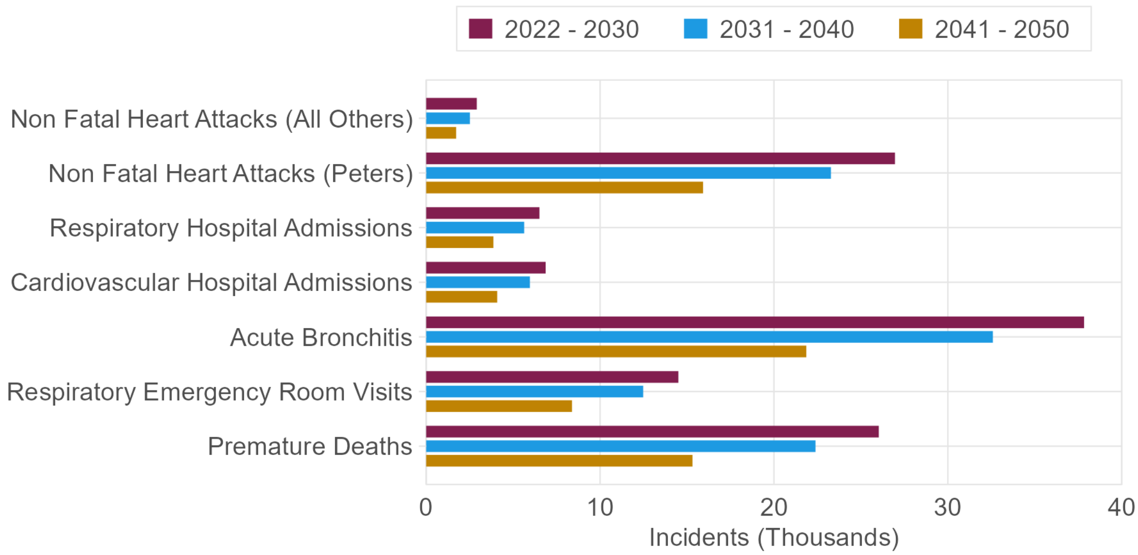


Figure 8-50: Cumulative Emission Health Impacts in the Reference Baseline Scenario (Part 2)



Health-related incidents decrease as CAFE stringencies increase because of reductions in fuel consumed. Although the net emissions of SO_X see only a marginal change in some action alternatives, the decreases in net NO_X and fine $PM_{2.5}$ emissions lead to an eventual decline in adverse health outcomes. Figure 8-51 and Figure 8-52 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 PC6LT8 sees the greatest reduction in the number of incidents among the alternatives evaluated. However, the differences between all alternatives during the first decade (CY 2022-2030) are marginal.

Figure 8-51: Changes in Cumulative Emission Health Impacts Compared to Reference Baseline (Part 1)

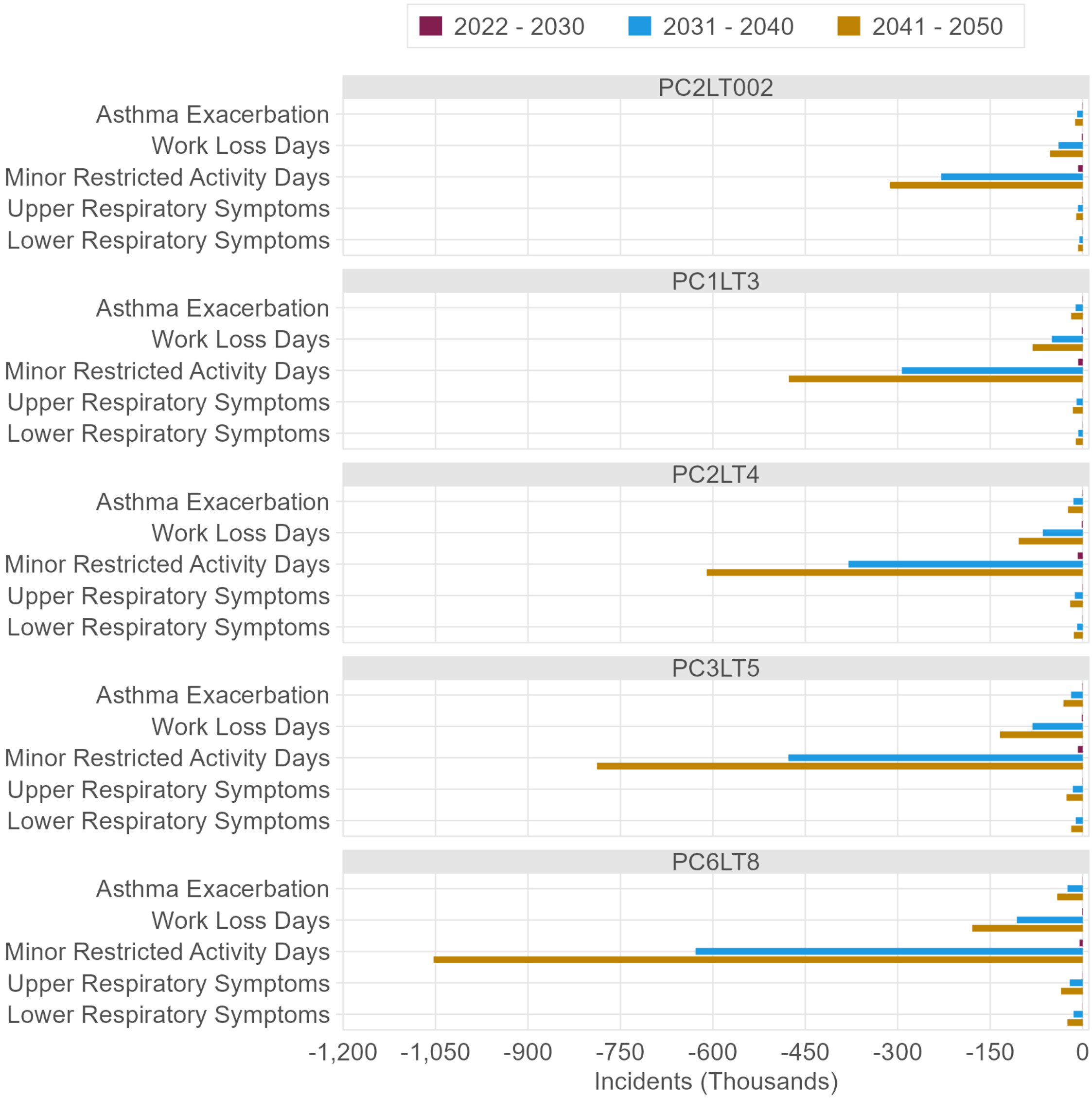
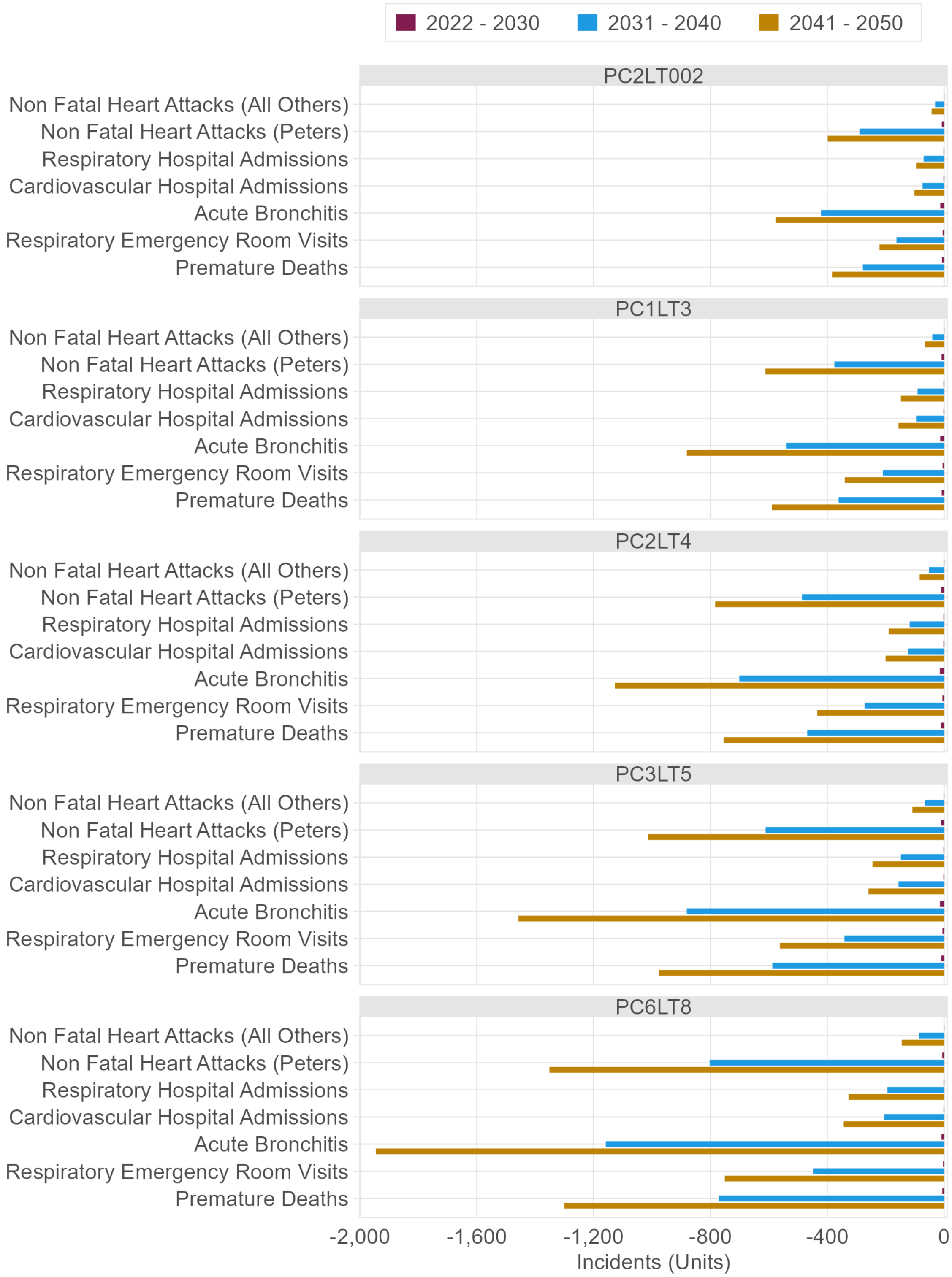


Figure 8-52: Changes in Cumulative Emission Health Impacts Compared to Reference Baseline (Part 2)



8.2.6. Effects of Augural Standards

8.2.6.1. Overview

NHTSA conducted a separate set of CAFE Model runs that include augural standards for MY 2032. As discussed in Section VI.A of the preamble, the augural standards are included for informational purposes only, and results of these runs were not used to inform selection of the preferred alternative, which covers MYs 2027-2031. This section contains tables summarizing the results of these analyses of augural MY 2032 standards, and in many instances compares results to those from the standard-setting results presented throughout Chapter 8.2. A full set of results for the augural-standards analysis is included on NHTSA's website.[220]

8.2.6.2. Effects Summary

Table 8-18: Compliance for Total Light Duty Fleet Under the Preferred Alternative, PC2LT002 (MPG)

	2027	2028	2029	2030	2031	2032
Standard						
Standard-setting	47.3	47.4	48.4	49.4	50.4	50.4
With augural	47.3	47.4	48.4	49.4	50.4	51.4
Difference	0.0	0.0	0.0	0.0	0.0	+1.0
Achieved						
Standard-setting	49.9	50.2	50.8	51.1	52.5	53.0
With augural	50.0	50.3	50.9	51.3	52.7	53.5
Difference	+0.1	+0.1	+0.1	+0.2	+0.2	+0.5

Table 8-19: Compliance for Passenger Car Fleet Under the Preferred Alternative, PC2LT002 (MPG)

	2027	2028	2029	2030	2031	2032
Standard						
Standard-setting	60.0	61.2	62.5	63.7	65.1	65.1
With augural	60.0	61.2	62.5	63.7	65.1	66.4
Difference	0.0	0.0	0.0	0.0	0.0	+1.3
Achieved						
Standard-setting	68.6	68.4	68.6	68.6	70.8	71.7
With augural	68.6	68.4	68.6	68.6	71.0	72.3
Difference	0.0	0.0	0.0	0.0	+0.2	+0.6

Table 8-20: Compliance for Light Truck Fleet Under the Preferred Alternative, PC2LT002 (MPG)

	2027	2028	2029	2030	2031	2032
Standard						
Standard-setting	42.6	42.6	43.5	44.3	45.2	45.2
With augural	42.6	42.6	43.5	44.3	45.2	46.2
Difference	0.0	0.0	0.0	0.0	0.0	+1.0
Achieved						

[220] https://www.nhtsa.gov/laws-regulations/corporate-average-fuel-economy#light-duty-vehicles.

	2027	2028	2029	2030	2031	2032
Standard-setting	43.7	44.2	44.9	45.3	46.4	46.8
With augural	43.8	44.3	45.0	45.5	46.6	47.3
Difference	+0.1	+0.1	+0.1	+0.2	+0.2	+0.5

Table 8-21: Selected Light Duty Fleet Technology Penetration Rates by Model Year Under the Preferred Alternative, PC2LT002 (Percent)

	2027	2028	2029	2030	2031	2032
Advanced engine						
Standard-setting	17.1	14.6	11.9	11.2	10.0	9.7
With augural	16.6	14.1	11.3	10.3	9.0	8.6
Difference	-0.5	-0.5	-0.6	-0.9	-1.0	-1.1
SHEV						
Standard-setting	22.6	25.3	29.2	30.0	28.3	28.6
With augural	23.1	26.1	30.2	31.2	29.9	31.9
Difference	+0.5	+0.8	+1.0	+1.2	+1.6	+3.3
PHEV						
Standard-setting	3.8	3.8	3.8	3.7	5.7	5.6
With augural	3.8	3.8	3.8	3.7	5.7	5.6
Difference	0.0	0.0	0.0	0.0	0.0	0.0
BEV						
Standard-setting	20.5	21.4	22.8	25.1	28.1	30.0
With augural	20.5	21.4	22.8	25.1	28.1	30.0
Difference	0.0	0.0	0.0	0.0	0.0	0.0

Table 8-22: Per-Vehicle Technology Costs by Model Year Under the Preferred Alternative (PC2LT002) Relative to the No-Action Alternative (NA column) and Relative to the Reference Baseline (RB column) ($2021)[221]

	2027		2028		2029		2030		2031		2032	
	NA	RB	NA	RB	NA	RB	NA	RB	NA	RB	NA	RB
BMW	-10	-	41	-	46	-	64	-	17	-	23	+11
Mercedes-Benz	-104	-	-98	-	-101	-	14	-1	-91	-1	-167	-
Stellantis	252	-	259	-	306	-	389	-	391	-	520	+140
Ford	195	+88	401	+118	518	+139	514	+129	527	+127	525	+133
GM	376	-	367	-	550	-	556	-	1,545	+9	1,626	+23
Honda	300	-	272	-	247	-	221	-	142	-	81	-
Hyundai	175	-	188	-	337	-	357	-	351	+8	442	+110
Kia	-7	-	680	-	1,126	-	1,198	-	1,167	+32	1,105	+32
JLR	-2	-	-	-	1	-	115	-	142	+13	159	+36

[221] Dashes indicate no difference.

	2027		2028		2029		2030		2031		2032	
	NA	RB	NA	RB	NA	RB	NA	RB	NA	RB	NA	RB
Mazda	17	-	-22	-	3	-	-3	-	-114	-	-195	-
Mitsubishi	-12	-	44	-	44	-	49	-	128	+36	128	+36
Nissan	-27	-1	19	+6	62	+6	265	+84	195	+71	268	+136
Subaru	-25	-	-35	-	-39	-	-46	-1	-120	-	-120	-
Tesla	-15	-	-15	-	-15	-	-15	-	-15	-	-15	-
Toyota	-23	-	-32	-	-35	-	-38	-1	-69	+9	-106	+9
Volvo	-55	-	-54	-	-53	-	175	+4	146	+4	227	+56
VWA	32	-	221	-	235	-	328	-1	361	+33	337	+54
Karma	-	-	-	-	-	-	-	-	-	-	-	-
Lucid	-	-	-	-	-	-	-	-	-	-	-	-
Rivian	-	-	-	-	-	-	-	-	-	-	-	-
Industry	131	+10	192	+14	264	+17	297	+21	401	+26	419	+57

Table 8-23: Total Costs Under the Preferred Alternative (PC2LT002) Relative to the No-Action Alternative (NA column) and Relative to the Reference Baseline (RB column) ($2021 billions)[222]

	Total through MY 2031						Total through MY 2032					
	Technology Costs		Civil Penalties		Regulatory Costs		Technology Costs		Civil Penalties		Regulatory Costs	
	NA	RB	NA	RB	NA	RB	NA	RB	NA	RB	NA	RB
BMW	0.1	-	-	-	0.1	-	0.1	-	-	-	0.1	-
Mercedes-Benz	-0.1	-	-	-	-0.1	-	-0.2	-	-	-	-0.1	-
Stellantis	2.8	-	0.4	-	3.1	-	3.6	+0.2	0.4	-	4.0	+0.2
Ford	3.9	+1.1	-	-	3.9	+1.1	4.8	+1.3	-	-	4.8	+1.3
GM	6.6	-	0.9	-	7.5	-	9.8	+0.1	1.2	+0.2	10.9	+0.2
Honda	1.7	-	-	-	1.7	-	1.9	-	-	-	1.9	-
Hyundai	1.3	-	-	-	1.3	-	1.7	+0.1	-	-	1.7	+0.1
Kia	2.6	-	0.1	-	2.7	-	3.3	+0.1	0.1	-	3.4	+0.1
JLR	-	-	-	-	0.1	-	-	-	-	-	0.1	-
Mazda	-	-	-	-	-	-	-0.1	-	-	-	-0.1	-
Mitsubishi	-	-	-	-	-	-	-	-	-	-	-	-
Nissan	0.5	+0.2	0.2	-	0.7	+0.1	0.8	+0.3	0.2	-	1.0	+0.3
Subaru	-0.2	-	-	-	-0.2	-	-0.3	-	-	-	-0.3	-
Tesla	-	-	-	-	-	-	-	-	-	-	-	-
Toyota	-0.5	-	-	-	-0.5	-	-0.8	-	-	-	-0.7	+0.1

[222] Dashes indicate no difference.

	Total through MY 2031						Total through MY 2032					
	Technology Costs		Civil Penalties		Regulatory Costs		Technology Costs		Civil Penalties		Regulatory Costs	
	NA	RB	NA	RB	NA	RB	NA	RB	NA	RB	NA	RB
Volvo	-	-	-	-	-	-	0.1	+0.1	-	-	0.1	+0.1
VWA	0.8	+0.1	0.1	-	0.9	+0.1	1.0	+0.1	0.1	-	1.1	+0.1
Karma	-	-	-	-	-	-	-	-	-	-	-	-
Lucid	-	-	-	-	-	-	-	-	-	-	-	-
Rivian	-	-	-	-	-	-	-	-	-	-	-	-
Industry	19.3	+1.3	1.8	-	21.2	+1.4	25.6	+2.2	2.1	+0.2	27.6	+2.3

Table 8-24: Benefits and Costs of Augural Standards Under the Preferred Alternative, PC2LT002 ($2021 billions, 3% Social Discount Rate, 2.0% SC-GHG Discount Rate)

	Lifetime through MY 2031		Lifetime through MY 2032	
	Total	Annualized	Total	Annualized
Total social costs				
Standard-setting	24.5	0.96	30.8	1.20
With augural	26.8	1.05	34.1	1.33
Difference	+2.3	+0.09	+3.3	+0.13
Total social benefits				
Standard-setting	59.7	2.34	80.5	3.13
With augural	65.3	2.56	89.5	3.48
Difference	+5.6	+0.22	+9.0	+0.35
Net social benefits				
Standard-setting	35.2	1.38	49.7	1.93
With augural	38.4	1.51	55.4	2.15
Difference	+3.2	+0.13	+5.7	+0.22

Table 8-25: Benefits and Costs of Augural Standards Under the Preferred Alternative, PC2LT002 ($2021 billions, 7% Social Discount Rate, 2.0% SC-GHG Discount Rate)

	Lifetime through MY 2031		Lifetime through MY 2032	
	Total	Annualized	Total	Annualized
Total social costs				
Standard-setting	16.2	1.18	20.1	1.45
With augural	17.7	1.29	22.1	1.60
Difference	+1.5	+0.11	+2.0	+0.15
Total social benefits				
Standard-setting	47.0	3.41	63.1	4.57
With augural	51.3	3.72	69.9	5.06
Difference	+4.3	+0.31	+6.8	+0.49
Net social benefits				

	Lifetime through MY 2031		Lifetime through MY 2032	
	Total	**Annualized**	**Total**	**Annualized**
Standard-setting	30.8	2.23	43.0	3.12
With augural	33.5	2.44	47.7	3.46
Difference	+2.7	+0.21	+4.7	+0.34

8.2.7. Effects Relative to the No ZEV Alternative Baseline

8.2.7.1. Overview

The No ZEV alternative baseline cancels out the process wherein some sales volumes in MYs 2023 and beyond turn into ZEVs to align with our understanding of OEM deployment plans consistent with the amounts that would be required if the relevant Section 177 states had adopted the ZEV programs developed by California. Specifically, the No ZEV alternative baseline removes from the reference baseline compliance with ACC I and ACT, which are legally binding, and also removes automaker voluntary ZEV deployment beyond legal requirements, using ACC II (which is not currently legally binding) as a proxy. There are still BEVs and PHEVs present in the results of this case, but they are those that were already observed in the MY 2022 analysis fleet, as well as any made by the model outside of standard setting years for LD BEVs (or in all years, in the case of PHEVs and HDPUV BEVs). As a reminder, the CAFE Model still will build BEVs outside of the standard-setting years if it is cost-effective for manufacturers to do so. This is referred to in our documents as the “30 month payback assumption” and is discussed in more detail in TSD Chapter 5 and the preamble.

In the reference baseline No Action Alternative, BEVs make up approximately 28 percent of the total light-duty fleet by MY 2031; they make up only 19 percent of the total light-duty fleet by 2031 in the No ZEV alternative baseline’s No Action Alternative. Under the Preferred Alternative, PC2LT002, the tech penetration of BEVs in both cases (relative to the reference baseline and to No ZEV) is the same in the reference baseline and in the No ZEV baseline by MY 2031. This is as expected because we do not permit any BEV adoption in the standard setting years and the penetration of this technology in the No Action Alternative is equal to the penetration in the Preferred Standard.

PHEVs have virtually the same tech penetration in the reference baseline as in the No ZEV alternative baseline, as our focus in the ZEV modelling is not PHEVs, increasing only from 2 percent in the reference case to 3 percent in the No ZEV alternative baseline by MY 2031. Strong hybrids have a slightly higher tech penetration rate under the reference baseline than in the No ZEV case in model years between 2027 and 2031 at 27 percent compared to 23 percent in the reference baseline in MY 2031. This difference increases in magnitude under the preferred alternative PC2LT002 (28 percent in MY 2031 when compared to the reference baseline versus 45 percent when PC2LT002 is compared to the No ZEV alternative baseline).

Running alternatives compared to the No ZEV alternative baseline also differs from runs relative to the reference baseline in terms of fuel consumption and electricity consumption, mainly because of how ZEV changes technology rates in the reference baseline. When the preferred alternative (PC2LT002) is assessed relative to the reference baseline, it results in a 64 billion gallon reduction in gasoline consumption; when assessed relative to the No ZEV case, it results in a 115 billion gallon reduction in gasoline consumption. In the No ZEV case alternative baseline, this gasoline consumption is being measured relative to a baseline that has fewer BEVs and therefore has more room for gasoline consumption reductions when other technologies are applied in response to CAFE standards. The increase in electricity consumption is also higher when the preferred alternative is compared to the No ZEV alternative baseline (493 TWh) relative to the reference baseline (333 TWh). This is because although PHEV fuel economy is only counted assuming operation in charge sustaining mode, in accordance with 49 USC 32902(h) limitations, the actual electricity use of the vehicle in charge depleting mode is accounted for in the effects analysis.

When Alternative PC2LT002 is assessed against the No ZEV alternative baseline, net benefits are higher than when it is assessed against the reference baseline. Using the 2% SC-GHG discount rate under the lifetime costs and benefits perspective (MY), total benefits change from $59.7 billion when assessed relative to the reference baseline to $80.3 billion when assessed relative to the No ZEV alternative baseline and total costs increase from $24.5 billion when assessed relative to the reference baseline to $35.4 when assessed against the No ZEV alternative baseline. These changes in costs and benefits are driven partly by changes in technology application and the corresponding technology costs.

8.2.7.2. Effects Summary

The following tables show selected effects for the No Action and final standards (PC2LT002) for both the reference baseline analysis and the No ZEV alternative baseline analysis.

Table 8-26: Selected Effects Summary, Reference Baseline and No ZEV Alternative Baseline, No Action and PC2LT002

	Reference Baseline		No ZEV Alternative Baseline	
	No Action	PC2LT002	No Action	PC2LT002
Average annual sales MY 2027-2031 (millions)	15.17	15.15	15.17	15.15
Gasoline consumption CY 2022-2050 (billions of gallons)	2,578	2,514	2,665	2,549
CO_2 emissions CY 2022-2050 (MMT)	29,628	28,969	30,480	29,273
Net benefits (3% discount rate)	-	35.2	-	44.9
Per vehicle cost MY 2031	1,149	1,541	928	1,589
Per vehicle fuel expenditure MY 2031	14,251	13,612	14,963	13,902
Fleet average fuel economy MY 2031 (MPG)	52.1	52.5	48.8	51.2

Table 8-27: Compliance for Total Light Duty Fleet Under No ZEV Alternative Baseline, No Action and PC2LT002 (MPG)

	2027	2028	2029	2030	2031
Standard					
No Action	47.0	46.9	46.9	46.9	46.9
PC2LT002	47.3	47.4	48.4	49.4	50.4
Difference	+0.3	+0.5	+1.5	+2.5	+3.5
Achieved					
No Action	50.0	49.5	49.2	48.7	48.8
PC2LT002	49.6	49.7	50.2	50.7	51.2
Difference	-0.4	+0.2	+1.0	+2.0	+2.4

Table 8-28: Compliance for Passenger Car Fleet Under No ZEV Alternative Baseline, No Action and PC2LT002 (MPG)

	2027	2028	2029	2030	2031
Standard					
No Action	58.8	58.8	58.8	58.8	58.8
PC2LT002	60.0	61.2	62.5	63.7	65.1
Difference	+1.2	+2.4	+3.7	+4.9	+6.3
Achieved					
No Action	68.9	67.5	65.9	64.4	64.5
PC2LT002	67.9	68.0	68.3	68.5	69.9
Difference	-1.0	+0.5	+2.4	+4.1	+5.4

Table 8-29: Compliance for Light Truck Fleet Under No ZEV Alternative Baseline, No Action and PC2LT002 (MPG)

	2027	2028	2029	2030	2031
Standard					
No Action	42.6	42.6	42.6	42.6	42.6
PC2LT002	42.6	42.6	43.5	44.3	45.2
Difference	0.0	0.0	+0.9	+1.7	+2.6
Achieved					
No Action	43.8	43.5	43.6	43.4	43.4
PC2LT002	43.5	43.7	44.3	44.8	45.2
Difference	-0.3	+0.2	+0.7	+1.4	+1.8

Table 8-30: Selected Light Duty Fleet Technology Penetration Rates by Model Year Under No ZEV Alternative Baseline, No Action and PC2LT002 (MPG)

	2027	2028	2029	2030	2031
Advanced engine					
No Action	16.9	15.8	14.5	14.3	14.3
PC2LT002	15.9	13.6	10.2	8.0	6.1
Difference	-1.0	-2.2	-4.3	-6.3	-8.2
SHEV					
No Action	23.4	24.2	26.2	26.7	26.8
PC2LT002	24.4	28.7	35.7	42.6	44.7
Difference	+1.0	+4.5	+9.5	+15.9	+17.9
PHEV					
No Action	2.9	2.9	2.9	2.9	2.9
PC2LT002	3.7	3.8	4.1	4.1	6.2
Difference	+0.8	+0.9	+1.2	+1.2	+3.3
BEV					
No Action	19.1	19.0	19.0	19.0	19.0
PC2LT002	19.1	19.0	19.0	19.0	19.0
Difference	0.0	0.0	0.0	0.0	0.0

Table 8-31: Per-Vehicle Technology Costs by Model Year, Preferred Alternative (PC2LT002) Relative to the No Action Alternative, No ZEV Alternative Baseline ($2021)

	2027	2028	2029	2030	2031
BMW	1	65	70	207	373
Mercedes-Benz	-102	-113	-102	48	-20
Stellantis	216	222	269	357	380
Ford	169	338	433	434	448
GM	375	367	550	557	1,572
Honda	-286	-117	42	184	117
Hyundai	134	137	443	498	518
KIA	-7	737	1,178	1,296	1,391
JLR	-3	-3	-3	2	2,635
Mazda	32	27	789	856	727
Mitsubishi	-12	95	95	163	203
Nissan	-26	-11	33	414	462
Subaru	-15	-20	412	756	652
Tesla	-15	-15	-15	-15	-15
Toyota	-15	51	128	375	491
Volvo	-43	-42	-42	68	31
VWA	43	190	208	355	506
Karma	0	0	0	0	0
Lucid	0	0	0	0	0
Rivian	0	0	0	0	0
Industry	67	154	297	428	601

Table 8-32: Total Costs Under the Preferred Alternative (PC2LT002) Relative to the No-Action Alternative, Reference Baseline and No ZEV Alternate Baseline ($2021 billions)[223]

	Total through MY 2031					
	Technology Costs		Civil Penalties		Regulatory Costs	
	Ref. Baseline	No ZEV Alt. Baseline	Ref. Baseline	No ZEV Alt. Baseline	Ref. Baseline	No ZEV Alt. Baseline
BMW	0.1	0.3	-	0.2	0.1	0.5
Mercedes-Benz	-0.1	-0.1	-	0.1	-0.1	-
Stellantis	2.8	2.5	0.4	0.7	3.1	3.2
Ford	2.8	3.3	-	-	2.8	3.3
GM	6.6	6.6	0.9	1.0	7.5	7.6

[223] Dashes indicate no difference.

	Total through MY 2031					
	Technology Costs		Civil Penalties		Regulatory Costs	
	Ref. Baseline	No ZEV Alt. Baseline	Ref. Baseline	No ZEV Alt. Baseline	Ref. Baseline	No ZEV Alt. Baseline
Honda	1.7	-0.1	-	-	1.7	-0.1
Hyundai	1.3	1.6	-	-	1.3	1.6
Kia	2.6	2.9	0.1	0.1	2.7	3.0
JLR	-	0.2	-	0.1	0.1	0.3
Mazda	-	0.5	-	-	-	0.5
Mitsubishi	-	0.1	-	-	-	0.1
Nissan	0.3	0.9	0.2	0.5	0.6	1.4
Subaru	-0.2	1.4	-	-	-0.2	1.4
Tesla	-	-	-	-	-	-
Toyota	-0.5	2.5	-	0.3	-0.5	2.8
Volvo	-	-	-	0.1	-	0.1
VWA	0.7	0.8	0.1	0.2	0.8	1.1
Karma	-	-	-	-	-	-
Lucid	-	-	-	-	-	-
Rivian	-	-	-	-	-	-
Industry	18.0	23.2	1.8	3.3	19.8	26.5

Table 8-33: Total GHG Emission Quantities, LD Fleet, CY 2022-2050

	No Action	Relative to No Action				
		PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
CO2 (mmt)						
Reference baseline						
Upstream	6,523	-94	-152	-200	-245	-333
Downstream	23,105	-566	-852	-1,110	-1,364	-1,872
Total	29,628	-659	-1,004	-1,310	-1,609	-2,205
No ZEV alternative baseline						
Upstream	6,606	-183	-256	-299	-333	-385
Downstream	23,874	-1,025	-1,398	-1,652	-1,877	-2,265
Total	30,480	-1,207	-1,654	-1,952	-2,211	-2,650
CH4 (t)						
Reference baseline						

	No Action	Relative to No Action				
		PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Upstream	39,586,800	-817,866	-1,257,120	-1,642,547	-2,017,050	-2,760,181
Downstream	766,997	-7,096	-9,036	-11,464	-15,180	-19,547
Total	40,353,797	-824,961	-1,266,156	-1,654,011	-2,032,229	-2,779,727
No ZEV alternative baseline						
Upstream	40,595,166	-1,511,998	-2,078,915	-2,449,245	-2,767,278	-3,297,864
Downstream	789,655	-11,622	-16,281	-19,591	-22,804	-29,544
Total	41,384,821	-1,523,620	-2,095,196	-2,468,836	-2,790,083	-3,327,408
N2O (t)						
Reference baseline						
Upstream	814,754	-18,502	-28,061	-36,611	-44,988	-61,672
Downstream	374,725	-4,982	-6,614	-8,495	-11,579	-15,032
Total	1,189,479	-23,484	-34,676	-45,107	-56,567	-76,704
No ZEV alternative baseline						
Upstream	839,062	-33,763	-46,199	-54,538	-61,844	-74,288
Downstream	389,685	-8,366	-11,773	-14,450	-17,197	-21,858
Total	1,228,747	-42,129	-57,972	-68,988	-79,041	-96,146

Table 8-34: Total Criteria Pollutant and Ozone Precursor Emission Quantities, LD Fleet, CY 2022-2050

	No Action	Relative to No Action				
		PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
CO (t)						
Reference baseline						
Upstream	1,907,486	-12,812	-25,554	-33,925	-41,077	-54,538
Downstream	171,545,683	-1,011,782	-1,256,006	-1,553,267	-2,025,460	-2,476,186
Total	173,453,170	-1,024,594	-1,281,559	-1,587,193	-2,066,538	-2,530,723
No ZEV alternative baseline						
Upstream	1,902,280	-30,156	-44,624	-50,930	-54,459	-56,764
Downstream	174,898,380	-1,631,301	-2,242,136	-2,670,016	-3,052,808	-3,837,561
Total	176,800,660	-1,661,457	-2,286,760	-2,720,945	-3,107,267	-3,894,325
VOC (t)						
Reference baseline						
Upstream	7,146,024	-165,524	-251,239	-327,501	-402,281	-551,191
Downstream	13,003,503	-71,535	-86,535	-104,590	-133,780	-159,745
Total	20,149,527	-237,058	-337,773	-432,091	-536,061	-710,936
No ZEV alternative baseline						

	No Action	Relative to No Action				
		PC2LT002	**PC1LT3**	**PC2LT4**	**PC3LT5**	**PC6LT8**
Upstream	7,364,698	-301,921	-413,017	-487,521	-552,870	-664,359
Downstream	13,249,478	-110,926	-150,609	-178,580	-202,300	-251,717
Total	20,614,176	-412,846	-563,626	-666,101	-755,170	-916,076
NOx (t)						
Reference baseline						
Upstream	3,526,543	-30,965	-57,237	-75,443	-91,593	-122,781
Downstream	5,749,026	-26,296	-33,345	-41,845	-55,242	-68,770
Total	9,275,569	-57,261	-90,583	-117,287	-146,836	-191,552
No ZEV alternative baseline						
Upstream	3,532,403	-67,634	-97,835	-112,672	-122,747	-134,034
Downstream	5,834,060	-43,128	-59,803	-71,826	-83,076	-104,958
Total	9,366,462	-110,762	-157,638	-184,497	-205,823	-238,992
SO2 (t)						
Reference baseline						
Upstream	1,206,194	+3,515	-1,183	-1,950	-1,644	-627
Downstream	109,044	-2,666	-4,017	-5,234	-6,432	-8,823
Total	1,315,238	+850	-5,199	-7,184	-8,077	-9,450
No ZEV alternative baseline						
Upstream	1,180,215	-489	-3,935	-2,882	-279	+7,780
Downstream	112,667	-4,831	-6,593	-7,791	-8,851	-10,676
Total	1,292,882	-5,320	-10,528	-10,673	-9,129	-2,896
PM2.5 (t)						
Reference baseline						
Upstream	258,194	-2,186	-4,079	-5,379	-6,527	-8,745
Downstream	270,245	-2,773	-3,567	-4,531	-6,062	-7,712
Total	923,989	-4,552	-6,988	-9,044	-11,508	-15,045
No ZEV alternative baseline						
Upstream	258,463	-4,818	-6,985	-8,037	-8,737	-9,489
Downstream	278,851	-4,536	-6,365	-7,733	-9,015	-11,395
Total	932,610	-8,522	-12,215	-14,424	-16,282	-19,266

Figure 8-53: Percentage Change in Sales Under No ZEV Alternative Baseline, by Action Alternative

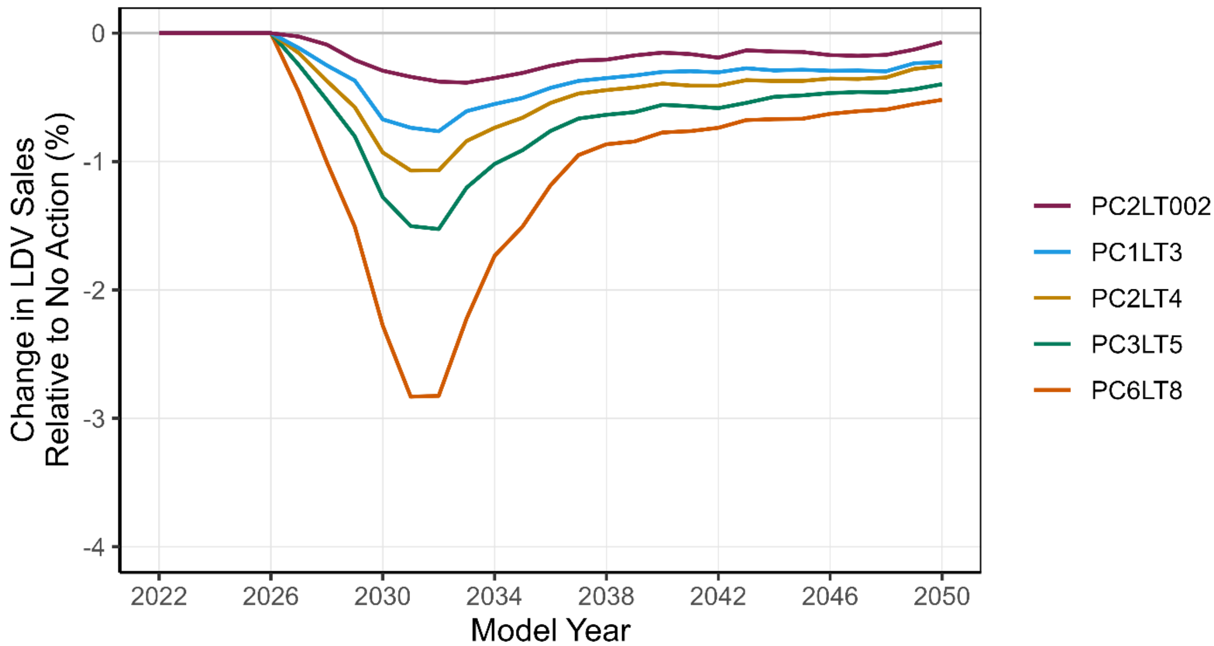


Table 8-35: Industry-Wide Labor Utilization Effects Under No ZEV Alternative Baseline (in Full-Time Equivalent Jobs)

Model Year	No Action Alternative	Difference from No-Action				
		PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
2022	880,265	0	0	0	0	0
2023	936,298	0	0	0	0	0
2024	943,458	0	0	0	0	0
2025	915,527	0	0	0	0	0
2026	921,657	0	0	0	0	0
2027	947,647	1,004	1,331	990	293	-1,345
2028	966,309	1,701	1,984	1,528	395	-2,101
2029	965,088	2,493	3,093	2,219	576	-4,076
2030	949,931	4,311	5,361	4,483	1,746	-5,445
2031	936,872	7,322	7,922	6,986	4,591	-5,780

Table 8-36: Benefits and Costs of Augural Standards Under the Preferred Alternative, PC2LT002 ($2021 billions, 3% Social Discount Rate, 2.0% SC-GHG Discount Rate)

	Lifetime through MY 2031		Lifetime through MY 2032	
	Total	Annualized	Total	Annualized
Total social costs				
Reference baseline	24.5	0.96	30.8	1.20

	Lifetime through MY 2031		Lifetime through MY 2032	
	Total	Annualized	Total	Annualized
No ZEV alternative baseline	35.4	1.39	46.8	1.82
Difference	+10.9	+0.43	+16.0	+0.62
Total social benefits				
Reference baseline	59.7	2.34	80.5	3.13
No ZEV alternative baseline	80.3	3.15	118.1	4.59
Difference	+20.6	+0.81	+37.6	+1.46
Net social benefits				
Reference baseline	35.2	1.38	49.7	1.93
No ZEV alternative baseline	44.9	1.76	71.3	2.77
Difference	+9.7	+0.38	+21.6	+0.84

Table 8-37: Benefits and Costs of Augural Standards Under the Preferred Alternative, PC2LT002 ($2021 billions, 7% Social Discount Rate, 2.0% SC-GHG Discount Rate)

	Lifetime through MY 2031		Lifetime through MY 2032	
	Total	Annualized	Total	Annualized
Total social costs				
Reference baseline	16.2	1.18	20.1	1.45
No ZEV alternative baseline	22.6	1.64	29.6	2.14
Difference	+6.4	+0.46	+9.5	+0.69
Total social benefits				
Reference baseline	47.0	3.41	63.1	4.57
No ZEV alternative baseline	62.4	4.53	91.2	6.61
Difference	+15.4	+1.12	+28.1	+2.04
Net social benefits				
Reference baseline	30.8	2.23	43.0	3.12
No ZEV alternative baseline	39.8	2.89	61.6	4.46
Difference	+9.0	+0.66	+18.6	+1.34

8.3. HDPUV Fleet

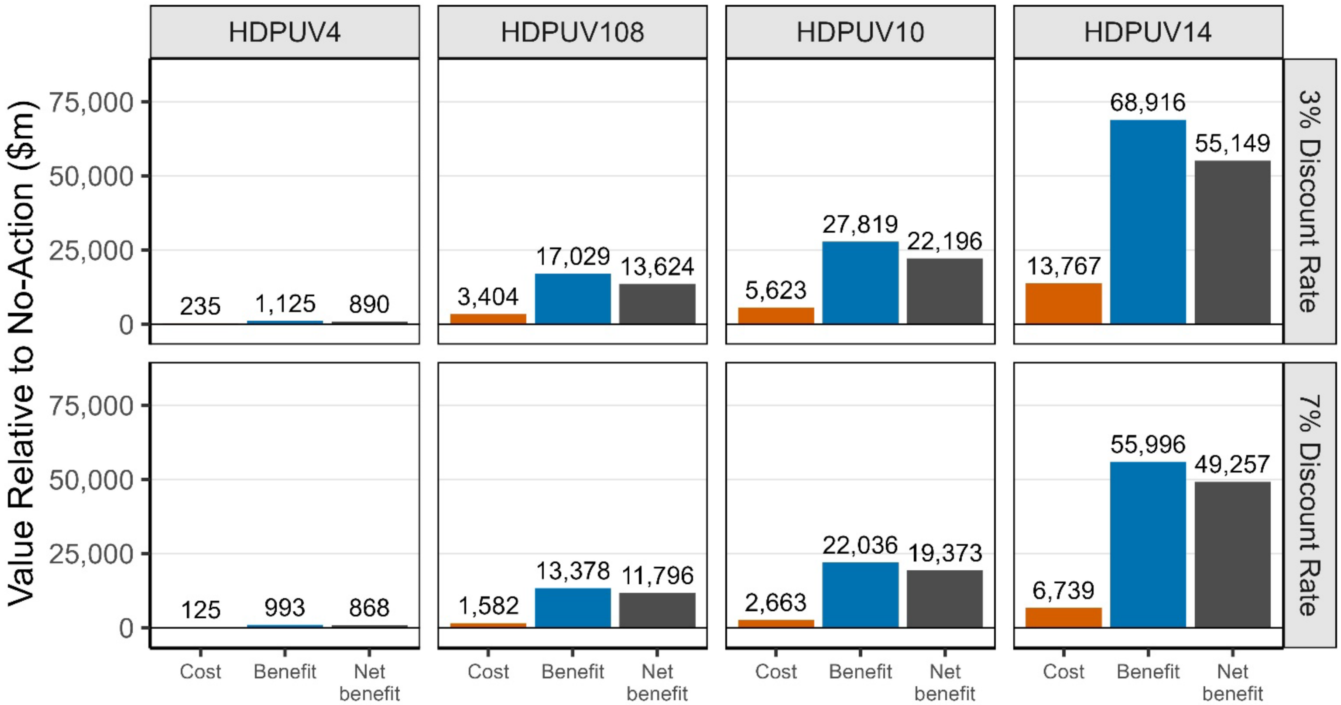
8.3.1. Summary of Benefits and Costs

To assess the effects 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. Figure 8-54 reports the outcome of this calculation for CYs 2022-2050 at both a three and seven percent social discount rate.[224] Examining costs and benefits across alternatives, both metrics

[224] Results are presented for SC-GHG discount rates of 2.0 percent. Benefit summaries for alternate SC-GHG discount rates are included in Chapter 8.3.4.6, Table 8-14.

increase with increases in stringency. Relative to the No-Action Alternative, program net benefits are positive across all alternatives. Aggregate costs and benefits in the HDPUV fleet are significantly smaller than those in the LD fleet (discussed in FRIA 8.2.1). The LD and HDPUV segments represent very different fleets with regard to technology levels in the reference baseline, available technology improvements, and overall fleet size. For example, the MY 2022 HDPUV fleet is approximately six percent of the size of the LD fleet of the same vintage. Consequently, the costs and benefits of the fuel efficiency standards are significantly less than those of the CAFE standards. The limited number of vehicle models within the HDPUV also means that changes to one or two vehicle lines within the fleet may create a sizeable difference in costs and benefits between alternatives.

Figure 8-54: Costs and Benefits for the HDPUV Fleet, CYs 2022-2050



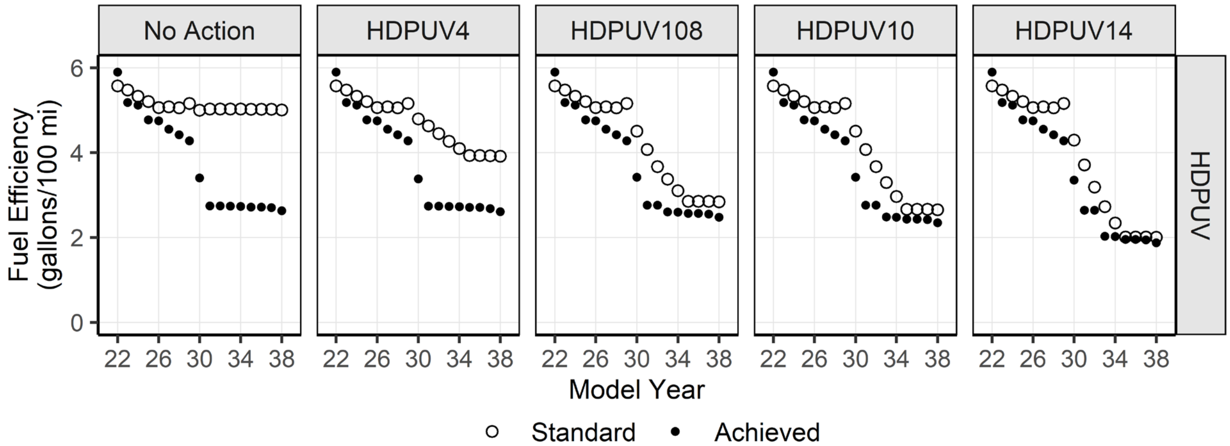
Chapter 8.3.4 outlines the main categories of costs and benefits aggregated to produce Figure 8-54. The largest component of these estimated costs is the technology cost that manufacturers pay to improve fleet fuel efficiency and meet the targets under each alternative. Reductions in fuel costs for consumers who purchase more fuel-efficient vehicles is the largest benefit component.

8.3.2. Effects on Vehicle Manufacturers

The CAFE Model produces the industry-level, achieved fuel efficiency values for the HDPUV fleet as shown in Figure 8-55. Note that these graphs plot fuel efficiency by model year, with fuel efficiency reported in gallons required to drive 100 miles. This is a more common metric in the HDPUV fleet compared to the light-duty fleet. Reporting time on the x axis and fuel efficiency on the y-axis means that a graph that slopes down and to the right represents increasing fuel efficiency over time. Under all scenarios, over the period from 2023 until 2038, the fleet's achieved fuel efficiency exceeds the regulatory standard. The No-Action and HDPUV4 scenarios see the highest levels of overcompliance. The one period in which the fleet average does not over-comply is in the starting year, MY 2022. In this year the achieved fuel efficiency displays a slight undercompliance with the regulatory standard[225].

[225] In modeling the baseline HDPUV fleet in the CAFE model, technology application by manufacturers is limited to fleets starting in MY 2023 and after. The baseline fleet is modeled from compliance data ranging from MY 2014 to MY 2022, and this accounts for the fleet modeled fuel efficiency to show a slight undercompliance with the regulatory standard for this year. TSD Chapter 1.4.1 discusses choices made in the baseline fleet, and TSD Chapter 2.2 discusses the input decisions and data for the HDPUV baseline vehicle market.

Figure 8-55: Fleet Modeled Fuel Efficiency

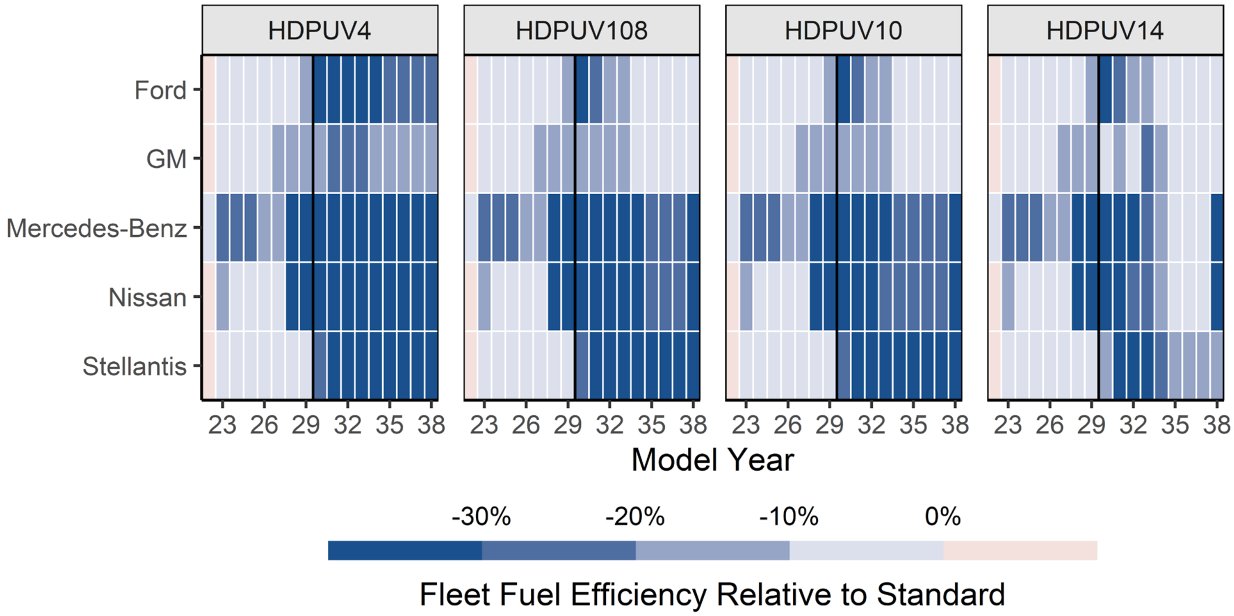


These are industry-wide, fleet-level results, and we note that results vary considerably among specific manufacturers. Figure 8-56 presents manufacturer-level differences between achieved and required fuel efficiency levels on a fleet-wide basis. Lighter colored shading represents manufacturer-years 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 pink fall short of their compliance thresholds. 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 using over-compliance credits from another fleet (i.e., credits obtained from another manufacturer) or model year, or by paying civil penalties[226], as discussed in Section VII of the preamble. The vertical line in the figure indicates the start of MY 2030, which would be the beginning of the new revised standards for the HDPUV fleet.

Mercedes-Benz, with its line of work vans, is able to meet compliance requirements over the time period of the analysis from 2022 to 2038 for all four scenarios. The other four manufacturers—Ford, GM, Nissan, and Stellantis—comply in every year except for the first year of the analysis, 2022, for all four scenarios.

[226] Civil penalties for HDPUVs are significantly higher than light-duty penalties, and manufacturers have not found them to be a cost-effective method for meeting the HDPUV standards. As such, no manufacturers use civil penalty payments to achieve compliance in our model runs.

Figure 8-56: Modeled Fleet-Wide Achieved Fuel Efficiency by HDPUV Manufacturer



8.3.2.1. Technology Application

To meet the required HDPUV fuel efficiency levels under each regulatory alternative, the CAFE Model simulates compliance in part by applying various technologies to vehicle models in each manufacturer's regulated fleet. The vertical dashed lines bracket MY 2030 to MY 2038. As shown in Figure 8-57, the majority of this technology application occurs for model years 2023 and 2025 and is clustered in some later years as defined by vehicle redesign schedules. The quantity and timing of technology application across the four scenarios is quite similar to the No-Action alternative, with some deviation across alternatives in MY 2033.

Figure 8-57: Timing of Technology Application in Response to Regulatory Alternatives

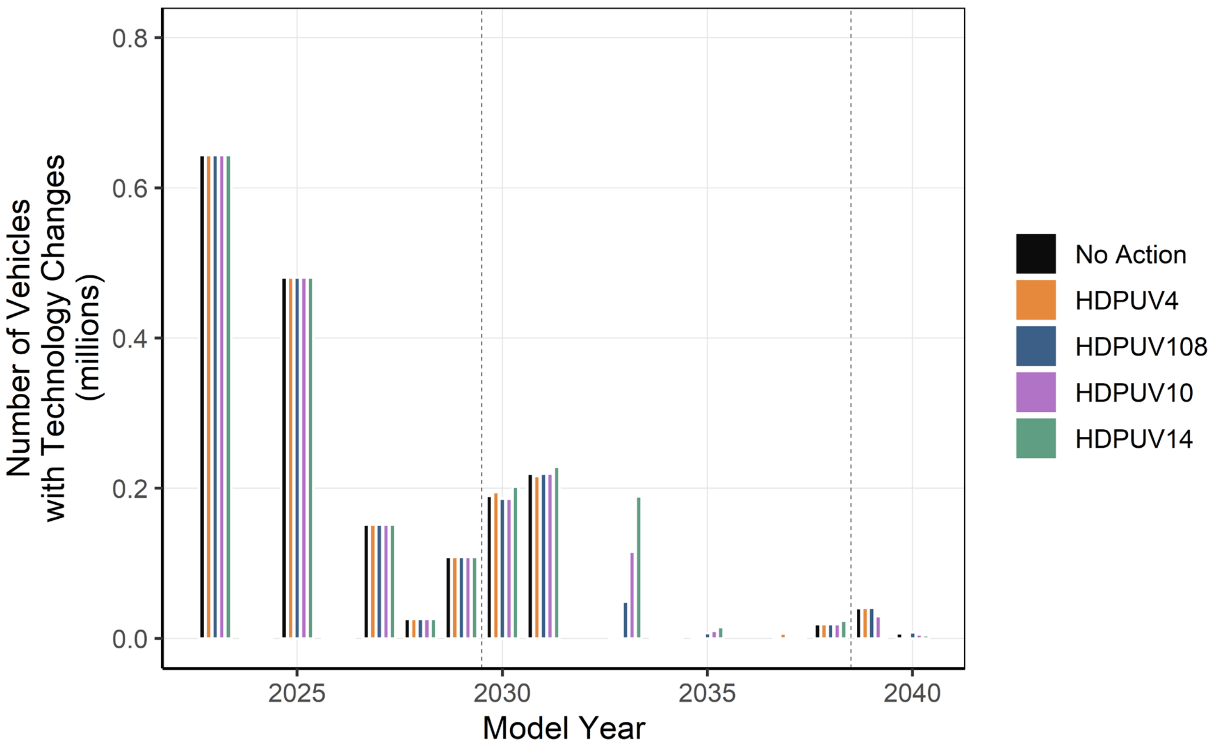
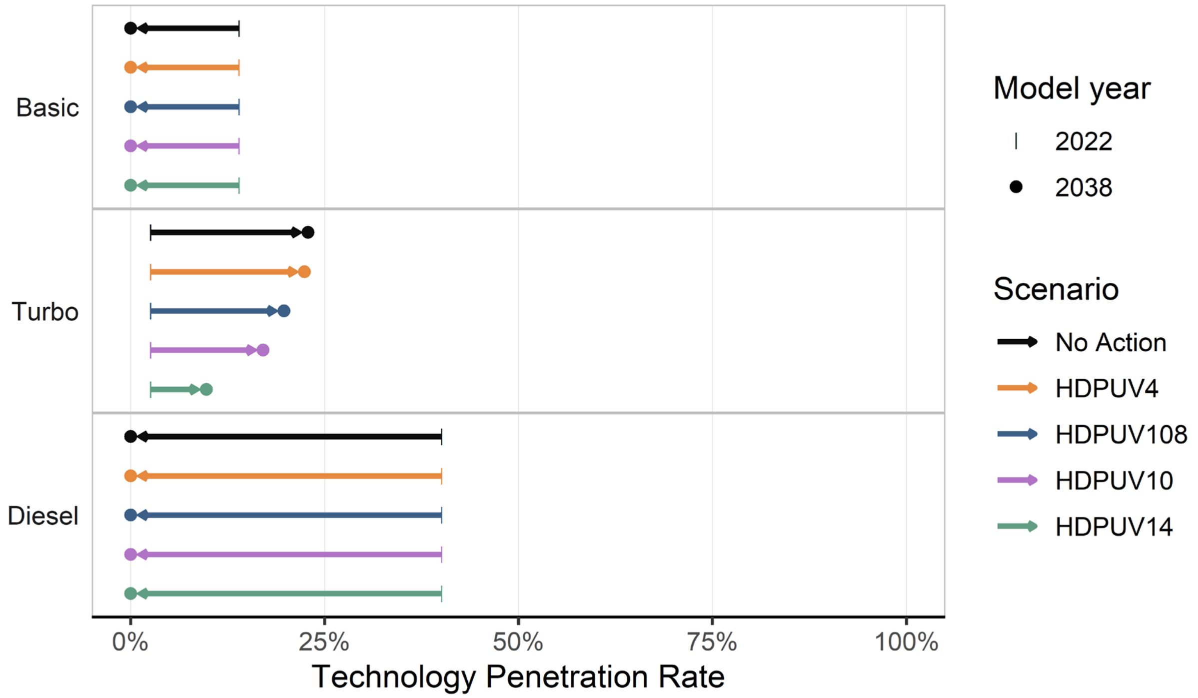


Figure 8-58 and Figure 8-59 present the resulting industry-wide technology penetration rates. Note that the spectrum of technologies applied in the light-duty fleet is broader than that of the HDPUV fleet. Consequently, there are technologies not included in the two graphs below that are included in similar graphs for the light-duty fleet, such as CVT technology. Such transmissions are common in the light-duty fleet but absent from the heavy-duty fleet because CVTs do not have the torque handling capability necessary to function properly on heavy duty trucks and work vans. In the technology prevalence figures below, each horizontal line segment represents the change in technology penetration between 2022 (represented by a short vertical line segment) and 2038 (represented by a circle). Arrows indicate the direction of the change (increase of decrease in percent penetration) and line colors represent the regulatory alternative. Between 2022 and 2038, CAFE Model estimates reveal several trends, including:

Engine technology (Figure 8-58):

- Basic engine technology (including SOHC, DOHC, VVL, DEAC, and stoichiometric gasoline direct injection [SDGI]) penetration rates decrease close to zero percent by MY 2038 across all scenarios.
- ICE application of Turbo between MY 2022 and MY 2038 increases for the No-Action Alternative, HDPUV4, HDPUV108, and HDPUV10 alternatives and also increases by roughly 10% for the most stringent alternative, HDPUV14.
- Diesel engine penetration approaches zero for all scenarios by MY 2038.

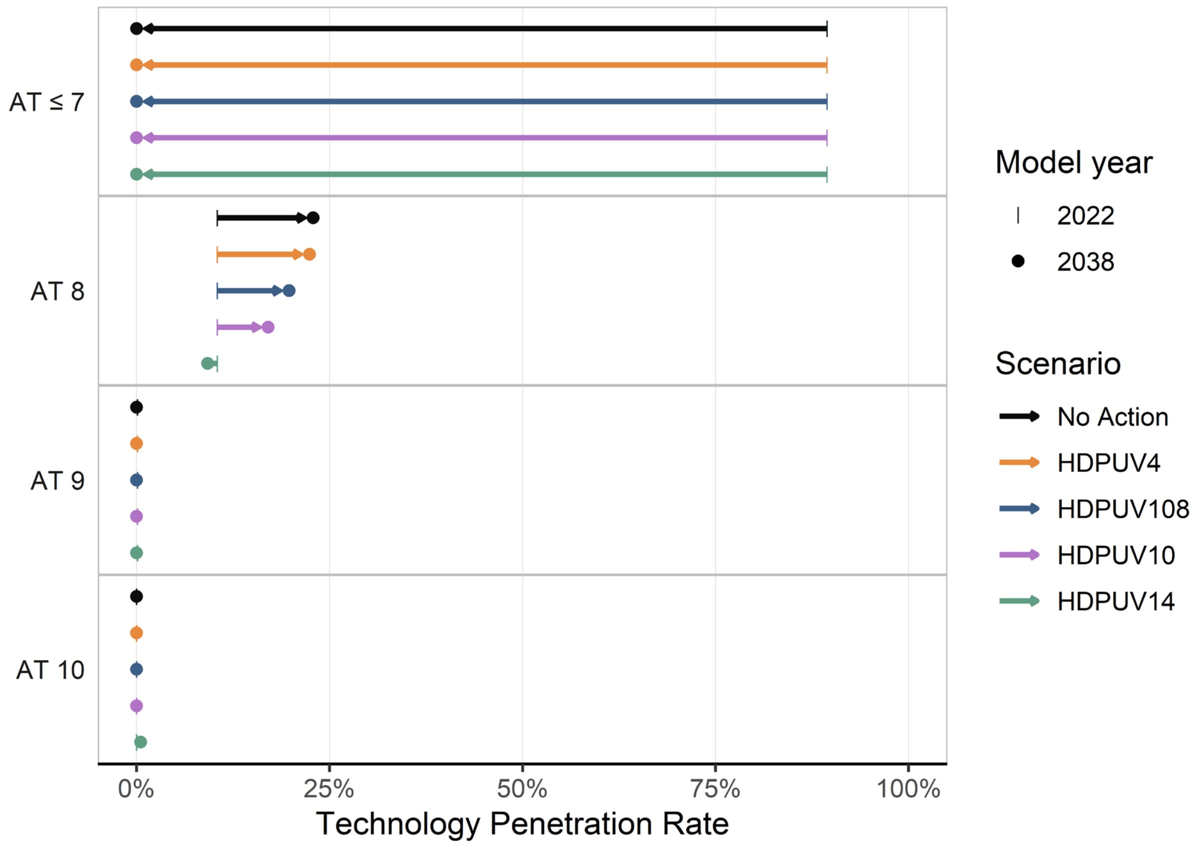
Figure 8-58: Prevalence of Engine Technology in the HDPUV Fleet Under Different Regulatory Alternatives



Transmission technology (Figure 8-59):

- Penetration of AT7 approaches zero by MY 2038. The AT7 transmissions are partially replaced with AT8 except in the most stringent scenario HDPUV14 which requires replacing a very small proportion of the AT7s with AT10s. By 2038, most of the ICE powertrains are replaced with hybrid electric or electric versions and in the process, the stand-alone multi-ratio transmissions noted above are replaced with hybrid powertrain multi-ratio transmissions or single speed transmissions.

Figure 8-59: Prevalence of Transmission Technology in the Fleet Under Different Regulatory Alternatives



Electrified powertrain technology (Figure 8-60):

- Trends in technology penetration rates for various electrified powertrain technologies are similar across model years.
- Penetration of SHEV technology increases from MY 2022 until MY 2032. Most of the movement in SHEV, PHEV, and BEV technologies occur prior to MY 2033. After this point, their penetration rates remain roughly steady through MY 2050, with some minor variation, especially in the case of HDPUV14.
- The main source of variation across alternatives is PHEV penetration levels, with higher stringencies seeing higher levels of PHEV application. The one exception is the highest stringency (HDPUV14), where BEV penetration rates increase, and SHEV penetration decreases relative to the No-Action case.
- The penetration of BEV technology never goes above roughly 50% for all scenarios.
- The penetration of SHEVs reaches about 35% by MY 2050 for all but the most stringent scenario.
- The penetration of PHEVs reaches 15% by MY 2050 for the most stringent scenario, HDPUV14.
- By MY 2050, the combined hybrid and electrified technology penetration rate reaches above 80% for all scenarios.

Figure 8-60: Hybrid and Electrified Technology Penetration Rates by Model Year

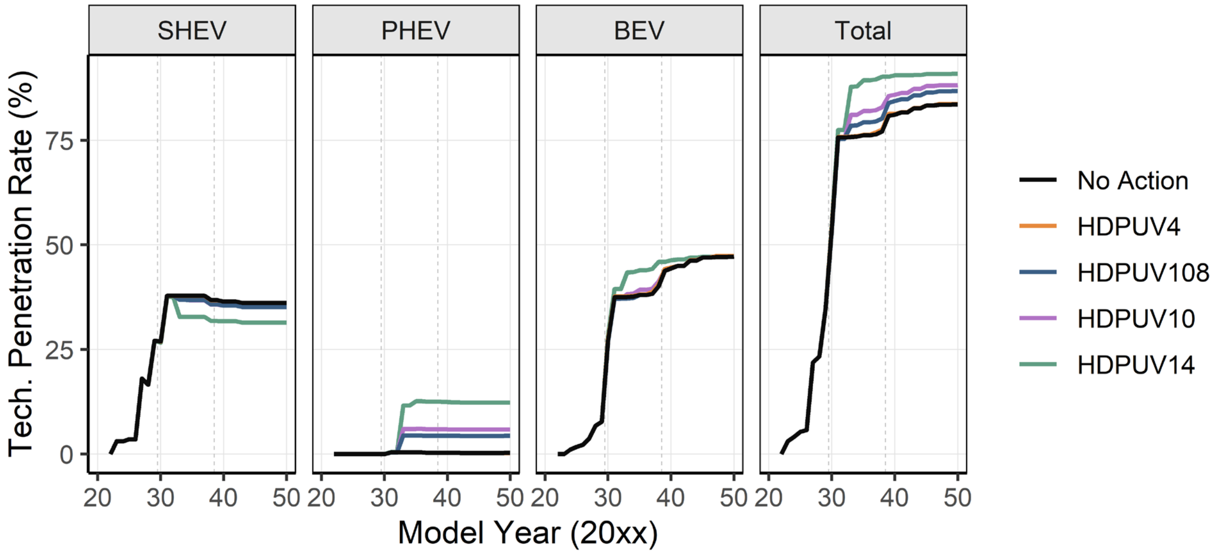


Figure 8-61 Provides more detail regarding the penetration of hybrid and electric powertrain technologies to the HDPUV fleet from MY 2022 through MY 2038.

- The use of ICE technology decreases to under 25 percent penetration by 2038 in each alternative. For the most stringent scenario, HDPUV14 the penetration of ICE technology goes down to under ten percent penetration.
- Most of the penetration in the heavy-duty fleet is BEV1 and penetration of BEV2 reaches only a few single percentage points.
- Penetration of SHEV technology is greater than PHEV technology in every scenario.

Figure 8-61: Prevalence of Powertrain Technology in the Fleet Under Different Regulatory Alternatives

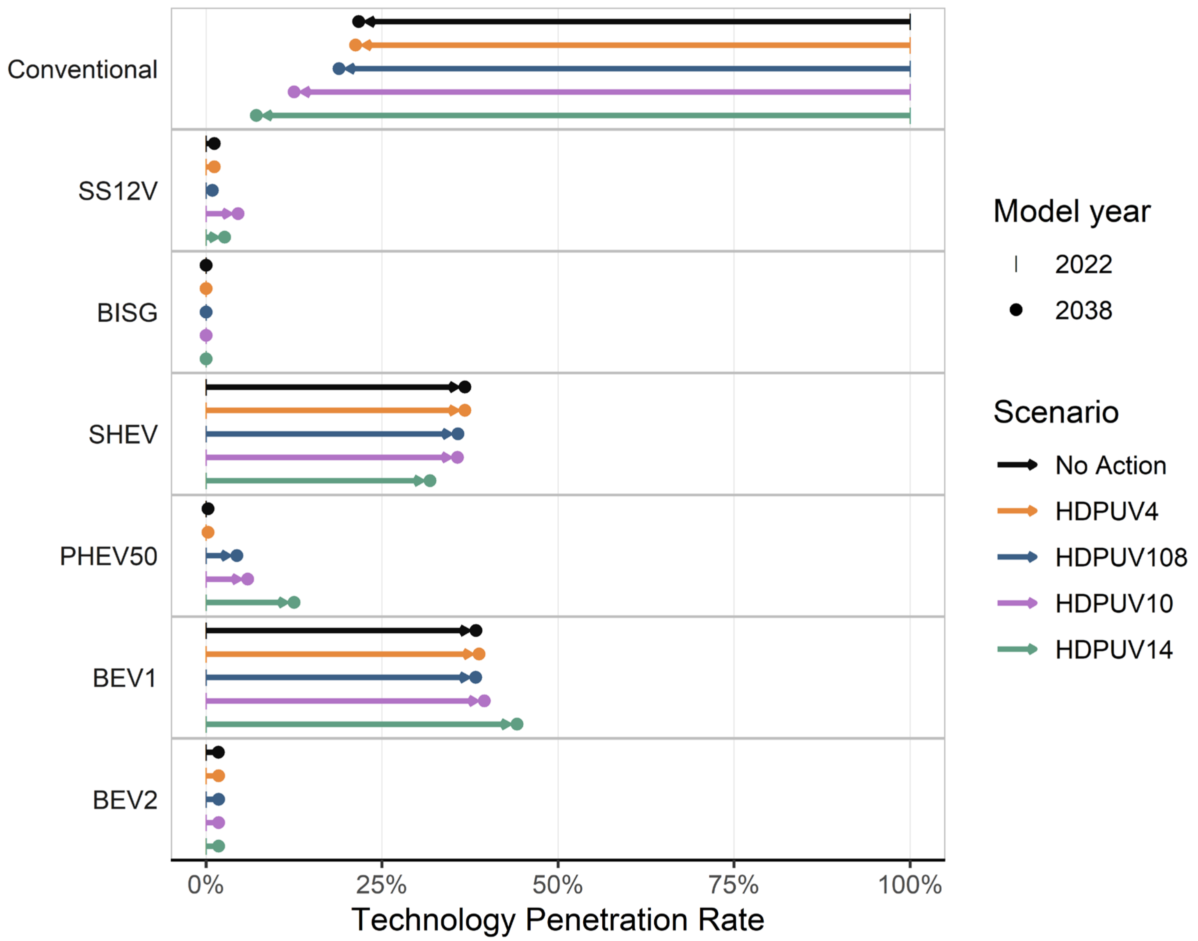
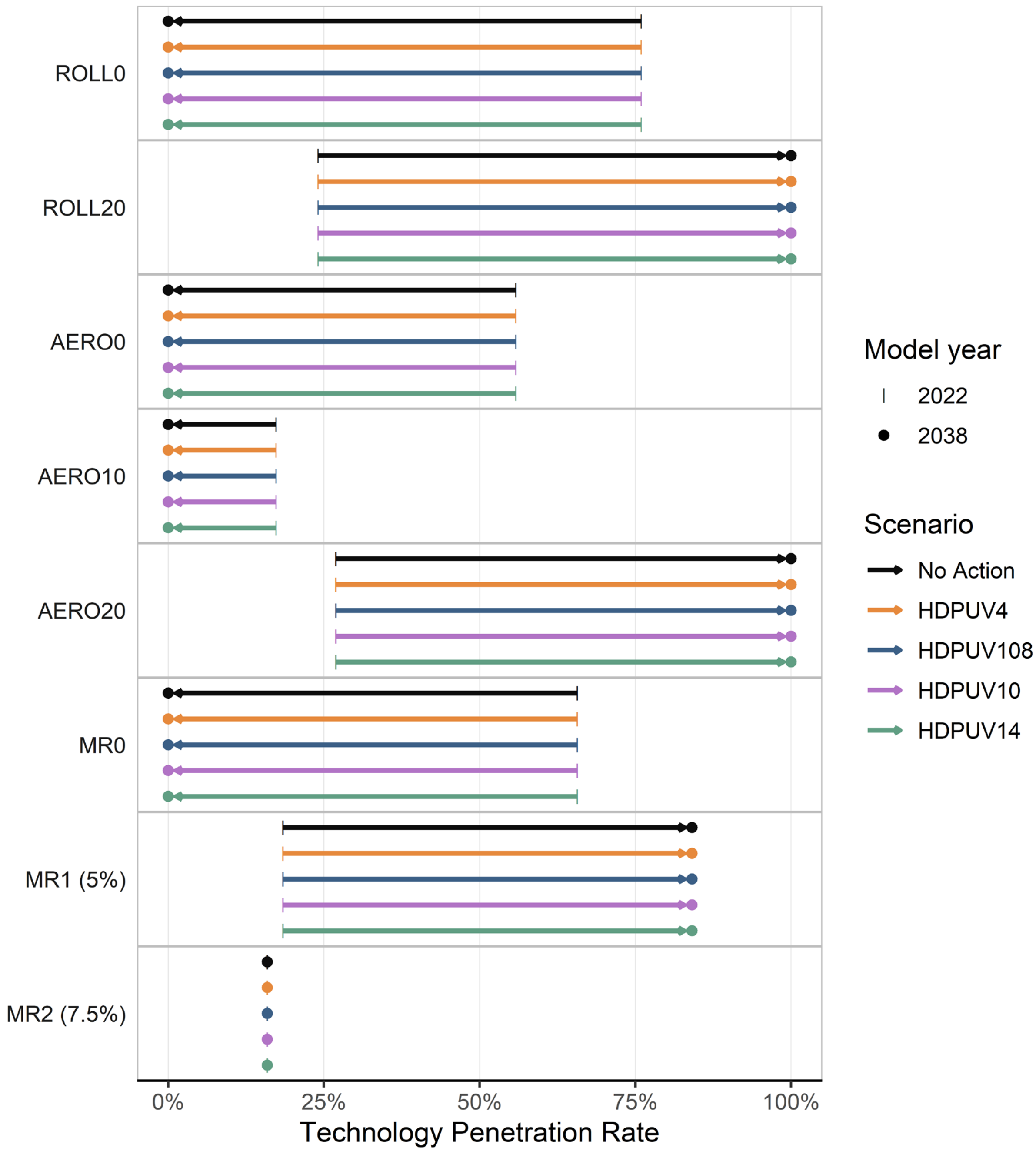


Figure 8-62 shows the penetration of road load reduction technologies for the heavy-duty fleet between MYs 2022 and 2038. The notable trends are as follows:

- Penetration of road load reduction technologies is the same for all scenarios.
- Low rolling resistance tires transition from ROLL0 to ROLL20 by MY 2038.
- Decrease in aerodynamic drag is broadly applied across the fleet for all scenarios. The penetration of AERO20 reaches nearly 100% for all scenarios over the period of the simulation.
- The model broadly applies moderate mass reduction technologies. MR1 is applied to nearly 80% of the fleet in all scenarios and MR2 is applied to a select number of models in the reference baseline and remains at that level across the other alternatives.

Figure 8-62: Prevalence of Tire Rolling Resistance, Aerodynamics, and Mass Reduction Technologies in the Fleet Under Different Regulatory Alternatives



8.3.2.2. Compliance Costs

Manufacturers comply with HDPUV FE by applying fuel economy-improving technologies or use over-compliance credits (whether earned or purchased). The CAFE Model computes both aggregate and per-vehicle values of these costs. Civil penalties for HDPUVs are significantly higher than light-duty penalties, and manufacturers have not found them to be a cost-effective method for meeting the HDPUV standards. As such, the regulatory costs for HDPUVs consist solely of the technology costs. Figure 8-63 reports industry-wide, model year trends in per-vehicle technology costs. In line with technology application trends, costs across alternatives remain within a relatively narrow band. Costs for alternative HDPUV4 are nearly identical to those in the reference baseline while both HDPUV108 and HDPUV10 present differences only beyond MY 2032. A portion of this clustering of modeled costs is due to the increase in technology cost in the reference baseline in MY 2030. This cost increase and the associated decrease in fleet-wide fuel efficiency is the result of assumed redesign scheduling (e.g., a tranche of Ford vans in MY 2030) and the relative cost-effectiveness levels of technology available at that time (e.g., BEVs relative to alternative technology options).

Figure 8-63: Average Per-Vehicle Technology Cost

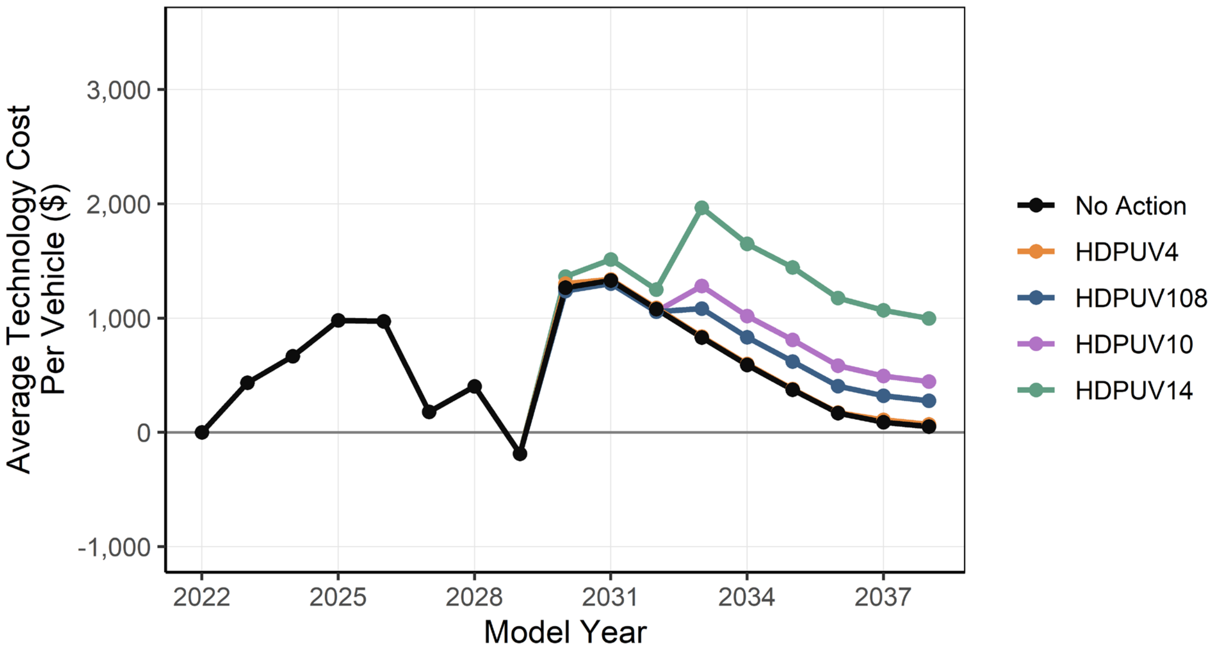


Figure 8-63 presents per-vehicle technology costs for MY 2038 vehicles by manufacturer in each alternative. Gray bars in the figure are costs in the No-Action Alternative. Total No-Action Alternative costs are listed in the data labels in the “No-Action” panel. The portions of the bar in color represent the changes in manufacturer technology costs for each action alternative. For example, average per-vehicle technology costs for Ford are $710 for the No-Action scenario. The cost increases by $170 for the second most stringent scenario, HDPUV10, for a total cost of $880 (an increase of 24%). Moreover, the cost would increase by $830 to a total of $1,540 (an increase of 117%) for Ford to achieve the most stringent scenario, HDPUV14. Some manufacturers like Nissan and Mercedes-Benz meet the standards of the action alternatives without any additional costs. For two manufacturers, Stellantis and GM, the No-Action Alternative shows negative per-vehicle technology costs. This results from technology costs being defined on an incremental basis, with costs in the No-Action Alternative equal to the total technology costs minus the costs of the relevant technology in the initial reference baseline MY 2022 fleet. In the case of MY 2038, GM is increasing its turbo parallel engine technology penetration, which is modeled as a lower cost than the superseded advanced diesel engine technology in the reference baseline. For a more detailed explanation of No-Action Alternative technology cost assumptions, please refer to TSD Chapter 3.1. As the regulatory stringency increases, some manufacturers shift towards a higher proportion of PHEV penetration in the 2038 fleet. For example, this shift for GM results in a per vehicle cost increase of $680 for HDPUV108, $990 for HDUPUV10, and $1,900 for HDPUV14.

Figure 8-64: Per-Vehicle Technology Cost, MY 2038 Vehicle

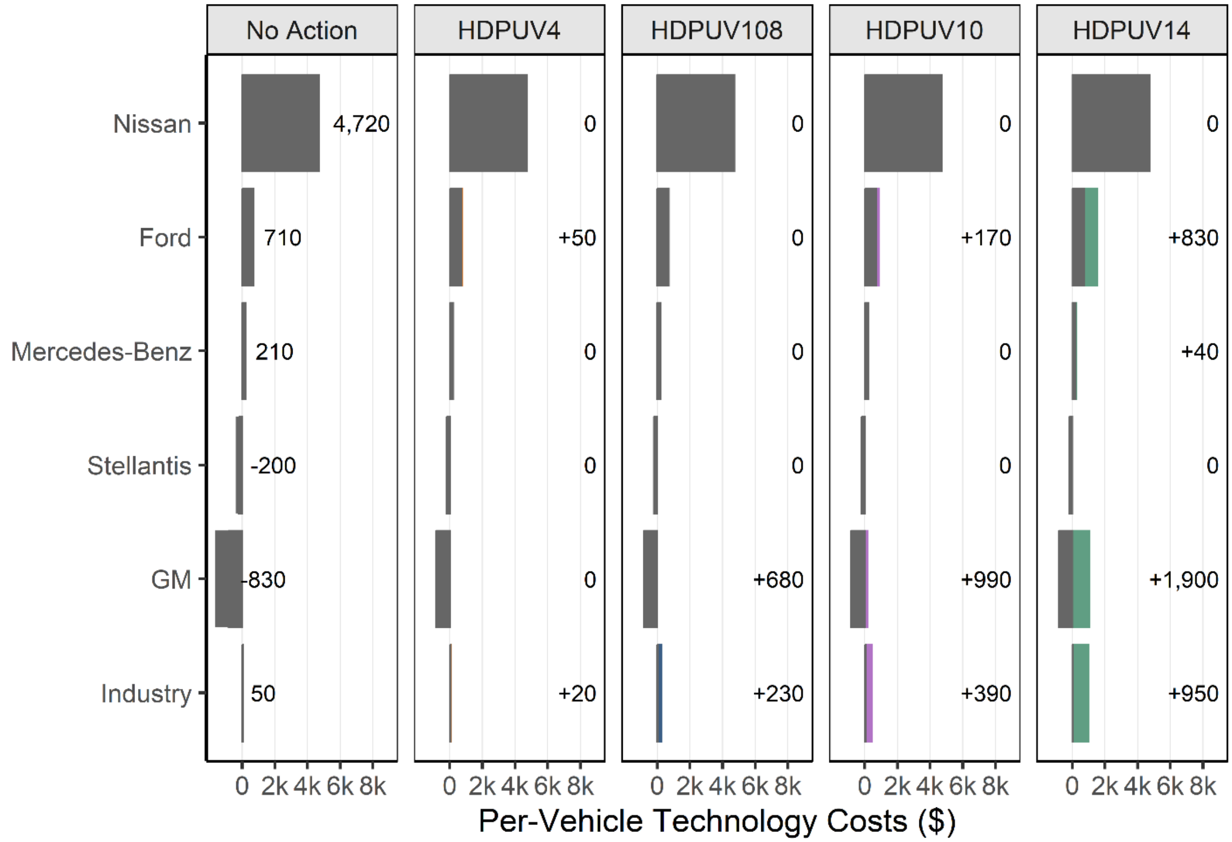
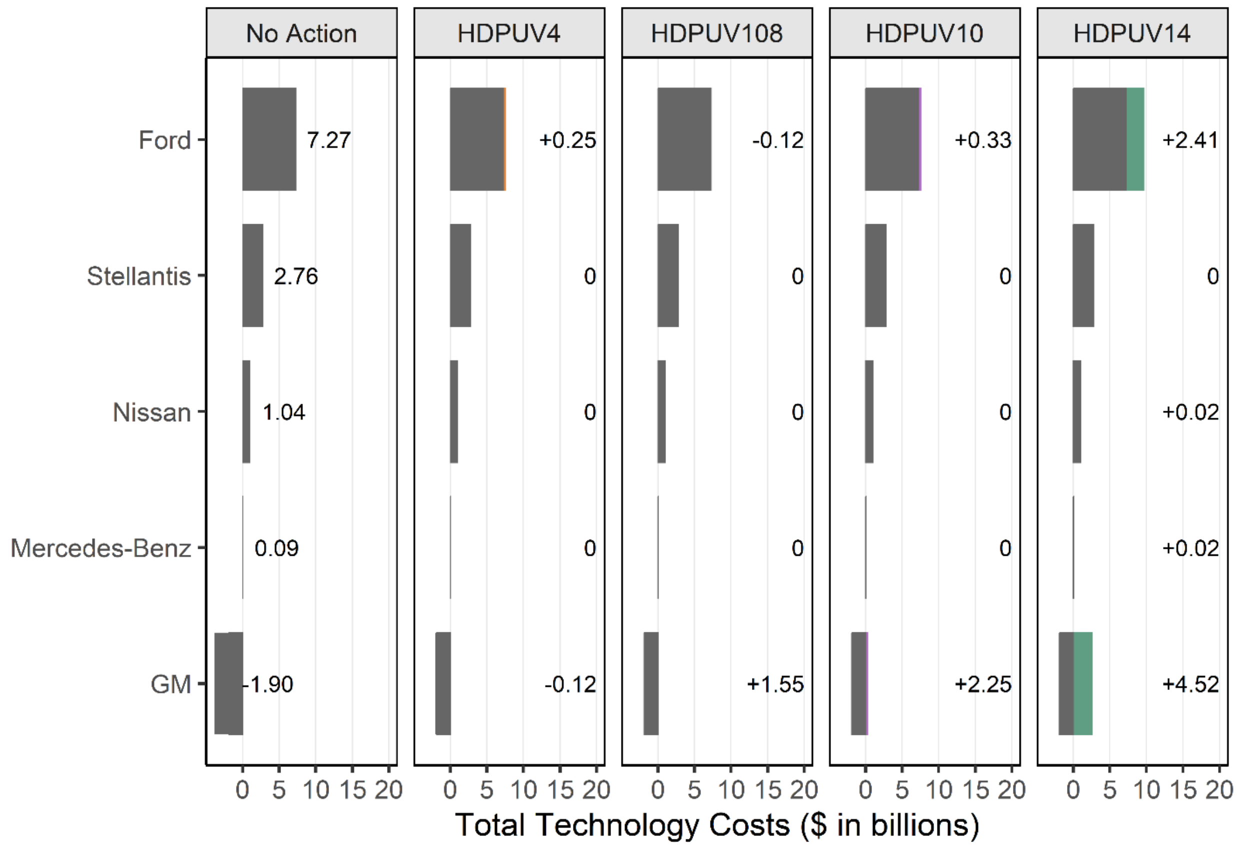


Figure 8-65 reports total technology costs for MYs 2022 through 2038 in the No-Action Alternative alongside labeled aggregate technology cost increases for each action alternative. In most cases, differences in manufacturer rankings between Figure 8-64 and Figure 8-65 are the result of production-scale variation (e.g., and importantly, Ford's large production volumes means it has the largest total technology cost even though Ford's average per-vehicle costs place it in the second position of the manufacturer ranking in Figure 8-64). As with the per-vehicle technology costs, Stellantis, Nissan, and Mercedes-Benz incur minimal to no additional technology costs beyond the No-Action alternative (the only exception being a slight cost increase in the most stringent alternative for Nissan and Mercedes-Benz). These manufacturers are in compliance in the No-Action alternative and therefore do not require any fuel efficiency technology to meet a given standard. GM shows a negative total technology cost in the No-Action alternative for the same hybrid technology shift decisions that were discussed with Figure 8-64. Starting with MY 2027 in the No-Action scenario, GM switches a significant portion of their fleet from a mild hybrid to a strong hybrid, resulting in a negative cost. As was observed with the per-vehicle cost, the total technology cost increases with increased regulatory stringency as the manufacturer increases the PHEV penetration in its fleet in order to achieve compliance.

Figure 8-65: Technology Costs by Manufacturer, MYs 2022-2038



8.3.2.3. Sales and Employment Impacts

As manufacturers modify their vehicle offerings and utilize fuel-efficient technologies in response to HDPUV FE standards, vehicle costs may increase. The analysis assumes any cost increases are passed on to consumers and higher retail prices decrease vehicle sales. Alternatives HDPUV108, HDPUV10, and HDPUV14 lead to technology costs above those of the No-Action reference baseline, resulting in sales declines in these alternatives relative to the No-Action Alternative.[227] Figure 8-66 illustrates the rather minute magnitude (less than a single percentage point) of this effect in the context of total sales from MY 2022 through MY 2050.

[227] 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.

Figure 8-66: Industry-Wide Sales

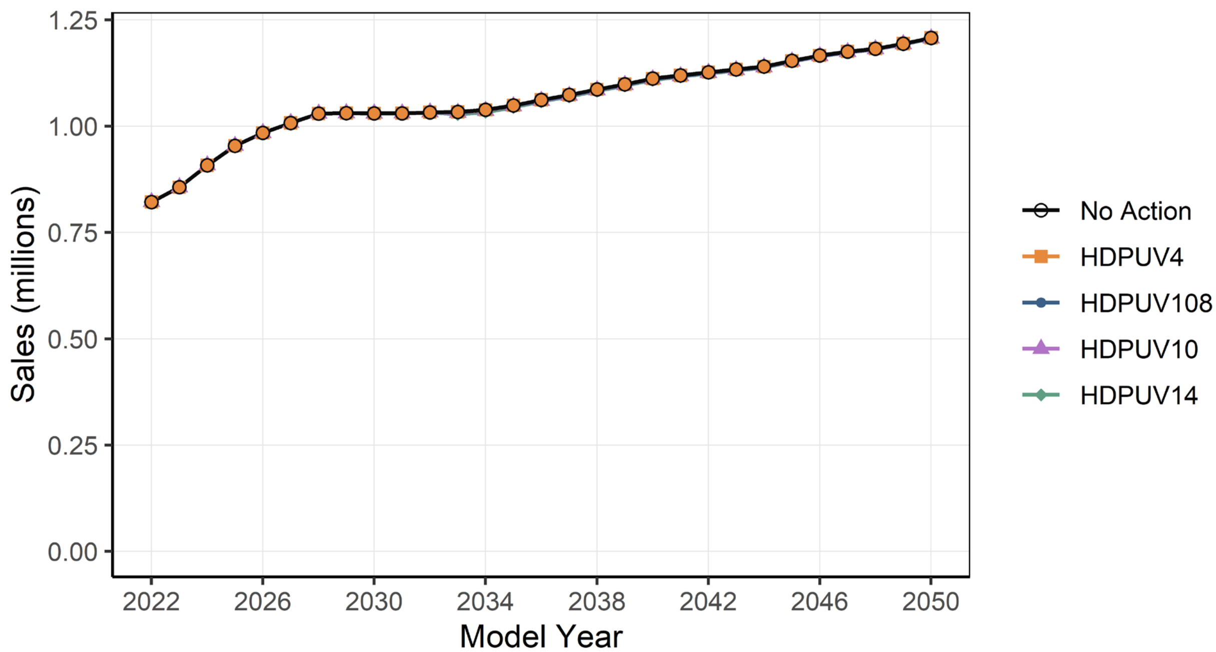
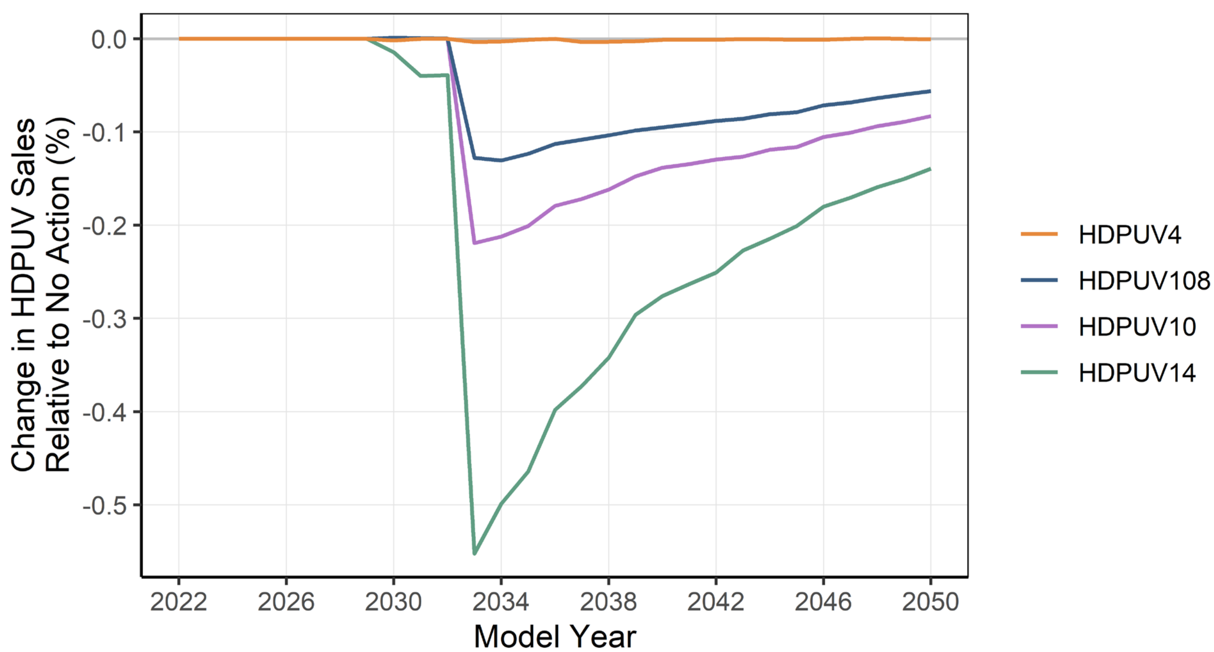


Figure 8-67 shows the simulated sales differences for the current analysis at the industry level across alternatives relative to the No-Action alternative between MY 2022 and MY 2050. Because HDPUV4 produces minimal change in cost, there is nearly no change in annual sales from reference baseline levels. For the other alternatives, sales stay constant relative to the No-Action Alternative through the early part of 2030. After this, sales begin to decline in each scenario in response to cost increases associated with FE technology adoption. As the stringency level increases within each scenario, the sales decrease accelerates. Sales begin to rebound in the most stringent action alternatives in MY 2034. With the exception of HDPUV14, the change in sales across alternatives stays within about a 0.21 percent change relative to the No-Action scenario.

Figure 8-67: 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 8-67 reduces industry-wide labor hours. However, development and deployment of new fuel-efficient technologies increases demand for labor. Overall estimated impacts on employment utilization depend on the relative magnitude of these two factors. Table 8-38 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, net employment utilization increases over time as industry-wide sales increase. The first scenario, HDPUV4 does not add or subtract substantially from the No Action alternative. However, the three remaining alternatives (HDPUV108, HDPUV10, and HDPUV14) all slightly reduce the employment utilization in the reference baseline, with the more stringent alternatives having the largest impact, but still staying within a 0.6 percent change relative to the reference baseline.

Table 8-38: Industry-Wide Labor Utilization Effects (in Full-time Equivalent Jobs)

Model Year	No Action	HDPUV4	HDPUV108	HDPUV10	HDPUV14
2030	32,324	-1	0	0	-4
2031	32,336	0	0	0	-13
2032	32,408	0	0	0	-12
2033	32,441	-1	-42	-71	-180
2034	32,590	-1	-43	-70	-163
2035	32,925	0	-41	-67	-154
2036	33,330	0	-38	-61	-133
2037	33,695	-1	-37	-59	-126
2038	34,106	-1	-36	-56	-118

8.3.3. Effects on New HDPUV Buyers

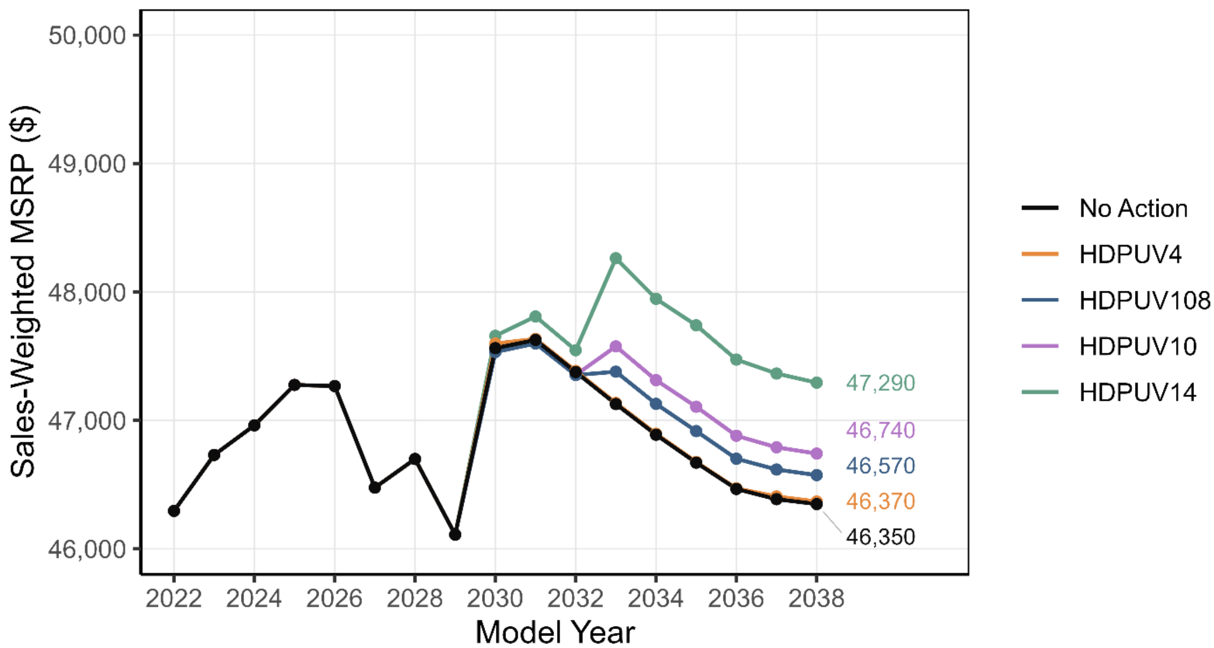
8.3.3.1. Vehicle Purchasing Price

The approach that CAFE Model uses to model vehicle purchase prices is equivalent to its treatment of light-duty vehicles. Individual vehicle MSRP values for the 2022 fleet are modified for each successive model year to incorporate the costs of compliance, and do not include the effects of tax credits for electric vehicles and batteries.[228] While increasing the stringency of standards over time affects the compliance costs for manufacturers, it is important to note that prices evolve over time even in the No-Action Alternative as manufacturers decide to adopt cost-effective technology. In Figure 8-68 we show the evolution of the sales weighted average MSRP between MY 2022 and MY 2038 in each of the regulatory alternatives. Prior to 2030, technology is added only in cases in which the value of the fuel savings and incentives that it generates are high enough to make the buyer willing to pay for the additional cost of technology. While prices generally rise throughout the 2020s, they do drop between MYs 2026 and 2029. This is the result of some technologies that improve fuel economy decreasing in price over time, leading manufacturers to adopt these technologies even as standards plateau. Since these technologies are assumed to be less expensive than the vehicles' initial technology, this leads to lower production costs and sticker prices for consumers in the early years. Following MY 2030, when the regulatory alternatives phase in, there is initially no variation from the No-Action Alternative except in the most stringent scenario. This is because much of the technology applied in this period to meet higher fuel efficiency standards in the regulatory alternatives is freely applied in the No-Action Alternative, since under NHTSA's assumptions, the fuel savings and incentives generated by this technology adoption will make buyers willing to pay for the price increases these fuel saving technologies incur. Between 2032 and 2033, when prices rise in most of the alternatives, the average price in the HDPUV14 alternative

[228] While the MSRP reported here does not include the value of tax credits passed through to consumers, these credits are included in the sales model as discussed in Chapter 4 of the TSD.

spikes significantly higher than the other alternatives, as compliance in this alternative requires greater technology adoption. Even as standards continue to increase out until 2035, the prices of new vehicles decline, as the costs of batteries and other fuel saving technologies are assumed to decrease over this period. By the end of the period prices in the most stringent alternative are about $900 higher than the No-Action Alternative. Since the least stringent alternative, HDPUV4, never separates significantly from the reference baseline, the technologies needed to comply with this alternative are also cost-effective.

Figure 8-68: Sales-Weighted MSRP for HDPUVs



8.3.3.2. Additional Buyer Purchasing Costs and Benefits

The CAFE Model computes the same categories of buyer costs and benefits for HDPUVs as it does for light-duty vehicles.[229] Table 8-39 presents a summary of these buyer costs and benefits for MY 2030 and MY 2038 vehicles. The values presented represent per-vehicle aggregate values for the No-Action Alternative, and the incremental difference from the No-Action Alternative for each of the other regulatory alternatives.[230] As is the case for light-duty vehicles, the insurance cost and vehicle taxes and fees for HDPUVs are all derived as a portion of modeled MSRP levels and hence vary directly with MSRP across alternatives. Regulatory costs are composed of compliance costs due to technology application and therefore increase as alternative stringency increases. As shown in Table 8-39, this regulatory cost component increases by only a minimal amount over the No-Action Alternative for all but the most stringent alternative, where the increase in costs represents an increase of about 8 percent. In two cases incremental regulatory costs are negative for model year 2030, although in these cases results are close to zero and are essentially artifacts of the compliance simulation algorithm.[231]

For HDPUVs, estimated buyer benefits include decreased fuel expenditures, time saved due to less frequent fueling, realized benefits from rebound travel miles, and any EV tax credits and battery tax credits that are passed on to buyers. In 2030, EV tax credits amount to $574 per vehicle in the No-Action Alterative, though additional incremental credits are minimal across alternatives. EV battery credits add an additional $474 per vehicle in model year 2030 and follow a similar pattern to the EV credits. By 2038, both tax credits are fully phased out and thus are zero by default in Table 8-39. As presented in Table 8-39, fuel savings benefits are

[229] As is the case with light-duty vehicles, the buyer costs and benefits reported represent only private costs and benefits. Chapter 8.3.4 presents the model's results for costs and benefits attributable to society as a whole.
[230] Results for additional regulatory fleet aggregations and discount rates are included in Appendix I and II.
[231] In its sensitivity analysis NHTSA explored the possibility that for commercial operators any increase in the net private benefits of buyers related to fuel efficiency are offset by a decrease in the other attributes of the vehicle which are not modeled. However, this is not included in the central analysis.

substantially higher in the most stringent alternative in MY 2038. Overall, the savings represent less than 12 percent of total fuel outlays in the No-Action Alternative for each of the regulatory alternatives in both years.

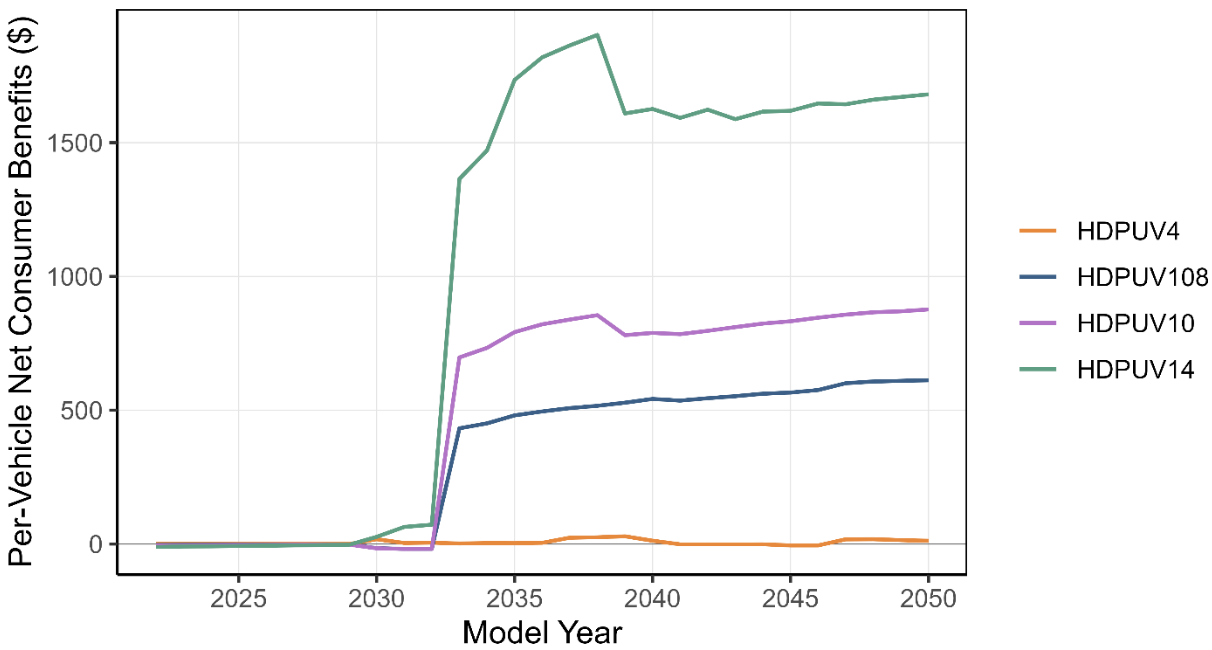
Table 8-39: Per-Vehicle HDPUV Buyer Costs and Benefits (2021$, 3% Discount Rate)

	MY 2030					MY 2038				
	No Action	Relative to No Action				No Action	Relative to No Action			
		HDPUV4	HDPUV 108	HDPUV 10	HDPUV 14		HDPUV4	HDPUV 108	HDPUV 10	HDPUV 14
HDPUV buyer costs										
Regulatory cost	1,267	36	-30	-30	96	51	20	226	394	946
Insurance cost	4,486	3	-3	-3	9	4,372	2	21	37	89
Ownership taxes and fees	2,597	2	-2	-2	5	2,531	1	12	21	52
Foregone consumer sales surplus	0	0	0	0	0	0	0	0	0	1
Total HDPUV buyer costs		41	-35	-35	110	0	23	260	453	1,088
HDPUV buyer benefits										
Retail fuel savings	-33,527	97	-82	-83	229	-29,753	103	717	1,366	3,523
Refueling time benefit	-4,554	-57	48	48	-137	-6,087	-56	44	-93	-600
Mobility benefit	643	1	-1	-1	1	894	1	16	35	68
Refueling benefit	0	0	0	0	0	0	0	0	0	0
EV tax credit	574	10	-8	-8	25	0	0	0	0	0
EV battery tax credit	472	8	-7	-7	20	0	0	0	0	0
Total HDPUV buyer benefits		59	-50	-51	137		49	776	1,308	2,991
HDPUV buyer net-benefits		18	-16	-16	27		25	517	855	1,903

Note: Negative retail fuel savings and refueling time benefits represent per-vehicle fuel costs and refueling time costs in the No-Action alternative.

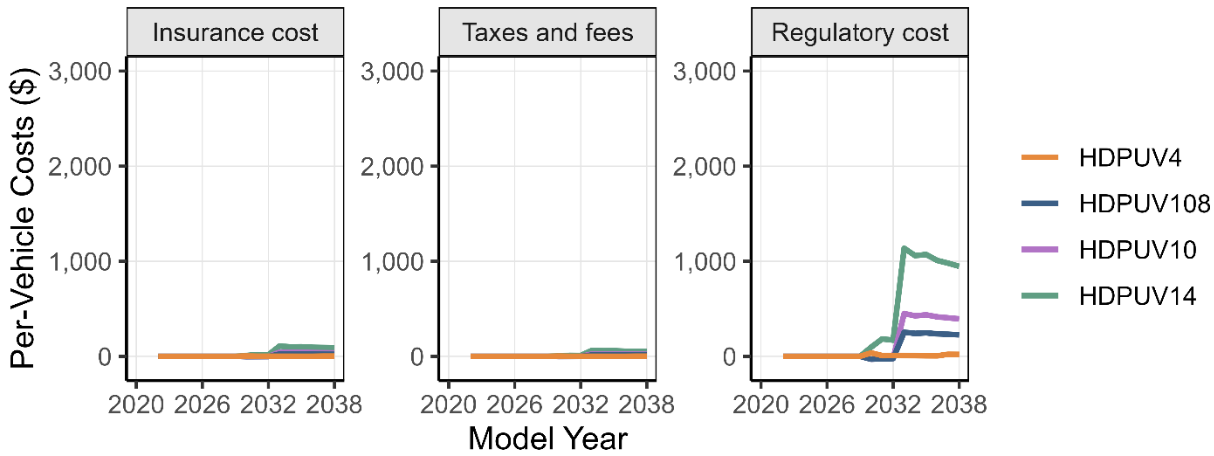
As shown in Figure 8-69 private net buyer benefits from HDPUV purchases are higher in each of the regulatory alternatives than the No-Action Alternative from the early 2030s onward, following the institution of new fuel efficiency standards. Buyer net-benefits are only marginal in the least stringent alternative, a reflection of the limited additional technology adoption required to comply with these standards. This is also the case in the first few years for the HDPUV10 and HDPUV108 regulatory alternatives, though they quickly increase in MY 2033 and remain above $500 per vehicle in the following years. In the most stringent alternative, the growth in buyer net benefits is uneven over time reflecting the path of technology costs over time. While incremental buyer net benefits grow to over $1,500 per vehicle in this alternative, they eventually fall somewhat in the late 2030s. Chapter 9 of this document explores the sensitivity of these results to alternate modeling assumptions.

Figure 8-69: Private Buyer Net Benefits, HDPUVs, 3% Discount Rate



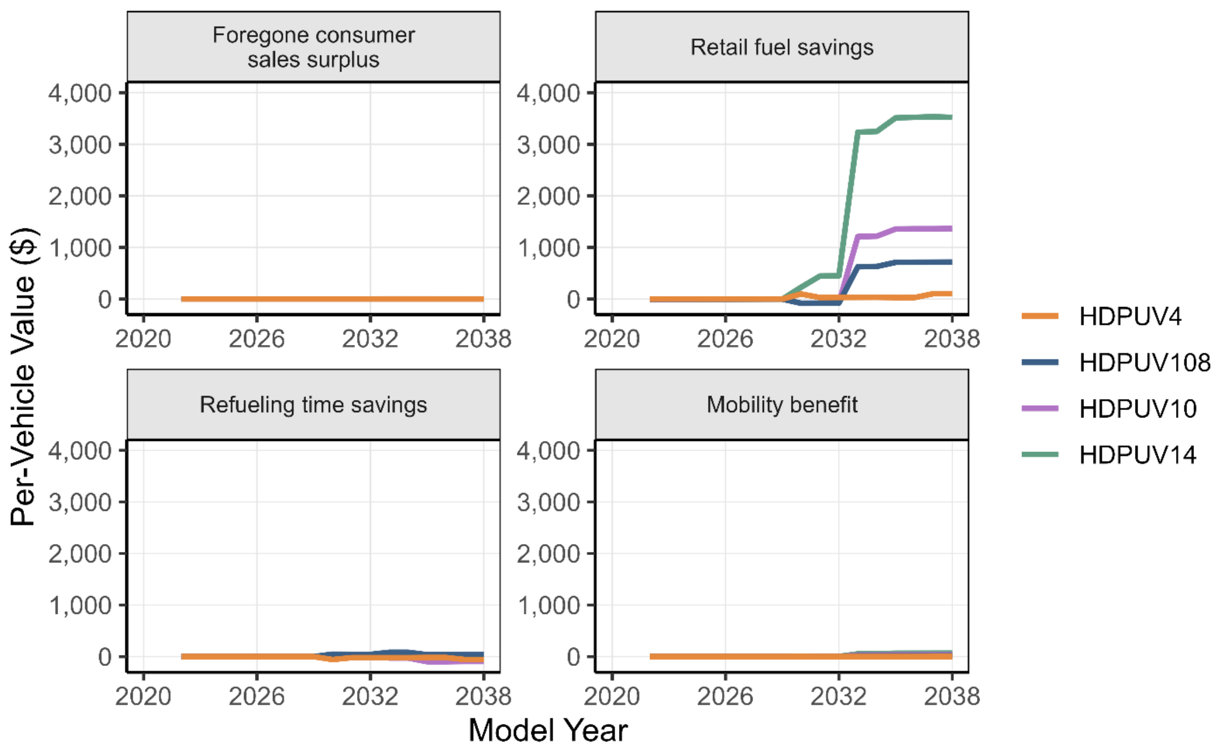
We next show the trends in each of the components of buyer costs that relate to MSRP for HDPUVs. In Figure 8-70 we show incremental per vehicle insurance cost, taxes and fees, and regulatory costs for each of the regulatory alternatives. Patterns are similar for each, with sharp increases in the early 2030s, followed by a plateau and gradual decline through much of the mid to late 2030s. In the three most stringent alternatives costs increase substantially in 2033 rather than decrease as they do in the No-Action Alternative. These are all driven by additional technology costs, since insurance costs, taxes, and fees all scale proportionately with MSRP. Manufacturers do not pay fines during any period. The increase, in costs seen in the early 2030s is due to the standards inducing some additional technology adoption immediately after implementation. It varies directly with the stringency of the alternative and is significantly higher in the most stringent alternative throughout the 2030s.

Figure 8-70: HDPUV MSRP-Based Buyer Incremental Costs, 3% Social Discount Rate



We next examine the other buyer incremental costs and benefits in Figure 8-71. We find that incremental fuel costs savings due to technology adoption in the most stringent alternative begin occurring in the late-2020s. Fuel cost savings increase significantly in all the alternatives besides HDPUV4 starting in 2033. The magnitude of each of the other buyer benefits is dwarfed by the fuel savings benefits which climb well above $1,000 in the two most stringent alternatives. Thus, buyer net benefits are primarily driven by the difference in fuel savings benefits and regulatory costs, both of which follow similar patterns.

Figure 8-71: HDPUV Buyer Incremental Costs and Benefits, 3% Social Discount Rate



8.3.3.3. Total Cost of Ownership Payback Period

To compare the impact of different stringencies of fuel efficiency regulations on buyer costs and benefits, NHTSA also determines the time required for owners to realize positive net benefits on average for vehicles produced in each model year under the different regulatory alternatives. To estimate the payback period for

TCO changes, the model aggregates regulatory costs net of any tax credits. 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.[232] The age at which the running total of cost savings outweigh the additional costs represents the payback period length. Figure 8-72 shows the HDPUV distribution of payback periods for all vehicles in the MY 2030 and MY 2038 fleets.

Figure 8-72: HDPUV Distribution of Vehicle TCO Payback for MYs 2030 and 2038

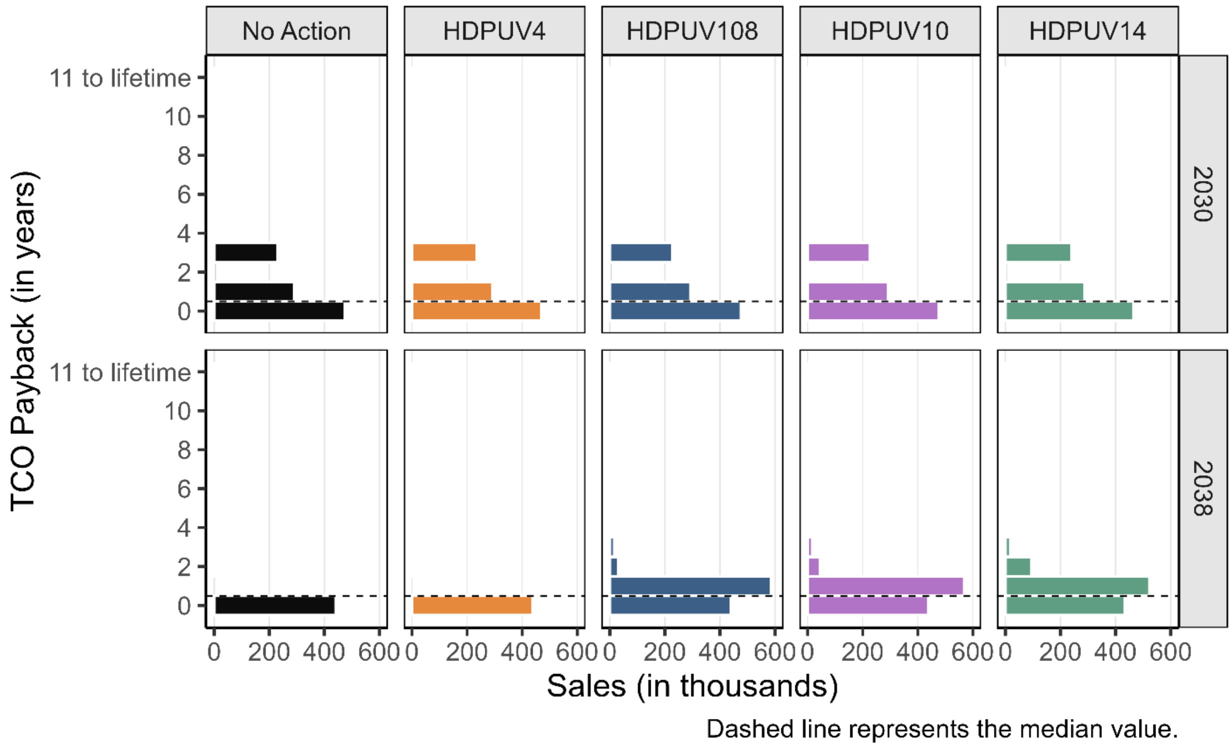


Figure 8-72 summarizes payback periods for undiscounted costs from the CAFE Model's vehicles report.[233] Across regulatory alternatives payback period length does not exceed 3 years for any of the vehicles. In contrast with the light-duty fleet, where several vehicles do not payback the costs of technology adoption over their lifetimes, the HDPUVs generally do so in the first two years of ownership. Indeed, in the No-Action Alternative, the average payback period in MY 2038, no vehicle requires a full two years to pay back its costs. In Figure 8-72 we see that across alternatives a significant share of the fleet shifts from having a payback period of 3 years in 2030, to having a payback period of one year in 2038. Even in the most stringent alternative in MY 2038, the majority of vehicles pay back their costs of ownership in less than two years. Table 8-40 summarizes these results and shows that more stringent alternatives on average require only slightly longer horizons to produce positive returns. The difference between the least stringent and most stringent alternatives does not change substantially between model year 2030 and model year 2038. This affirms that a significant share of the technology adoption appears to take place in the No-Action Alternative, especially in the earlier year. The overall differences between alternatives, and the change in these differences over time is much smaller than the light-duty fleet. This points to the fact that tech adoption costs are more smoothly distributed across larger light-duty fleet.

[232] The "initial state" of each vehicle is based on the vehicle's technology status in MY 2022.
[233] Unlike light duty vehicles, there are no instances in which costs outweigh benefits over the full vehicle lifetime.

Table 8-40: HDPUVs Payback Times by Regulatory Class (in Years)

	MY 2030					MY 2038				
	No Action	HDPUV 4	HDPU V 108	HDPUV 10	HDPUV 14	No Action	HDPUV 4	HDPU V 108	HDPUV 10	HDPUV 14
Mean	1.1	1.1	1.1	1.1	1.2	0.7	0.7	0.7	0.7	0.8
Median	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

8.3.4. Effects on Society

This chapter discusses social benefits and costs associated with the different rulemaking alternatives, including external benefits and costs pertaining to the following: GHGs, criteria pollutant emissions, congestion, noise, energy security, and safety. The following chapters (8.3.4.1 through 8.3.4.5) discuss the external effects to society. Chapter 8.3.4.6 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 8.3.2 and Chapter 8.3.3.

The CAFE Model records costs and benefits for particular model years but also reports these measures over the lifetime of the vehicle and allows for the accounting of costs and benefits across CYs. Examining program effects through this lens illustrates the temporal differences in overall societal costs and benefits. Figure 8-73 displays annual costs and benefits from CYs 2022-2050. Benefits exceed costs in the mid-2030s using the 3 percent and 7 percent discount rates under Alternative HDPUV108, Alternative HDPUV10, and Alternative HDPUV14. Prior to these CYs, costs exceed benefits, driven mostly by the costs associated with applying efficiency-improving technologies.

Under alternative HDPUV4, the differences between costs and benefits are small relative to the other action alternatives. Figure 8-74 reports the cost and benefit metrics as computed in Figure 8-73 but does so for Alternative HDPUV4 in *millions* of dollars. Under Alternative HDPUV4, benefits begin to exceed costs in 2031 using the 3 and 7 percent discount rates. The differences in costs across alternatives and calendar years are driven mainly by changes in technology costs based on differences in technologies applied.

Figure 8-73: Annual Costs and Benefits on a CY Basis, All Action Alternatives

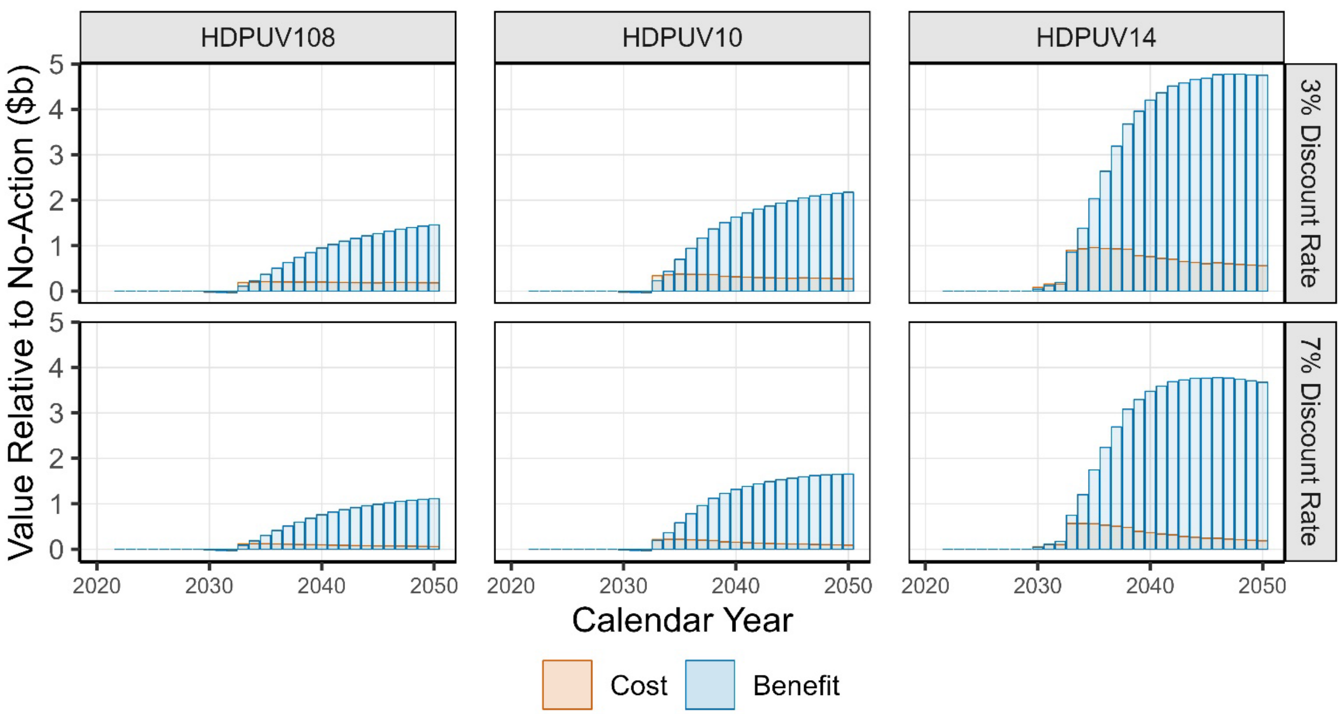
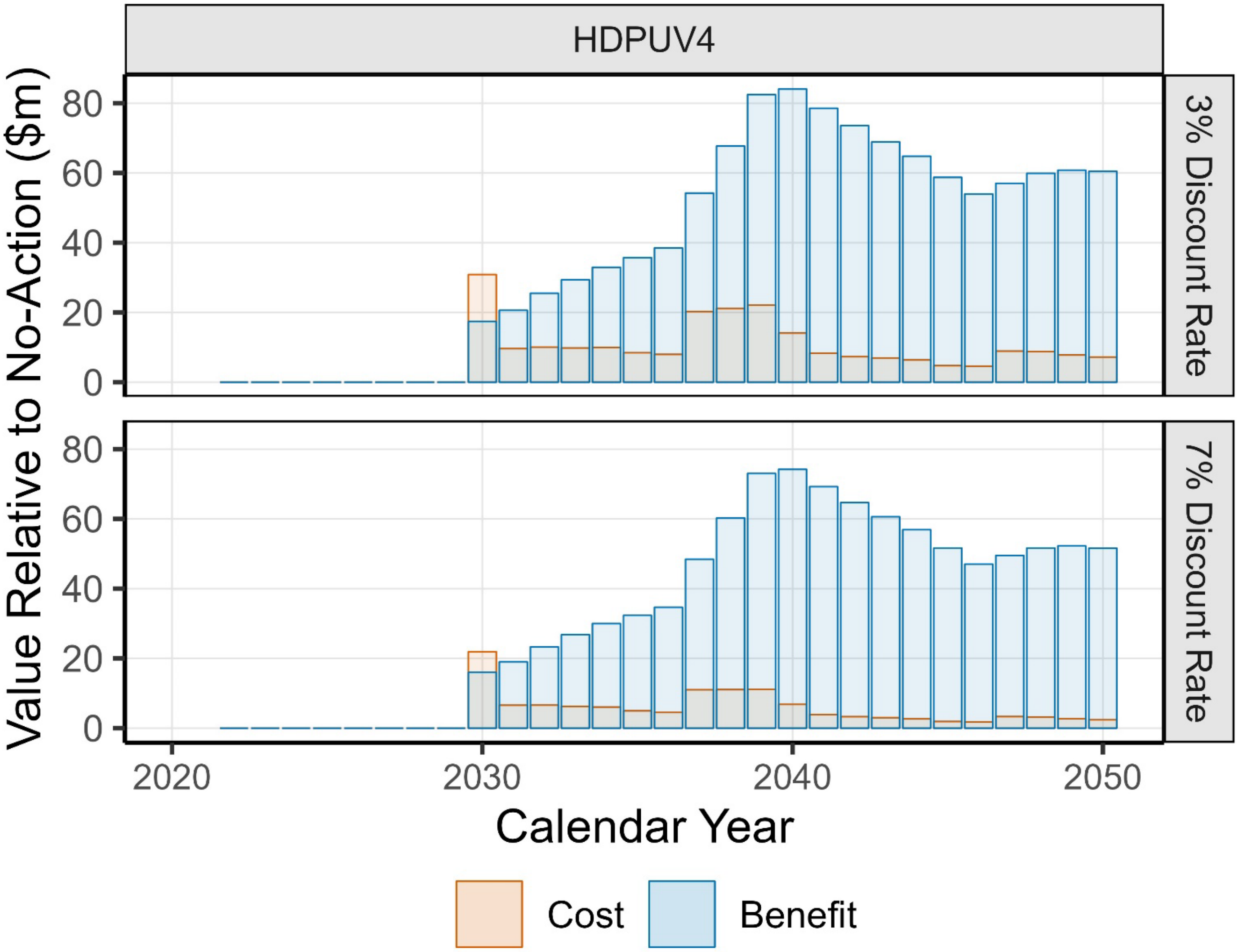


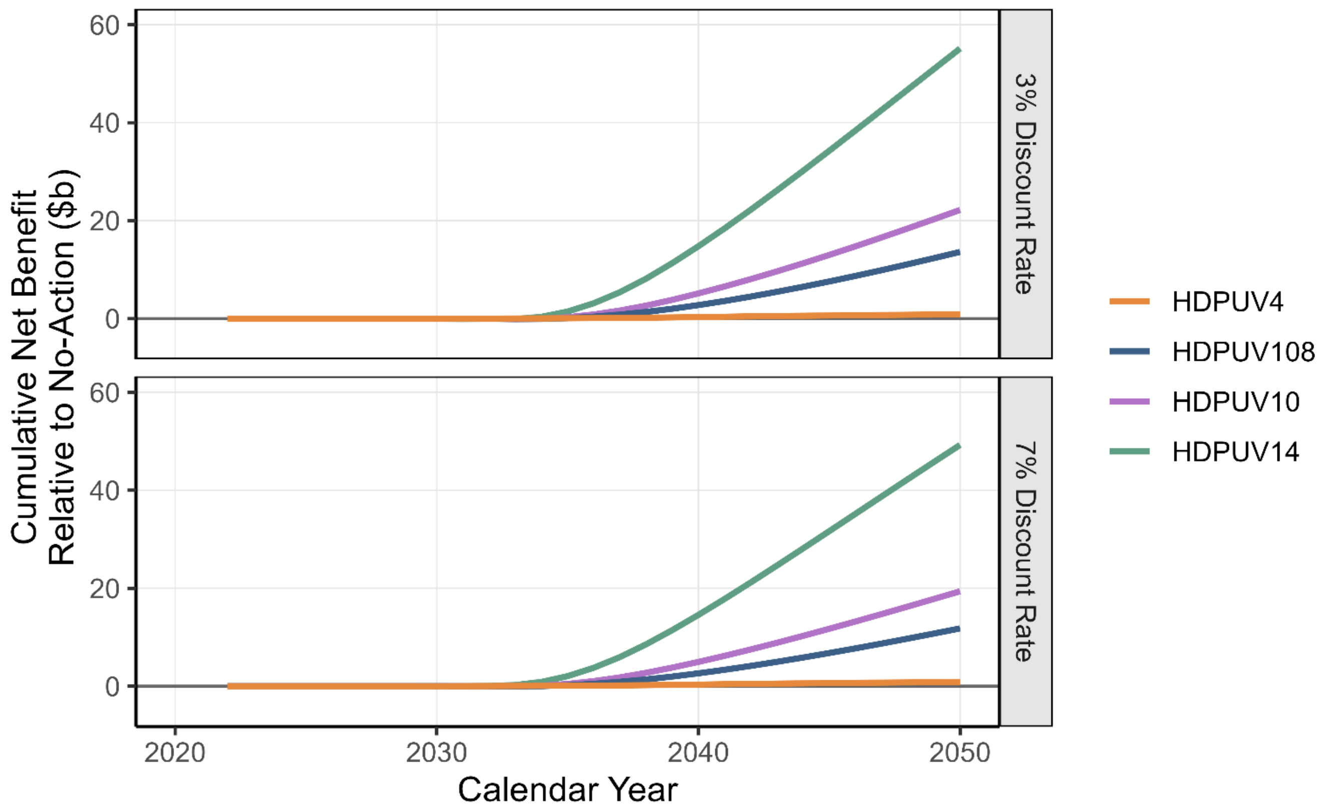
Figure 8-74: Annual Costs and Benefits on a CY Basis, Alternative HDPUV4



Unlike CAFE standards for the light-duty fleet, HDPUV FE standards continue in perpetuity until they are amended. Since the HDPUV FE standards remain in place, we only analyze the effects of the HDPUV standards on a CY basis.[234] Figure 8-75 aggregates annual cost and benefit streams to produce cumulative net benefits, by CY, for the three modeled alternatives. Cumulative net benefits remain low in all years under Alternative HDPUV4 but rise significantly in the other alternatives, under both the 3% and 7% discount rates. Cumulative net benefits begin growing in the mid-2030s.

[234] For more discussion on the decision to only display effects by calendar year and the differences between calendar year and model year accounting, see Chapter 5.4 of this FRIA.

Figure 8-75: Cumulative Net Benefits, CY 2022-2050



8.3.4.1. Social Benefits of Reducing GHG Emissions

Table 8-41 lists the total costs of GHG emissions by alternative, for CYs 2022-2050, based on the three different SC-GHG discount rates. All values in Table 8-41 are in absolute terms, monetizing the incurred costs of emissions in billions of dollars. Social costs decrease for all GHGs as stringency increases across the alternatives.

Table 8-41: Total Social Costs of GHG Emissions Across Alternatives (2021$, in Billions)

	No Action	HDPUV4	HDPUV108	HDPUV10	HDPUV14
2.5% SC-GHG discount rate					
CO_2	404.87	404.73	405.11	405.11	403.92
CH_4	7.24	7.24	7.24	7.24	7.22
N_2O	8.48	8.48	8.49	8.49	8.47
2% SC-GHG discount rate					
CO_2	678.10	677.86	678.51	678.51	676.49
CH_4	9.54	9.54	9.55	9.55	9.52
N_2O	13.24	13.24	13.25	13.25	13.21
1.5% SC-GHG discount rate					
CO_2	1190.25	1189.82	1190.97	1190.97	1187.38
CH_4	13.27	13.27	13.28	13.28	13.24
N_2O	21.62	21.61	21.63	21.63	21.57

Figure 8-76 and Figure 8-77 show how the social costs of the three GHGs change over time from the reference baseline. 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 8.3.5.2), 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 (discounted at 1.5 percent), damage costs due to GHG emissions peak at over 320 billion dollars per year and then decline from there. In contrast, the lowest estimates (discounted at 2.5 percent) amount to approximately 110 billion dollars per year at their highest point, and then decline in future years. These decreases over time and the relative proportions of the different GHG costs occur in each of the action alternatives as well.

Figure 8-76: Social Costs of GHGs (CO_2, CH_4, and N_2O combined) in the No-Action Alternative Across CYs (2022-2050), Discounted at 2.5%

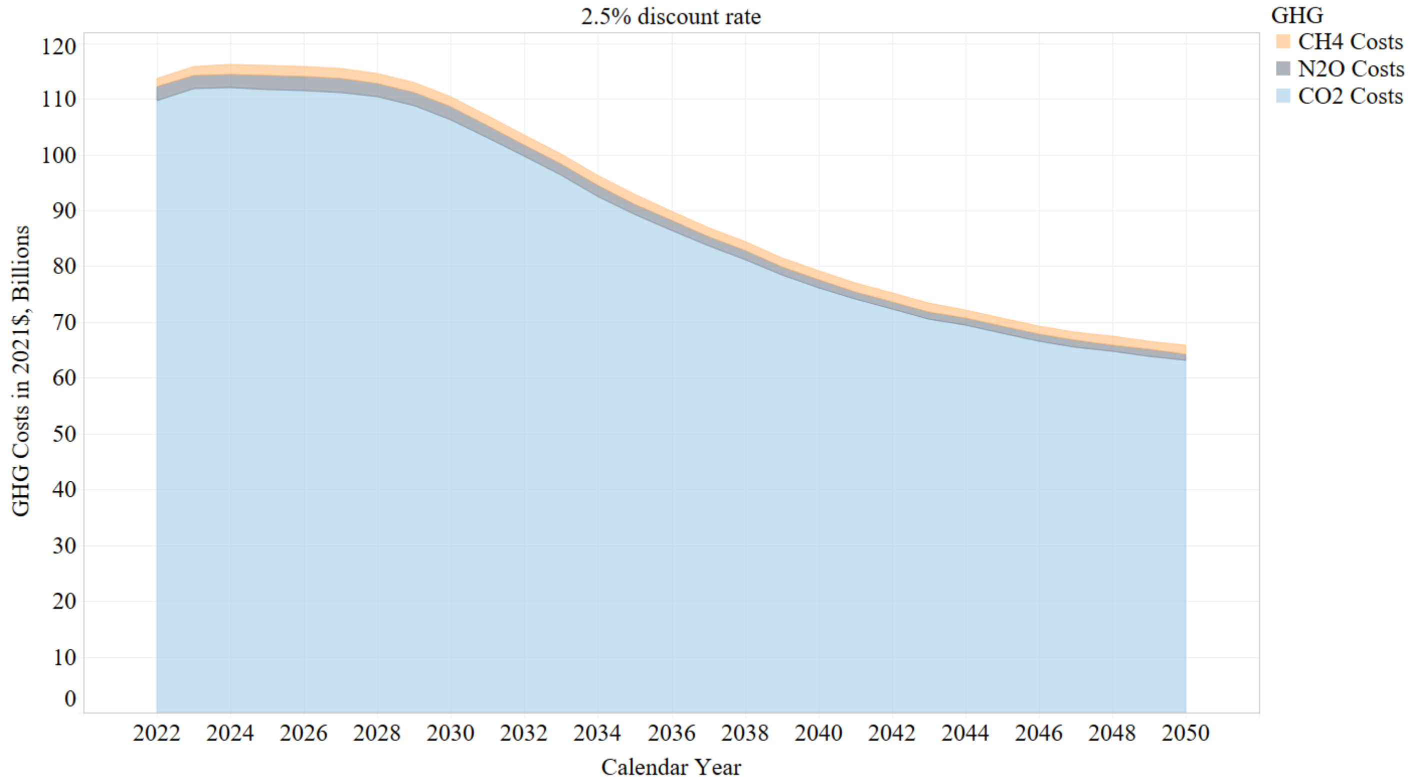
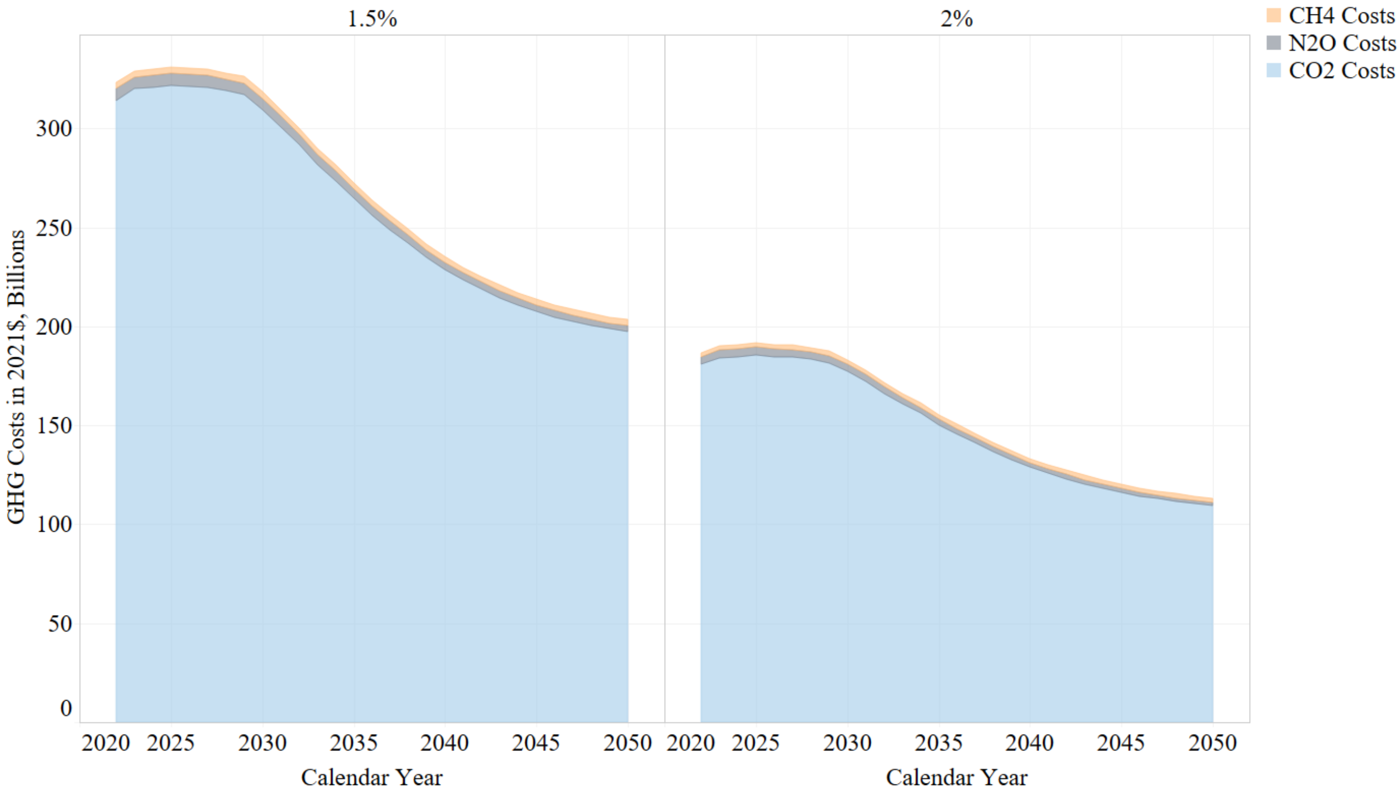
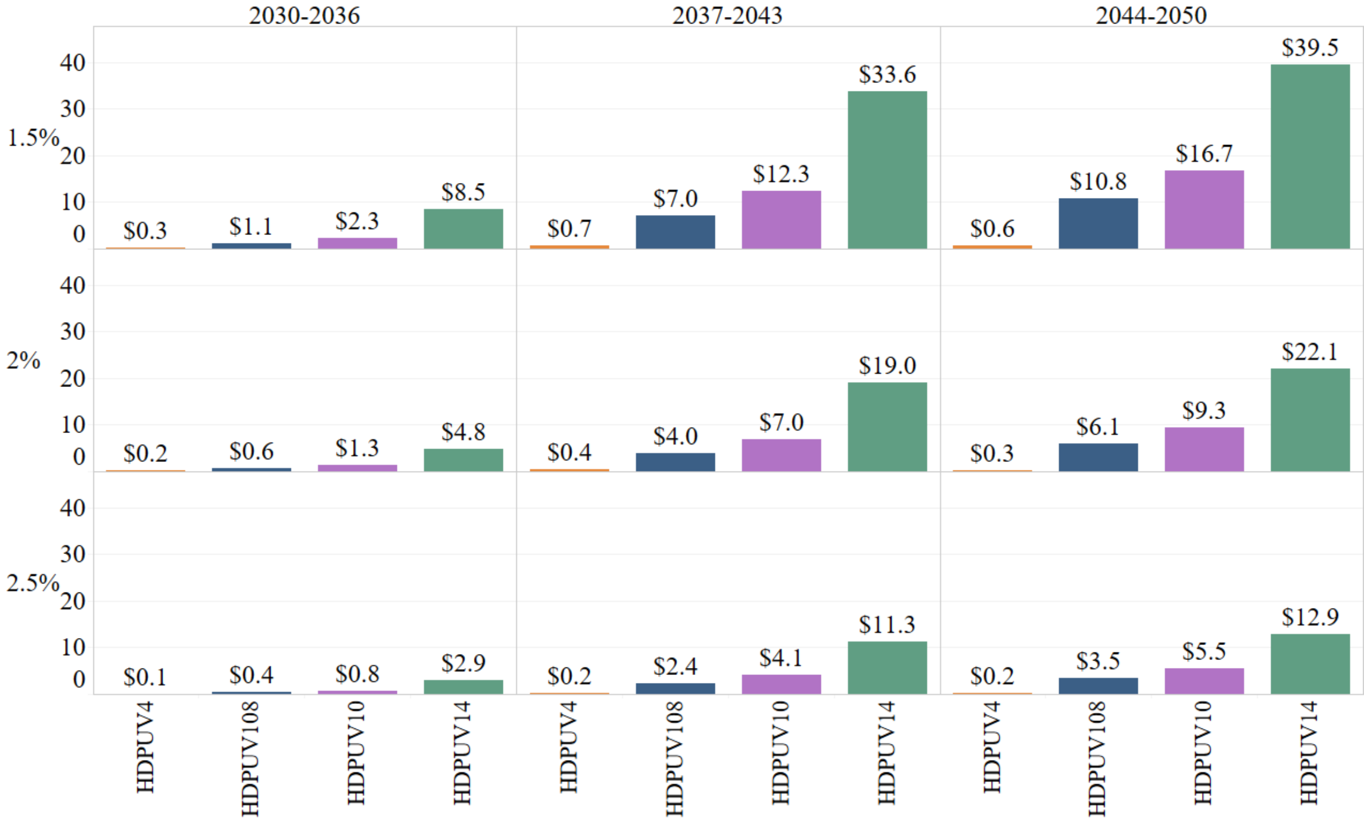


Figure 8-77: Social Costs of GHGs (CO_2, CH_4, and N_2O combined) in the No-Action Alternative Across CYs (2022-2050), Discounted at 2% and 1.5%



Relative to the No-Action Alterative, the action alternatives produce social benefits through the reduction of GHG costs (corresponding to the reduction of tons of GHGs emitted, described in Chapter 8.3.5.2). Figure 8-78 and Figure 8-79 represent the benefits of reduced GHG costs across alternatives, split by SC-GHG discount rate. The more stringent the HDPUV alternative, the larger the increases in GHG cost reductions. The figures split the benefits by seven-year time span groupings to highlight the differences in magnitude of short-term vs longer-term benefits.

Figure 8-78: GHG Benefits Across Alternatives (Relative to the No-Action Alternative), by Selected CY Cohorts (2021$, in Billions), Discounted at 2.5%, 2%, and 1.5%



8.3.4.2. Social Benefits of Reducing Criteria Pollutant Emissions

The criteria pollutant emissions computed by the CAFE Model—NO_X, SO_X, $PM_{2.5}$—are linked to various health impacts (see TSD Chapter 5.4).[235] 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 Output Files. For further information pertaining to these criteria pollutant emissions, see also Chapter 4 in the Final EIS.

Table 8-42 shows the social costs of criteria pollutants in the reference baseline and three alternatives from the CY perspective, by social discount rate. These results are presented as the totals of pollutant costs from both downstream and upstream pollutants. See Chapter 8.3.5.3 for details on the split between downstream and upstream emissions in each CY.

Table 8-42: Total and Incremental Social Costs of Criteria Pollutants Across Alternatives (MYs 1983-2035, 3% and 7% Discount Rates, 2021$, in Millions)

	Totals	Incremental to No Action Alternative			
	No Action	HDPUV4	HDPUV108	HDPUV10	HDPUV14
	3% Discount Rate				
NO_X	18,178	-0.3	-1.4	-3.1	-10.8

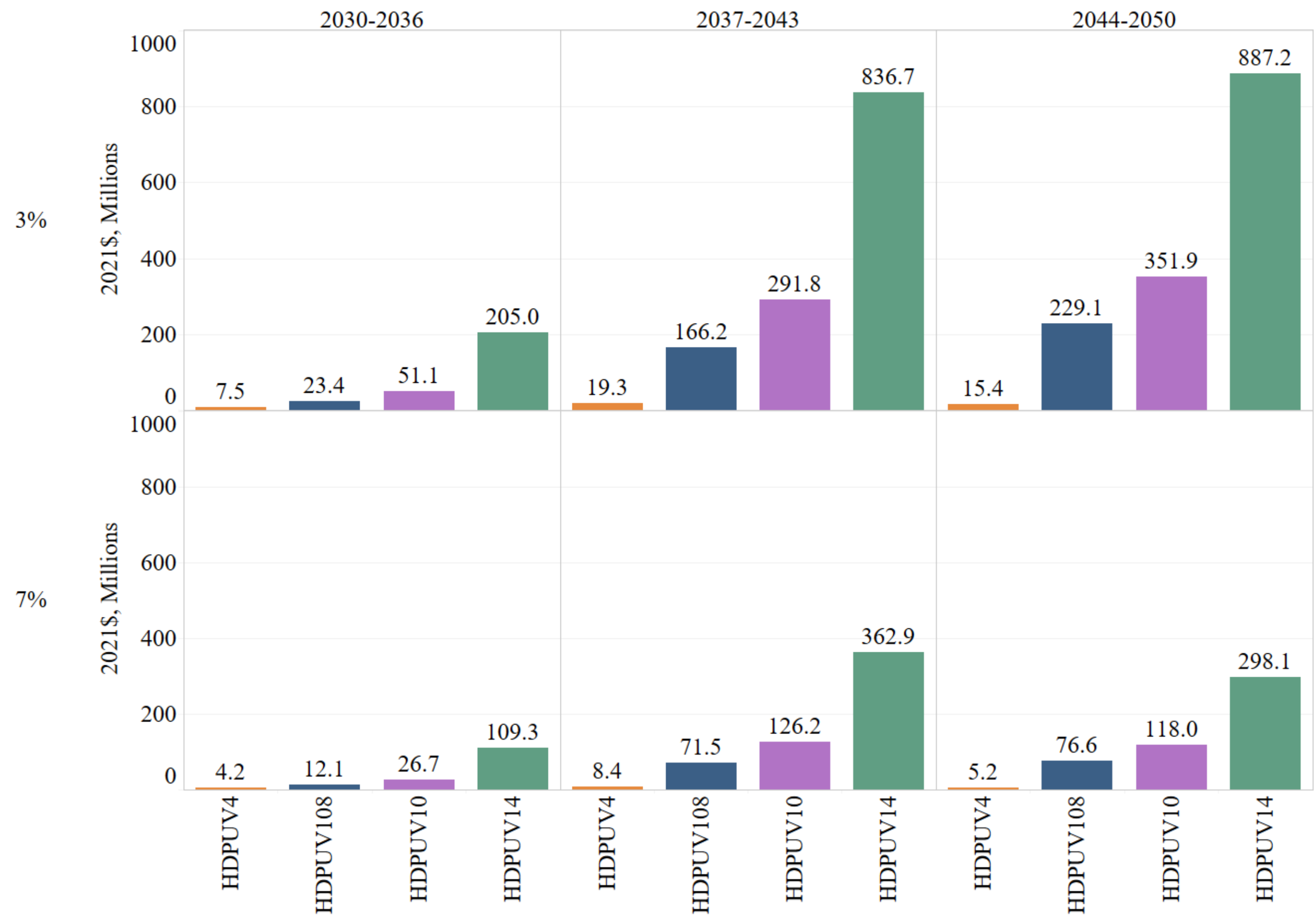
[235] The morbidity health impacts included in the per-ton monetized values are: acute bronchitis, asthma exacerbation, cardiovascular hospital admissions, lower respiratory symptoms, minor restricted activity days, non-fatal heart attacks, respiratory emergency room visits, respiratory hospital admissions,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

SO_X	8,623	1.2	-3.6	-8.5	-7.8
$PM_{2.5}$	65,529	-21.0	-105.6	-210.5	-757.9
	7% Discount Rate				
NO_X	12,871	-0.1	-0.5	-1.2	-4.1
SO_X	5,200	0.6	-1.7	-3.9	-3.7
$PM_{2.5}$	43,627	-9.4	-42.4	-85.7	-317.0

Social costs of PM2.5 are higher than the social costs of the other two pollutants both because there are higher levels of PM2.5 emissions overall in all alternatives, but also because the per ton cost value is higher for PM2.5 than for the other two pollutants.

This point is further shown in Figure 8-79 which presents combined criteria pollutant benefits split across seven-year CY groupings. The majority of the benefits occur in later CYs, between 2036 and 2050.

Figure 8-79: Criteria Pollutant Benefits Across Alternatives Relative to Reference Baseline, by Selected CY Cohorts (2021$, in Millions)



8.3.4.3. Social Costs of Changes to Congestion and Road Noise

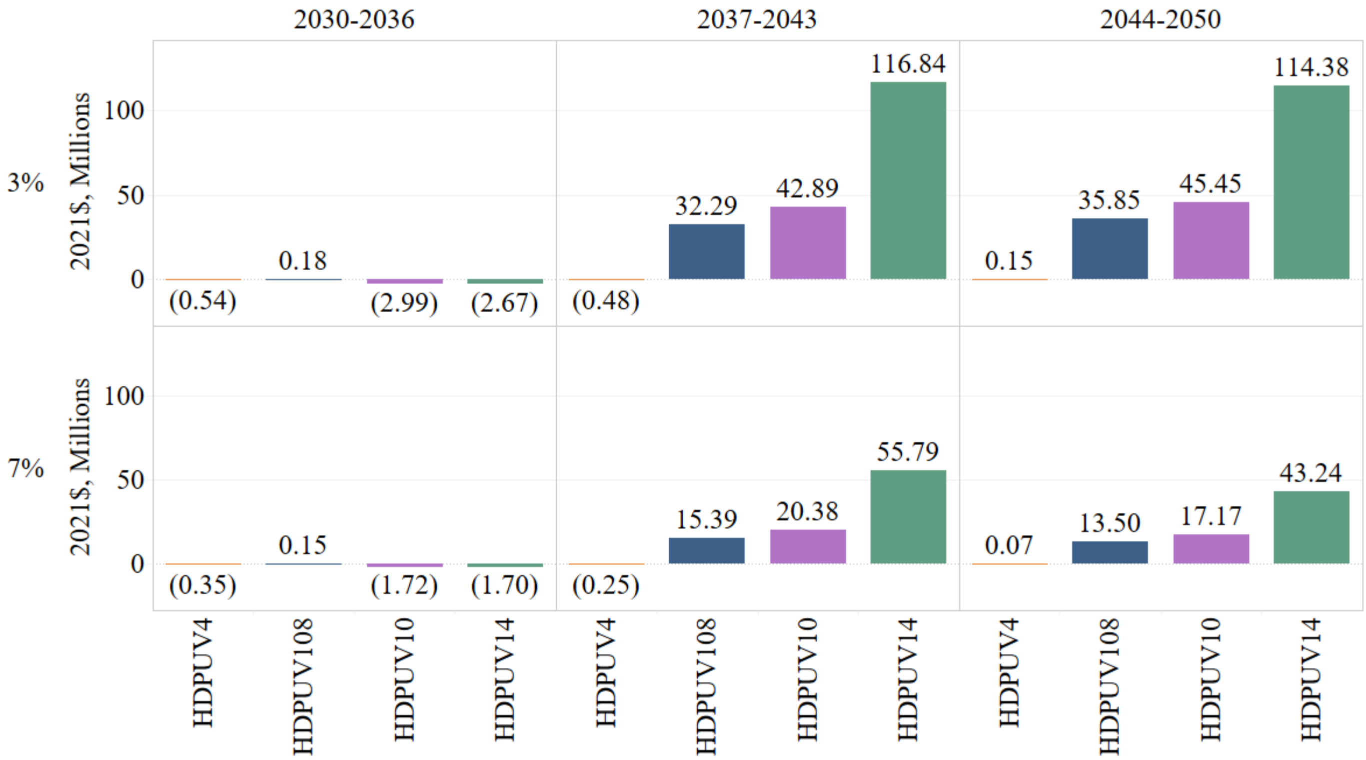
Table 8-43 reports the incremental social costs of congestion and noise for the action alternatives alongside the aggregate social costs for these categories in the No-Action alternative. Congestion cost and noise costs are functions of VMT, and the changes in these costs are largely related to changes in VMT (see Chapter 8.3.5.1). 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. While VMT per vehicle increases as alternatives become more stringent from rebound driving, sales decrease across alternatives and the reduction in VMT from fewer sales outweighs the increase in per vehicle use, which causes congestion and noise costs across the lifetimes of all model years included in the table to decrease relative to the reference baseline in alternatives HDPUV108, HDPUV10, and HDPUV14. Congestion and noise costs increase slightly relative to the reference baseline in Alternative HDPUV4.

Table 8-43: Social Costs of Congestion and Noise Across Alternatives for MYs 1983-2035 (2021$, in Millions)

	3% Discount Rate					7% Discount Rate				
	No Action	Relative to No Action				No Action	Relative to No Action			
		HDPUV4	HDPUV108	HDPUV10	HDPUV14		HDPUV4	HDPUV108	HDPUV10	HDPUV14
Congestion	382,711	0.30	-21.33	-28.87	-99.95	254,464	0.29	-8.08	-10.31	-38.59
Noise	3,831	0.00	-0.21	-0.29	-1.00	2,547	0.00	-0.08	-0.10	-0.39

Figure 8-80 presents the avoided noise and congestion costs (benefits) combined across CYs, split into seven-year time spans. The cost changes relative to the reference baseline are lower in the earlier CYs, but the relative changes between the two later time intervals are not very pronounced. Noise and congestion costs changes (in this case, benefits) relative to the reference baseline have a significantly greater magnitude under Alternative HDPUV14 compared to the other two action alternatives.

Figure 8-80: Avoided Congestion and Noise Incremental Costs (Benefits) Across Alternatives, by Selected CY Cohorts (2021$, in Millions)



8.3.4.4. 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 internalized by consumers through long-run equilibrium gasoline 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.

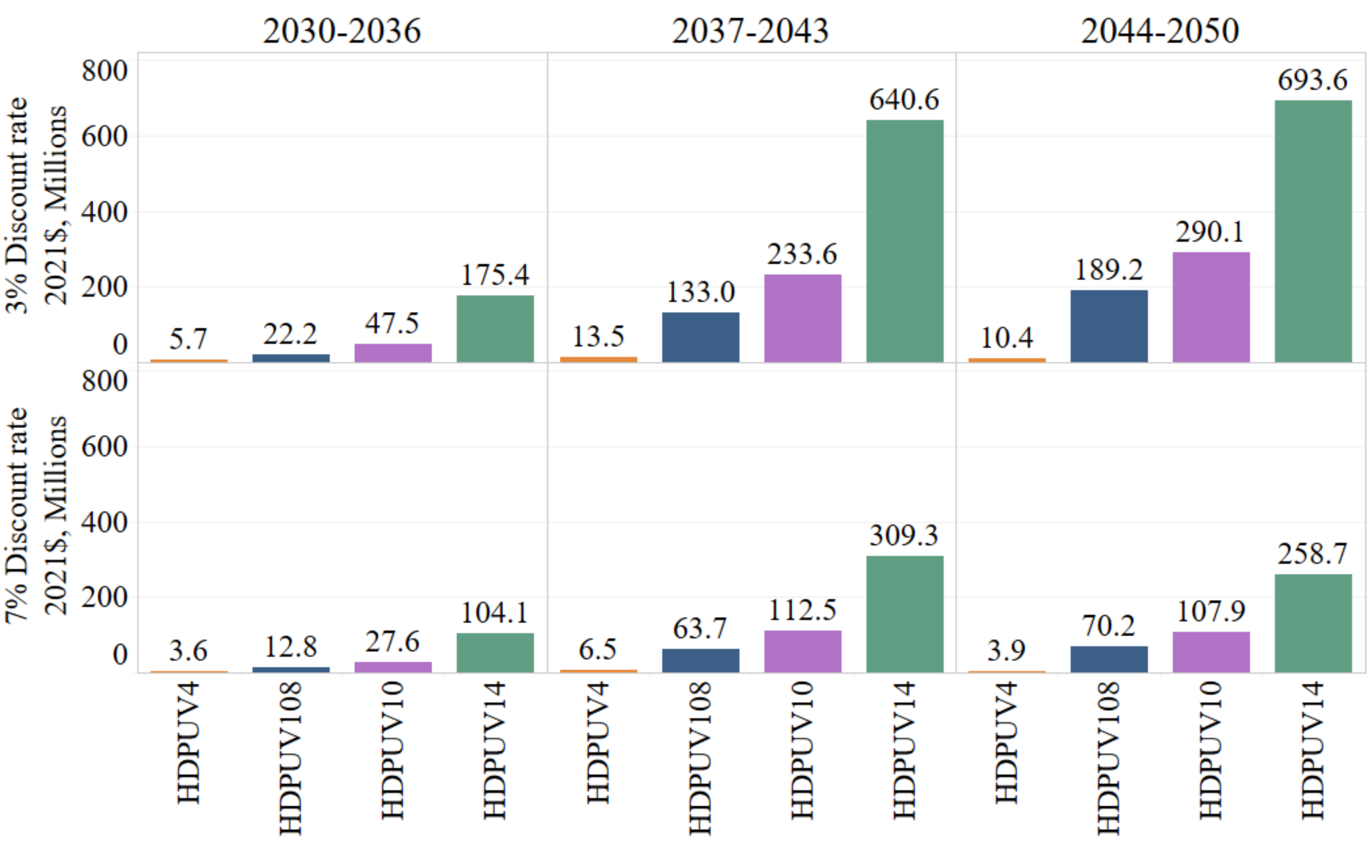
Table 8-44 presents the sum of total energy security costs in model years 1983-2035 of the analysis, across alternatives. These costs decrease slightly as the alternatives become more stringent, with the largest decrease occurring under Alternative HDPUV14.

Table 8-44: Total Energy Security Costs Across Alternatives, MYs 1983-2035 (2021$, Billions)

	No Action	HDPUV4	HDPUV108	HDPUV10	HDPUV14
3% discount rate	24.60	24.59	24.52	24.43	24.04
7% discount rate	16.67	16.67	16.63	16.59	16.40

Figure 8-81 focuses on the decreases between the alternatives, presenting the changes in costs as incremental benefits relative to the reference baseline. The figure splits the benefits across seven-year time spans to highlight when the largest share of benefits is accrued, in this case the last CYs of the analysis period. The benefits with the highest magnitude occur in Alternative HDPUV14.

Figure 8-81: Energy Security Benefits Across Alternatives, by Selected CY Cohorts (2021$, in Millions)



8.3.4.5. Safety Effects (Economic) of Changing Standards

Table 8-45 through Table 8-47 summarize the safety impacts of each alternative broken down by safety factor for HDPUVs. These impacts are summed over the lifetimes of vehicles from CYs 2022-2050. Fatality, non-fatal injury, and PDO counts are undiscounted. The safety differences between alternatives relative to the reference baseline scenario are small in absolute magnitudes.

As noted previously, safety impacts are driven by changes in vehicle mass (vehicles are made lighter to improve fuel efficiency), 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. The model does not show a significant change in mass across alternatives in large part because much of the HDPUV fleet electrifies due to the IRA in the No Action Alternative. Increasing the stringency of fuel efficiency standards does result in additional VMT for HDPUVs. This creates the positive rebound effects found in Table 8-48.

Changes to improve levels of fuel efficiency reduce driving costs and produce more rebound driving. Higher prices resulting from higher requirements slow fleet turnover. These composition changes reflect fewer new vehicles being purchased, older vehicles being retained longer, and a shift towards larger vehicles become more cost-efficient to operate. The reduction in HDPUV sales in response to standards offsets the increased fatalities, injuries, and PDO from rebound VMT. Fewer HDPUVs entering the future fleet results in fewer overall crashes across the future fleet. The magnitude of this sales effect is larger than the increase in crashes from rebound VMT. Again, since much of the HDPUV fleet comes into compliance with standards set in MY 2030 through 2035 due to the IRA, only the most stringent of standards affect sales and vehicle turnover in the fleet.

Since mass reduction in the model is applied in the No-Action Alternative, and no further mass reduction is applied by the model in the action alternatives, the mass effect estimated by the model is zero. The total fatal crash, total non-fatal crash, and total property damage crash values are at most in the tens of millions.[236] The magnitude of total social savings from crashes of these alternatives relative to the reference baseline range from less than $100 million to $500 million U.S. dollars (USD) at a 3% discount rate and are less than $200 million at for all alternatives under a 7% discount rate. Differences in fatalities across alternatives appear near or at zero, and the differences in non-fatal injuries and property damage across alternatives are also small in magnitude.

Table 8-45: Change in Safety Parameters from Alternative 0 (Reference Baseline) for CY 2022-2050 for HDPUV Fleet, 3% Discount Rate, by Alternative

Change in Safety Parameters from Alternative 0 (Reference Baseline) for CY 2022-2050 for HDPUV Fleet, 3% Discount Rate, by Alternative				
Alternative	**HDPUV4**	**HDPUV108**	**HDPUV10**	**HDPUV14**
Fatality Costs ($b)				
Fatality Costs from Mass Changes	0	0	0	0
Fatality Costs from Rebound Effect	0	0	0.1	0.1
Fatality Costs from Sales/Scrappage	0	-0.1	-0.1	-0.2
Total - Fatality Costs	0	0	0	-0.1
Non-Fatal Crash Costs ($b)				
Non-Fatal Crash Costs from Mass Changes	0	0	0	0
Non-Fatal Crash Costs from Rebound Effect	0	0.1	0.2	0.3
Non-Fatal Crash Costs from Sales/Scrappage	0	-0.2	-0.3	-0.6
Total - Non-Fatal Crash Costs	0	-0.1	-0.1	-0.3
Property Damage Costs ($b)				
Property Damage Costs from Mass Changes	0	0	0	0

[236] Many values presented in the tables are rounded down to zero due to their small magnitude. Values presented in the tables are rounded to the nearest hundred million.

Property Damage Costs from Rebound Effect	0	0	0	0
Property Damage Costs from Sales/Scrappage	0	0	0	-0.1
Total - Property Damage Costs	0	0	0	-0.1
Societal Crash Costs ($b)				
Crash Costs from Mass Changes	0	0	0	0
Crash Costs from Rebound Effect	0	0.1	0.2	0.5
Crash Costs from Sales/Scrappage	0	-0.3	-0.4	-0.9
Total - Societal Crash Costs	0	-0.1	-0.2	-0.5

Table 8-46: Change in Safety Parameters from Alternative 0 (Reference Baseline) for CY 2022-2050 for HDPUV Fleet, 7% Percent Discount Rate, by Alternative

Change in Safety Parameters from Alternative 0 (Reference Baseline) for CY 2022-2050 for HDPUV Fleet, 7% Percent Discount Rate, by Alternative				
Alternative	**HDPUV4**	**HDPUV108**	**HDPUV10**	**HDPUV14**
Fatality Costs ($b)				
Fatality Costs from Mass Changes	0	0	0	0
Fatality Costs from Rebound Effect	0	0	0	0.1
Fatality Costs from Sales/Scrappage	0	0	0	-0.1
Total - Fatality Costs	0	0	0	-0.0
Non-Fatal Crash Costs ($b)				
Non-Fatal Crash Costs from Mass Changes	0	0	0	0
Non-Fatal Crash Costs from Rebound Effect	0	0	0.1	0.1
Non-Fatal Crash Costs from Sales/Scrappage	0	-0.1	-0.1	-0.2
Total - Non-Fatal Crash Costs	0	0	0	-0.1
Property Damage Costs ($b)				
Property Damage Costs from Mass Changes	0	0	0	0
Property Damage Costs from Rebound Effect	0	0	0	0
Property Damage Costs from Sales/Scrappage	0	0	0	0
Total - Property Damage Costs	0	0	0	0
Societal Crash Costs ($b)				
Crash Costs from Mass Changes	0	0	0	0
Crash Costs from Rebound Effect	0	0.0	0.1	0.2
Crash Costs from Sales/Scrappage	0	-0.1	-0.2	-0.4
Total - Societal Crash Costs	0	-0.1	-0.1	-0.2

Table 8-47: Change in Change in Fatalities, Non-Fatal Injuries, and PDO from Alternative 0 (Reference Baseline) for CY 2022-2050 for HDPUV Fleet, by Alternative

Change in Safety Parameters from Alternative 0 (Reference Baseline) for CY 2022-2050 by Alternative				
Alternative	HDPUV4	HDPUV108	HDPUV10	HDPUV14
Fatalities				
Fatalities From Mass Changes	0	0	0	0
Fatalities from Rebound Effect	0	5	10	20
Fatalities from Sales/Scrappage	0	-12	-18	-40
Total Changes in Fatalities	0	-6	-8	-20
Non-Fatal Crashes				
Non-Fatal Crash from Mass Changes	0	0	0	0
Non-Fatal Crash from Rebound Effect	43	880	1,672	3,228
Non-Fatal Crash from Sales/Scrappage	-38	-1,873	-2,936	-6,538
Total - Non-Fatal Crash	5	-993	-1,264	-3,310
Property Damaged Vehicles				
Property Damage Vehicles from Mass Changes	0	0	0	0
Property Damage Vehicles from Rebound Effect	145	3,140	5,918	11,270
Property Damage Vehicles from Sales/Scrappage	-129	-6,805	-10,608	-23,211
Total - Property Damage Vehicles	16	-3,665	-4,690	-11,941

8.3.4.6. Summary of Social Benefits and Costs

Table 8-48 describes the costs and benefits of increasing HDPUV FE standards in each alternative, as well as the party to which they accrue, on a calendar year basis. 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 efficiency. We assume that those costs are fully passed through to HDPUV buyers, in the form of higher prices.

While incremental maintenance and repair costs would accrue to buyers of new cars and trucks affected by more stringent HDPUV FE 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 AFVs 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 HDPUV 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 (increased fuel efficiency 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 represents 90 percent of the additional safety risk from travel.[237] In its sensitivity analysis, NHTSA explored including an offset for the net private benefits attributed to commercial operators within the HDPUV fleet. This Commercial Operator Implicit Opportunity Cost is not included in our central analysis.

In addition to private benefits and costs—those borne by manufacturers, buyers, and owners of HDPUVs—there are other benefits and costs from increasing HDPUV FE standards that are borne more broadly throughout the economy or society, which the agency refers to as social costs.[238] Of these social costs, the largest is the loss in fuel tax revenue that occurs as a result of falling fuel consumption.[239] Buyers of new HDPUVs produced in model years subject to increasing HDPUV FE standards save on fuel purchases that include federal, state, and sometimes local or tribal 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 revenue represents a social cost.[240] 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 can also impose a small additional social cost to all road users. In the case of all alternatives except for HDPUV4, the congestion and noise costs decrease relative to the reference baseline due to decreases in sales having a stronger effect than the changes in VMT.

Among the purely external benefits created when HDPUV FE standards are increased, the largest is the reduction in damages resulting from GHG emissions. Table 8-48 shows the different social benefits 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 table also illustrates, the majority of both costs and benefits are social and external costs and benefits as opposed to private costs and benefits that accrue to buyers of new HDPUVs.

The choice of discount rate also affects the resulting benefits and costs. As the table shows, net social benefits are positive for all alternatives, and are greatest where climate benefits are monetized using SC-GHG estimates based on a 1.5 percent near-term Ramsey discount rate. Totals in the following table may not sum perfectly due to rounding.

Table 8-48: Incremental Benefits and Costs from CYs 2022-2050 (2021$ Billions), by Alternative

	3% Discount Rate				7% Discount Rate			
Alternative	**HDPUV4**	**HDPUV 108**	**HDPUV10**	**HDPUV14**	**HDPUV4**	**HDPUV 108**	**HDPUV10**	**HDPUV14**
Private Costs								
Technology Costs to Increase Fuel Economy	0.12	2.33	3.74	8.75	0.07	1.12	1.83	4.46
Increased Maintenance and Repair Costs*	-	-	-	-	-	-	-	-
Sacrifice in Other Vehicle Attributes*	-	-	-	-	-	-	-	-

[237] In the absence of a VMT reallocation mechanism, increased travel from this rebound effect and decreased sales combine to produce an overall change in aggregate mileage that depends on the relative magintudes of the two effects. These effects must then be differenced when assessing changes from the No-Action alternative. In the case of the action alternatives presented below, the (negative) sales effect on VMT exceeds the (positive) rebound effect across alternatives.
[238] 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.
[239] 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.
[240] It may subsequently be replaced by another source of revenue, but that is beyond the scope of this rulemaking to examine.

	3% Discount Rate				7% Discount Rate			
Alternative	**HDPUV4**	**HDPUV 108**	**HDPUV10**	**HDPUV14**	**HDPUV4**	**HDPUV 108**	**HDPUV10**	**HDPUV14**
Consumer Surplus Loss from Reduced New Vehicle Sales	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Safety Costs Internalized by Drivers	0.01	0.11	0.22	0.43	0.00	0.05	0.09	0.19
Subtotal - Private Costs	0.13	2.44	3.96	9.18	0.07	1.16	1.92	4.65
Social Costs								
Congestion and Noise Costs	0.00	-0.07	-0.09	-0.23	0.00	-0.03	-0.04	-0.10
Safety Costs Not Internalized by Drivers	0.00	-0.25	-0.40	-0.89	0.00	-0.10	-0.16	-0.38
Loss in Fuel Tax Revenue	0.11	1.28	2.15	5.71	0.05	0.55	0.94	2.57
Subtotal - Social Costs	0.11	0.96	1.67	4.59	0.05	0.42	0.74	2.09
Total Social Costs	0.24	3.40	5.62	13.77	0.12	1.58	2.66	6.74
Private Benefits								
Reduced Fuel Costs	0.40	4.94	8.38	21.25	0.19	2.11	3.65	9.49
Benefits from Additional Driving	0.01	0.22	0.43	0.79	0.00	0.09	0.19	0.35
Less Frequent Refueling	-0.24	0.45	0.09	-2.52	-0.11	0.21	0.03	-1.25
Subtotal - Private Benefits	0.17	5.61	8.90	19.51	0.08	2.42	3.87	8.59
External and Governmental Benefits								
Reduction in Petroleum Market Externality	0.03	0.34	0.57	1.51	0.01	0.15	0.25	0.67
Reduced Health Damages	0.04	0.42	0.69	1.93	0.02	0.16	0.27	0.77
SC-GHG at 2.5% DR	0.52	6.27	10.39	27.10	0.52	6.27	10.39	27.10
SC-GHG at 2% DR	0.88	10.65	17.65	45.96	0.88	10.65	17.65	45.96
SC-GHG at 1.5% DR	1.56	18.94	31.35	81.57	1.56	18.94	31.35	81.57
Total Social Benefits								

	3% Discount Rate				7% Discount Rate			
Alternative	**HDPUV4**	**HDPUV 108**	**HDPUV10**	**HDPUV14**	**HDPUV4**	**HDPUV 108**	**HDPUV10**	**HDPUV14**
SC-GHG at 2.5% DR	0.77	12.64	20.56	50.05	0.63	8.99	14.78	37.13
SC-GHG at 2% DR	1.13	17.03	27.82	68.92	0.99	13.38	22.04	56.00
SC-GHG at 1.5% DR	1.80	25.31	41.52	104.52	1.67	21.66	35.74	91.60
Net Social Benefits								
SC-GHG at 2.5% DR	0.53	9.24	14.94	36.28	0.51	7.41	12.12	30.39
SC-GHG at 2% DR	0.89	13.62	22.20	55.15	0.87	11.80	19.37	49.26
SC-GHG at 1.5% DR	1.57	21.91	35.90	90.75	1.55	20.08	33.08	84.86

* The costs of increased maintenance and repair and sacrifices in other vehicle attributes are not estimated.

8.3.5. Physical and Environmental Effects

For this analysis, NHTSA has adapted the 2023 AEO projections for estimating production volumes in future model years for the HDPUV fleet under the No-Action Alternative.[241] These projections show a slow growth in new vehicle sales for MYs 2022 – 2029 (average of 0.3%/year), followed by moderate increases thereafter (average of 1.2%/year). When combined with the CAFE Model's fleet turnover (or scrappage rate) estimates, the overall on-road HDPUV fleet is assumed to experience net annual growth in the reference baseline, as new sales exceed vehicle retirements.

Additionally, when considering the more stringent standards proposed by the action alternatives, NHTSA assumes that buyers are willing to pay for increases in vehicle's fuel efficiency that pays back within the first 35,000 miles of travel. Within the model, the agency assumes that technologies with a payback more than the first 35,000 miles will have a downwards pressure on new HDPUV sales. Hence, as the cost of compliance under the action alternatives is expected to go up with respect to the reference baseline scenario (the No-Action Alternative), the new vehicle sales are expected to decrease if the resulting fuel savings do not outweigh those added costs. As a result, the on-road population under the action alternatives is expected to decrease overall with respect to the reference baseline.

However, as will be presented throughout this chapter, the general lack of substantial differences between most alternatives is the combination of (1) the significant compliance benefit to the HDPUV fleet resulting from application of the PHEV and the BEV technologies; (2) the inclusion of the federal tax incentives for the PHEVs and the BEVs, which offset the added cost of the underlying electrifying technology; (3) the inclusion of the increasing requirements from the ZEV program as part of the CAFE Model simulation; and (4) the project cost savings of the P2 SHEV technology over diesel engines. This leads to the reference baseline scenario, along with all the action alternatives, adopting a similarly high degree of SHEV, PHEV, and BEV technologies throughout the analysis, albeit at a slightly varying cadence.

While the differences between alternatives in this analysis are minor, the annual impacts seen for each alternative are considerable. This occurs because improving the fuel efficiency of new HDPUV vehicle models sold during future model years is assumed to decrease the overall consumption of various fuel sources, as well as to reduce the emissions of CO_2 (the primary GHG released during vehicle operation). As a consequence of reduced overall fuel consumption, the on-road fleet also generates fewer emissions

[241] Refer to TSD Chapter 4.2.1.2 for more detail on the way NHTSA has modeled projections to HDPUV sales during the future years under the baseline (No-Action) and the action alternatives.

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. Since the first model year evaluated for this analysis begins in MY 2022, the first decade in the table and figure cover the range of CYs between CYs 2022 and 2030, while the latter two encompass effects over the full ten-year period. As such, the values shown for the first decade are marginally lower (by comparison) than what they would have been if the entire ten-year horizon was available. Nevertheless, the cumulative impacts are presented in such a way to provide a reader with a snapshot of the overall results of the analysis, while also demonstrating the relative differences between the decades. Meanwhile, the later chapters present this information in a disaggregated manner, by focusing on the effects during the individual CYs.

Table 8-49: Cumulative Impacts for All Alternatives

	No-Action	HDPUV4	HDPUV 108	HDPUV10	HDPUV14
	On-Road Fleet (Million Units)				
2022 – 2030	152	152	152	152	152
2031 – 2040	184	184	184	184	184
2041 – 2050	208	208	207	207	207
	Vehicle Miles Traveled (Billion Miles)				
2022 – 2030	1,992	1,992	1,992	1,992	1,992
2031 – 2040	2,584	2,584	2,583	2,583	2,583
2041 – 2050	2,917	2,917	2,916	2,916	2,914
	Fuel Consumption (Billion Gallons/GGE)				
2022 – 2030	143	143	143	143	143
2031 – 2040	145	145	144	143	140
2041 – 2050	131	131	128	126	119
	CO_2 Emissions (mmT)				
2022 – 2030	1,617	1,617	1,617	1,617	1,617
2031 – 2040	1,540	1,538	1,528	1,516	1,466
2041 – 2050	1,302	1,299	1,260	1,235	1,140

Figure 8-82: Cumulative Impacts for All Alternatives

As Table 8-49 and Figure 8-82 show, the differences between alternatives are mostly minor, with only the most stringent option (HDPUV14) showing marginal differences in the amount of aggregate fuel consumed and CO_2 emitted. As noted above, the lack of differences is the result of the reference baseline scenario absorbing most of the improvements from the adoption of SHEV, PHEV, and BEV technologies, dampening the magnitude of incremental changes observed in the actional alternatives. Conversely, for the No-Action Alternative and all the action alternatives, there is significant growth in the projected cumulative on-road fleet and VMT between the decades, while at the same time fuel consumption and CO_2 emissions see a noticeable decline during the last decade (covering CY 2041 to 2050). These annual increases to the fleet and VMT occur due to NHTSA's assumption that the new HDPUV vehicle sales will continue to grow moderately through MY 2029 (and gradually afterwards), while the sizable reductions in fuel consumption and CO_2 emissions are the result of the rapidly increasing presence of SHEVs, PHEVs, and BEVs within the fleet.

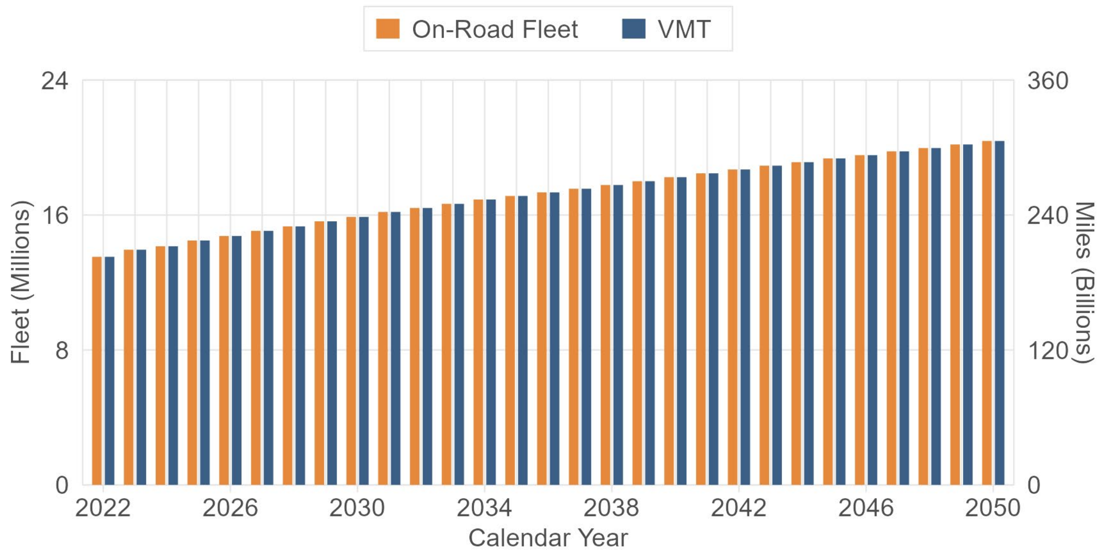
The chapters that follow provide additional detail of the aforementioned effects, while comparing the outcomes of the action and No-Action alternatives.

8.3.5.1. Changes to On-Road Fleet and Vehicle Miles Traveled

For this analysis, the CAFE Model relies on a predetermined forecast of new HDPUV vehicle sales when evaluating the No-Action Alternative. As such, changes to vehicle prices and fuel efficiencies do not produce a direct response in manufacturers' production decisions, when viewed from the perspective of the CAFE Model. Instead, the forecast is formulated with the intent of producing the same reference baseline that is representative of the future outlook of the aggregate HDPUV fleet. When evaluating the action alternatives, however, the CAFE Model simulates a response of the increasing vehicle prices and improvements to fuel efficiency on the sale of new vehicle models as well as the ancillary impacts these changes pose to the existing vehicle fleet. As HDPUV fuel efficiency standards become more stringent, the cost of new vehicles is expected to rise, which would cause a decline in sales if consumers perceived that the present value of fuel savings did not justify the increase in price. In such a case, this would extend to an overall slowing in the annual growth of the on-road fleet. At the same time, introducing more fuel-efficient options into the vehicle population (whether in the No-Action or the action alternatives) is assumed to produce a net marginal increase to the total VMT as the cost of travel becomes cheaper.

Figure 8-83 presents the size of the on-road HDPUV fleet through 2050, along with the total amount of miles the fleet is expected to travel under the No-Action Alternative. The vertical bars with *orange* coloring in the figure denote the annual progression of the fleet (in millions), while the vertical bars with *dark-blue* coloring correspond to the year over year growth in the associated VMT (in billions). As demonstrated by Figure 8-83, both the on-road fleet and the VMT increase in proportion to one-another, with VMT growth within the HDPUV sector being mostly a reflection of the rapidly increasing on-road population.

Figure 8-83: Total On-Road Fleet and VMT in the Reference Baseline Scenario

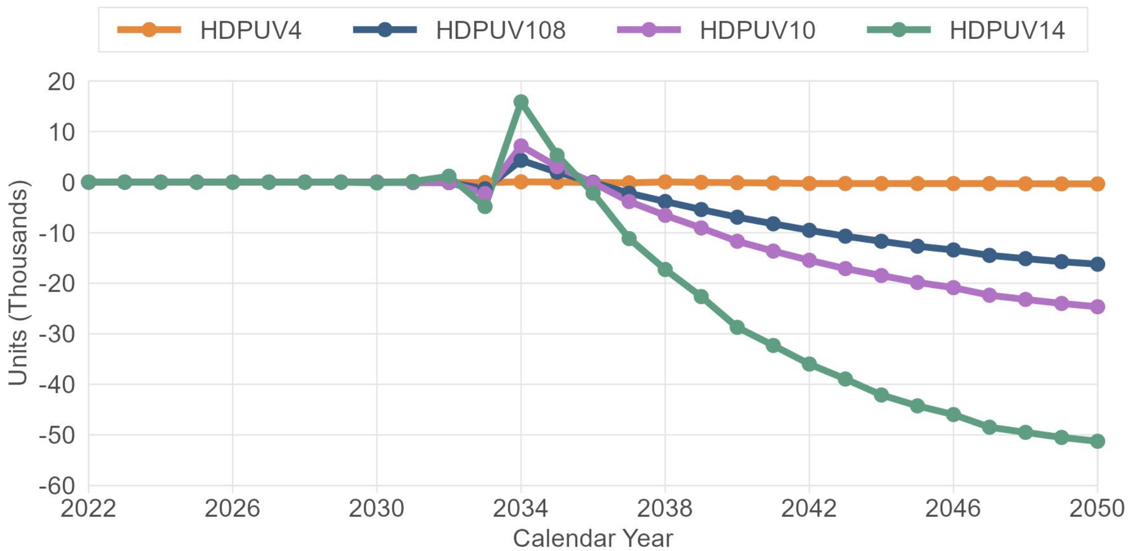


With most of the costs and improvements from the fuel saving technologies being absorbed by the No-Action Alternative, the increases in stringency from the action alternatives do not generate a significant difference to the number of new vehicles produced and sold during future model years.[242] As a result, the on-road population does not differ significantly, with only the most stringent alternative (HDPUV14) showing minor variances when compared to the reference baseline scenario. Figure 8-84 shows these incremental differences to the on-road fleet for each action alternative. Note, however, that the differences presented by the figure were magnified for illustrative purposes, where the changes are presented in thousands of units, while the reference baseline population is measured in millions.[243]

[242] Alternative HDPUV4 shows no meaningful differences in new vehicle sales when compared to the No-Action Alternative. Alternative HDPUV10 shows an insignificant change over the baseline, with a maximum decline in sales of 0.07% observed in MY 2034. Alternative HDPUV14 shows the largest difference in sales, though still marginal, having a maximum decrease 0.55% during MY 2035.

[243] As with the new vehicle sales, Alternative HDPUV4 shows no meaningful differences in the on-road population compared to the baseline. For Alternatives HDPUV10 and HDPUV14, the changes remain insignificant at a maximum decline of 0.11% and 0.23% respectively.

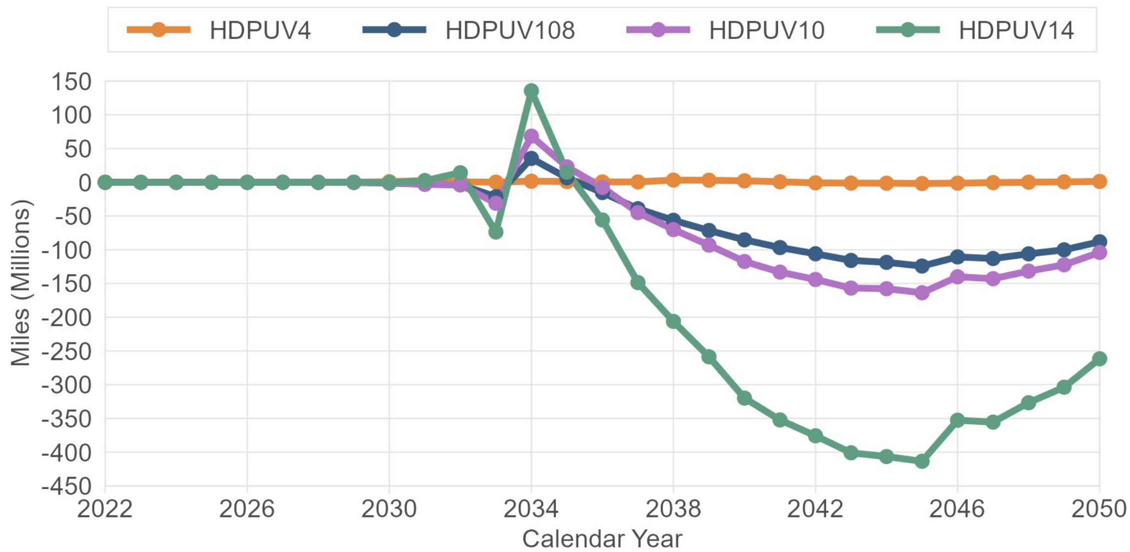
Figure 8-84: Changes in On-Road Fleet Compared to Reference Baseline



Along with the on-road HDPUV fleet that does not differ significantly between alternatives, the total miles driven by that fleet does not vary significantly. Unlike in the light-duty modeling, the agency does not constrain non-rebound VMT constant, so changes in the fleet size can affect the aggregate amount of VMT. As shown below, due to the total on-road population generally seeing a minor decline under some action alternatives, the amount of total miles traveled decreases marginally as a result. Despite the rebound effect inducing increased per-vehicle VMT as stringencies increase, this effect is outweighed by the reduction in sales caused by increased vehicle price, ultimately causing a marginal reduction in overall VMT. Figure 8-85 presents the incremental changes to VMT for each CY, with the differences being magnified substantially for clarity and to depict the general trends of alternatives.[244]

[244] The VMT differences in Figure 8-84 are denominated in millions of miles, while the VMT in the baseline (as shown by Figure 8-92) is measured in billions of miles. As such, the incremental changes seen under the action alternatives are insignificant, with the largest observed difference being 0.14% across all calendar years and alternatives.

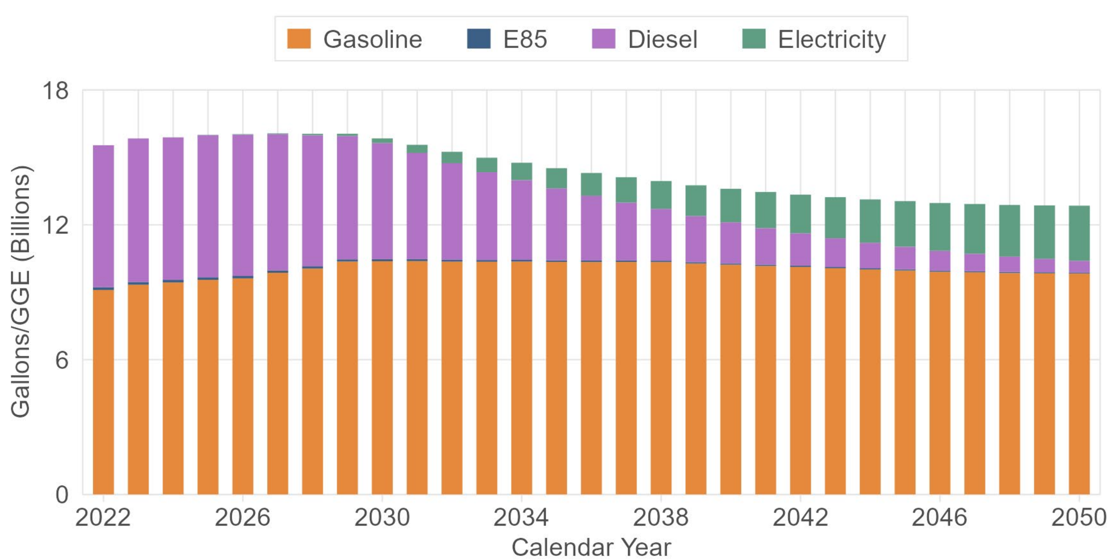
Figure 8-85: Changes in VMT Compared to Reference Baseline



8.3.5.2. Changes to Fuel Consumption and Emissions of GHGs

Improving the efficiency of new vehicle models reduces 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 CY, the benefits of more efficient vehicles introduced during earlier model years become even more apparent, as the annual fuel consumption of the U.S. HDPUV fleet declines further. Moreover, with the rise of AFVs, specifically PHEVs and BEVs, the presence of conventional gasoline- and diesel-powered ICE vehicles within the HDPUV fleet is gradually supplanted by electricity-powered variants. At the same time, as the utilization of gasoline SHEV options increases, the use of diesel as a fuel source diminishes further. Figure 8-86 presents the consumption of various fuel types in each CY for the No-Action Alternative. In Figure 8-86, 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 GGE.

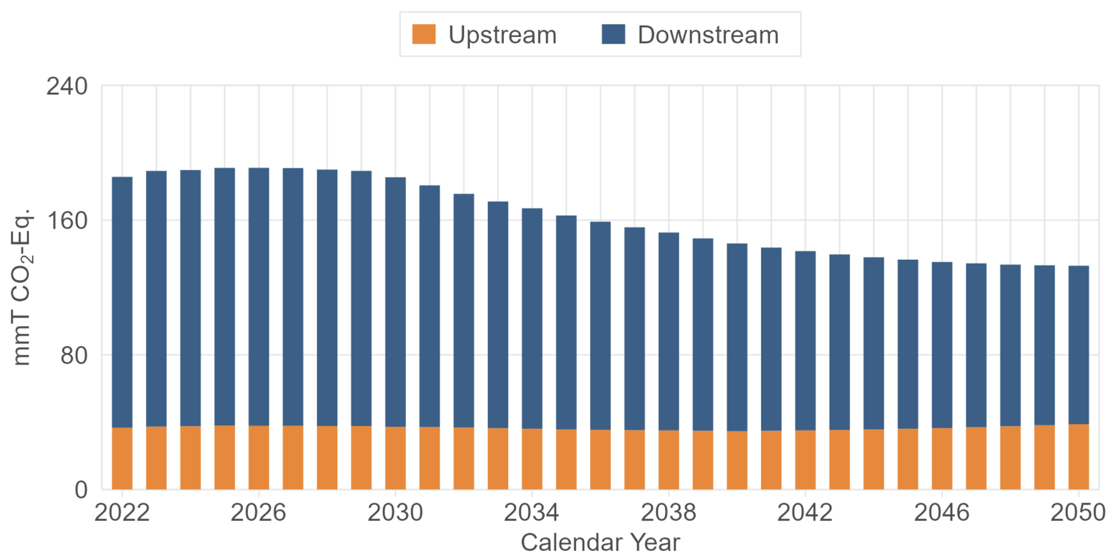
Figure 8-86: Fuel Consumption in the Reference Baseline Scenario



As illustrated by Figure 8-86, consumption of gasoline remains mostly steady under the No-Action Alternative, showing only small decreases between CY 2022 and CY 2050. This behavior is generally attributed to the adoption of SHEVs into the fleet during earlier model years, which brings with it the additional demand for gasoline in place of diesel, along with the moderate annual increases to the on-road fleet (as discussed earlier). Therefore, even though the average fuel efficiencies of the gasoline vehicles improve over time, the increased size of the on-road gasoline fleet mostly offsets any benefit from individual models. However, with the fleet gradually converting to SHEVs, PHEVs, and BEVs, the use of diesel greatly diminishes throughout the years. Meanwhile, electricity consumption rapidly increases year over year, culminating in about one quarter of the total amount of fuel consumed (on GGE basis) being attributed to electricity by CY 2050. Lastly, although E85 fuel is still present within the HDPUV fleet, it only makes up an insignificant fraction of the total energy consumed during each CY.[245]

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 8-87 displays the amount of annual GHG emissions generated by the HDPUV 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 mmT, while emissions coming from CH_4 and N_2O are scaled by the GWP multipliers of 25 and 298 respectively,[246] and are denominated using mmT of CO_2 equivalent emissions. However, CO_2 remains the predominant contributor of GHGs, making up approximately 99.3 percent of total GHG upstream emissions and 99.9 percent of GHG exhaust emissions.[247] As shown in Figure 8-87, the upstream emissions, which are attributed to the production and distribution of various types of fuel, increase moderately throughout the years in response to the growing on-road population and increasing use of electricity as a fuel source. The downstream emissions, which occur during vehicle operation, see a large declining trend similar to what was observed for the overall annual consumption of fuel.

Figure 8-87: Emissions of GHG in the Reference Baseline Scenario

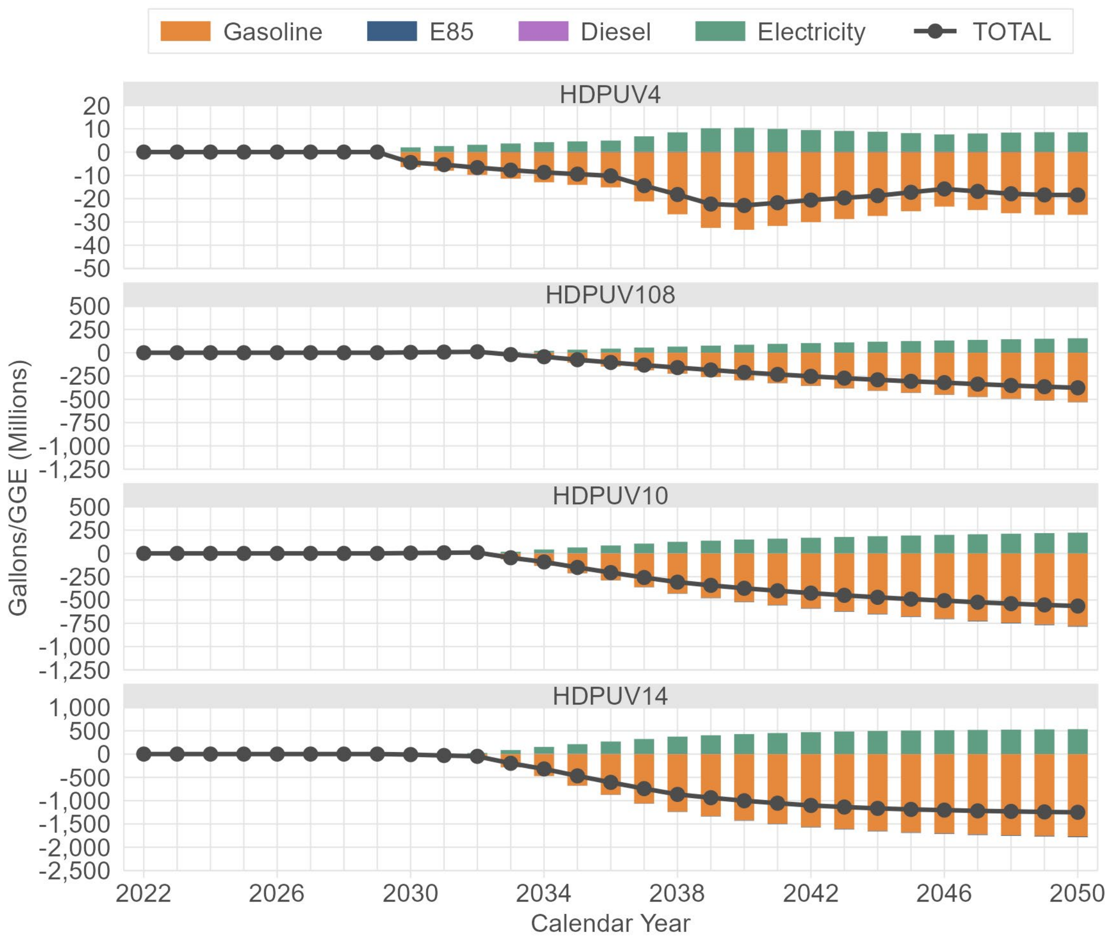


Fleet-wide fuel consumption and GHG emissions continue to decline further under the more stringent action alternatives in response to higher fuel efficiency standards. Figure 8-88 presents the incremental differences to the overall and fuel-specific energy consumption for each action alternative, as compared to the reference baseline scenario. For each alternative in the figure, note that the scale along the *y-axis* differs substantially, with the least stringent alternative (HDPUV4) being magnified 100 times compared to the most stringent option (HDPUV14). Figure 8-88 shows the same general pattern over the years for all alternatives, where

[245] In CY 2022, the total amount of E85 fuel consumed by the on-road fleet is 0.8 percent in the No-Action Alternative. By CY 2050, that number declines to 0.3 percent.
[246] 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 8-86. NHTSA calculates emissions of CH_4 and N_2O directly in terms of tons emitted for benefits purposes.
[247] Depending on calendar year being considered, the CO_2 share of GHG upstream emissions varies by up to 0.2 percent, while the share of downstream emissions varies by less than 0.1 percent.

gasoline consumption declines faster than an associated increase to electricity use, leading to an overall reduction in energy consumption. As was the case under the No-Action Alternative, gasoline remains the dominant source of fuel for the HDPUV fleet in all CYs, and for all action alternatives. At the same time, annual use of electricity continues to increase, while consumption of diesel and E85 remains largely unaffected. However, considering that the consumption of fuel in the No-Action Alternative is measured in billions of gallons/GGE, the incremental differences for Alternative HDPUV4 are small,[248] are only marginal for Alternative HDPUV108 and Alternative HDPUV10, and are moderate for Alternative HDPUV14. These changes in the alternatives are mostly attributed to the varying adoption rates of PHEV and BEV technologies. For example, in Alternative HDPUV4, the same utilization of PHEVs and BEVs as was seen under the reference baseline standards leads to inconsequential differences to fuel consumption. Meanwhile, under Alternative HDPUV14, PHEVs and BEVs were adopted at a slightly higher rate, which (when propagated to the on-road population over the years) lead to moderate reductions in fuel use.

Figure 8-88: Changes in Fuel Consumption Compared to Reference Baseline

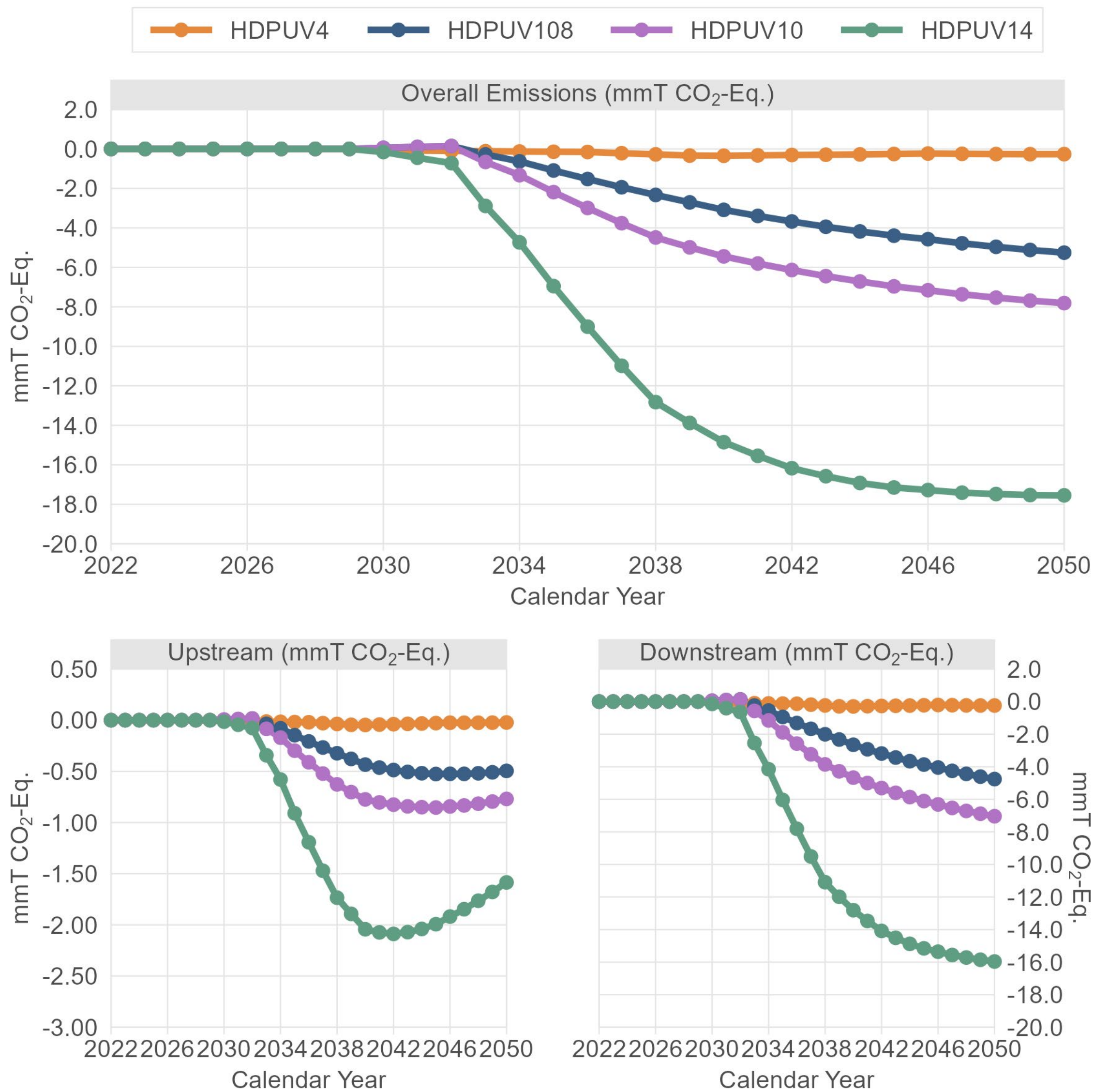


Along with the reduction of fuel use, the GHG emissions generated by the on-road fleet also decline in each action alternative, with the magnitude of the changes being proportional to the overall decreases in fuel consumption. Figure 8-89 presents the incremental changes to emissions of GHG as compared to the No-Action Alternative. The larger chart at the top presents the overall emissions of GHG, while the left and right portions at the bottom provide deconstructed views of upstream and downstream components, respectively. In each case, the incremental emissions of GHGs decrease at a greater rate as the standards defined by the action alternatives increase in stringency. However, as was the case for incremental differences of fuel

[248] However, note that the fuel consumption differences betwen Alternative HDPUV4 and the No-Action Alternative are exaggerated in Figure 8-87 for illustrative purposes.

consumption, the changes to GHG emissions range from insignificant under Alternative HDPUV4 to moderate under Alternative HDPUV14.

Figure 8-89: Changes in GHG Emissions Compared to Reference Baseline



8.3.5.3. 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 gasoline and diesel use in the HDPUV fleet. The 2022 Standard Scenarios forecast developed by NREL predicts electricity production will initially be more polluting than gasoline production in the early years of this analysis. However, the NREL forecast expects significant decarbonization of the electricity grid (see TSD Chapter 5.2) bringing the emissions associated with electricity production to parity with those of gasoline production, on a grams/BTU basis around 2030; the NREL forecast expects this trend to continue, making electricity production cleaner than gasoline production in the years after 2030, for most pollutants. This ultimately induces reductions in *upstream* emissions with stricter emissions standards, as the introduction of BEVs and PHEVs into the on-road fleet increases, and these vehicles are reliant on a cleaner form of energy than their gasoline counterparts. Similarly, 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.[249] This chapter 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 8.3.5.4.

Figure 8-90 and Figure 8-91 present annual upstream and downstream emissions of NO_X and $PM_{2.5}$ respectively, which are attributed to the HDPUV fleet under the standards defined by the No-Action Alternative. In the case of $PM_{2.5}$, downstream emissions are split and presented separately for emissions related to BTW and vehicular emissions originating at a vehicle's exhaust. 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. Given that vehicles operating on electricity do not emit criteria pollutants at the exhaust, the increased presence of PHEVs and BEVs within the No-Action Alternative further contribute to the accelerated reduction of downstream exhaust-based emissions shown in the figures. However, since the BTW emissions are defined at a constant rate, rather than varying by vehicle production year and age, downstream BTW emission of $PM_{2.5}$ are shown to increase proportionally as the HDPUV on-road population and the associated demand for travel go up.

The relative impacts on upstream emissions for both pollutants are comparatively less pronounced, however, they still indicate substantial annual increases. The annual upsurge in upstream emissions is congruent with the increases in the HDPUV fleet and VMT (see Figure 8-83).Although there is a sharp decline in diesel consumption under the No-Action Alternative, with significant portions of the diesel fleet being converted to more fuel-efficient SHEVs, and the growth to the overall HDPUV population, , outweigh the larger cumulative savings resulting from reduction in diesel use. As such, Figure 8-90 and Figure 8-91 show an annual increase to the upstream emissions of NO_X and $PM_{2.5}$.

Figure 8-90: Emissions of NO_X in the Reference Baseline Scenario

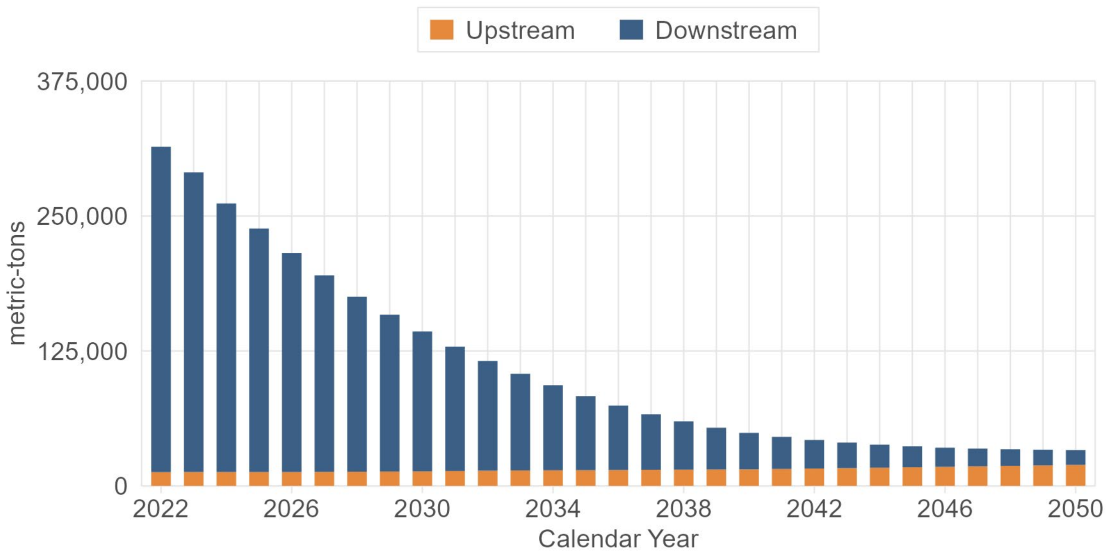


Figure 8-91: Emissions of $PM_{2.5}$ in the Reference Baseline Scenario

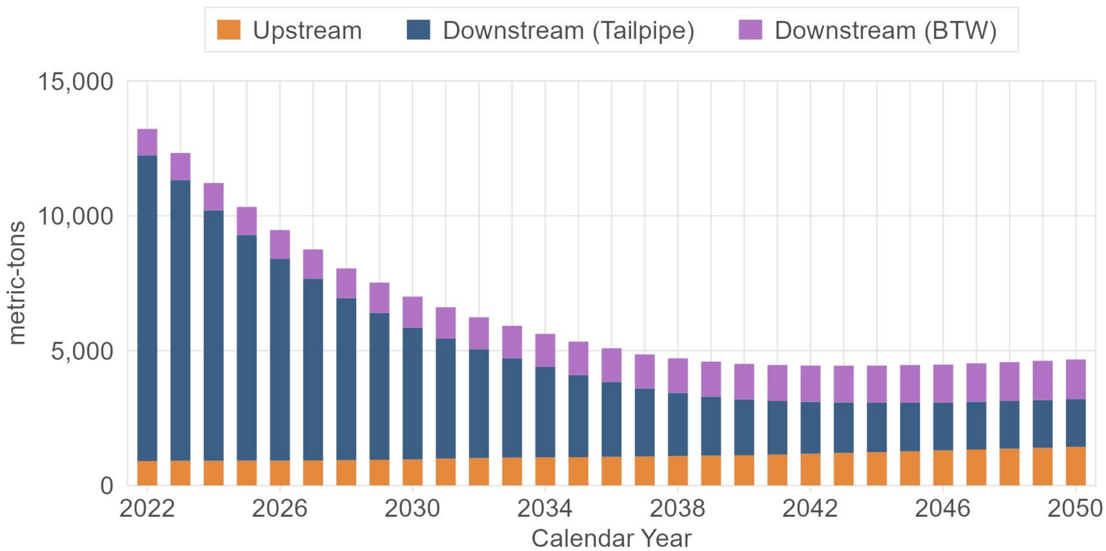
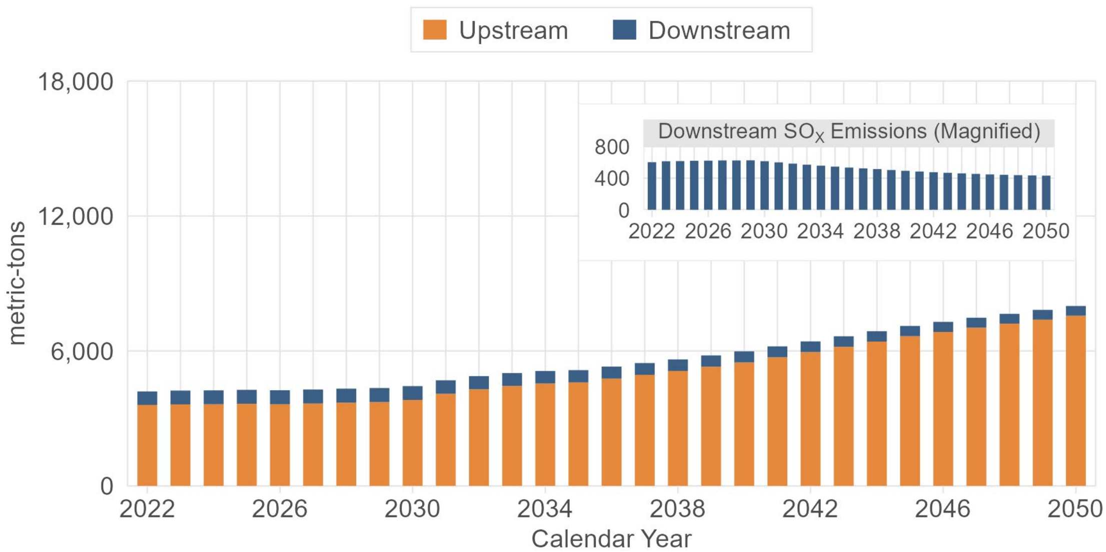


Figure 8-92 shows the annual SO_X emissions for the on-road fleet under the No-Action Alternative. Contrary to the previous two pollutants, downstream emissions of SO_X are measured based on the consumption of fuel, rather than on a per-mile basis dictated by the vehicle emissions standards. Hence, SO_X emissions are influenced directly by changes to the amount of fuel consumed, rather than the total miles traveled by the HDPUV fleet. Figure 8-92 shows the downstream component provides a marginal contribution to the overall SO_X emissions, and generally undergoes a downward trend as the overall fuel consumption decreases. The inner plot in the bottom-right corner of the figure presents a magnified view of the 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 increase moderately year over year due to a larger HDPUV fleet and a greater presence of electric-powered vehicles within it.

Figure 8-92: Emissions of SO_X in the Reference Baseline Scenario



As demonstrated in the next several figures, increases to the HDPUV fuel efficiency standards only lead to meaningful differences under the most stringent alternative (HDPUV14) that was evaluated for this analysis. The changes in Alternative HDPUV4 were insignificant for all pollutants, while Alternative HDPUV10 showed minor differences in overall emissions of NO_X and $PM_{2.5}$, and only marginal variances to total SO_X emissions when compared to the reference baseline scenario. All alternatives, however, showed an increase to the upstream emissions, while also presenting a decrease in downstream. The net changes to emissions, though, depend on the CY and pollutant being considered, where overall values may show an increase or a decrease in total emissions generated.

Figure 8-93 shows the incremental changes to NO_X emissions in the action alternatives verses the reference baseline scenario. The larger chart at the top displays the overall emissions of NO_X, while the left and right portions at the bottom provide deconstructed views of upstream and downstream components, respectively. Upstream emissions initially decrease during standard setting years before increasing in the later years, while the downstream emissions decline over time, relative to the No-Action alternative. As new electric-powered vehicles are gradually phased into the population, the amount of net upstream emissions decreases, as electricity production is cleaner than gasoline production in most model years; in the later years, upstream NOx emissions increase relative to the reference baseline as HDPUV VMT sees a small uptick across alternatives, and electricity production loses its advantage over gasoline production in terms of its associated emissions. At the same time, since consumption of electricity does not generate emissions of criteria pollutants during vehicle operation, the amount of downstream NO_X emission decreases. These variances between alternatives occur mostly due to the PHEVs and/or BEVs being adopted at a slightly faster rate under Alternatives HDPUV10 and HDPUV14 than in the reference baseline.

Figure 8-93: Changes in NO_X Emissions Compared to Reference Baseline

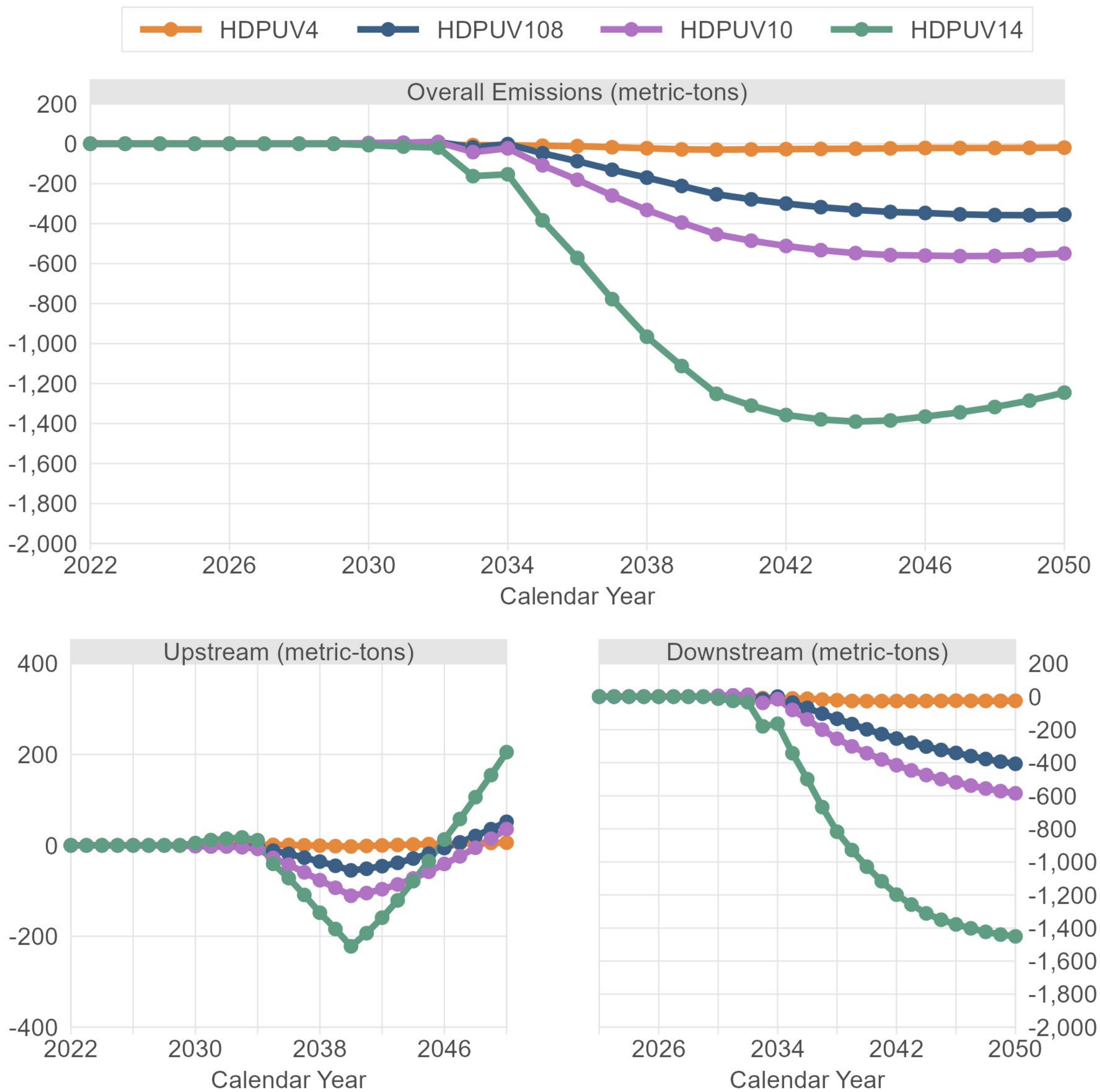


Figure 8-94 presents the incremental changes to $PM_{2.5}$ emissions in the action alternatives as compared to the reference baseline scenario. The upstream and downstream emissions trends for $PM_{2.5}$ criteria air pollutant are similar to that of NO_X, while also having the same underlying root causes for the observed behavior. In the case of $PM_{2.5}$, however, the downstream portion represents a combination of vehicle exhaust and BTW emissions.

Figure 8-94: Changes in $PM_{2.5}$ Emissions Compared to Reference Baseline

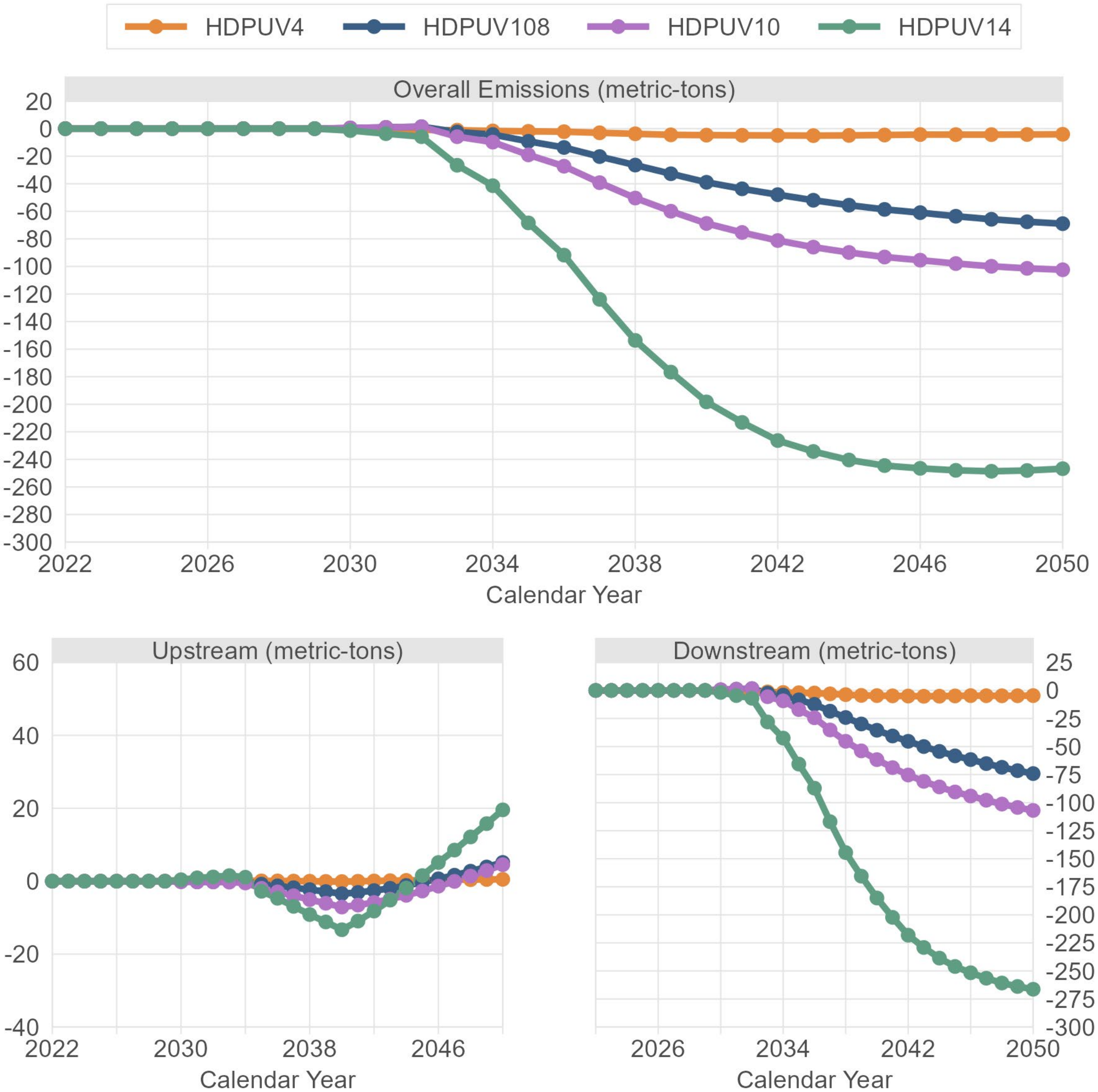
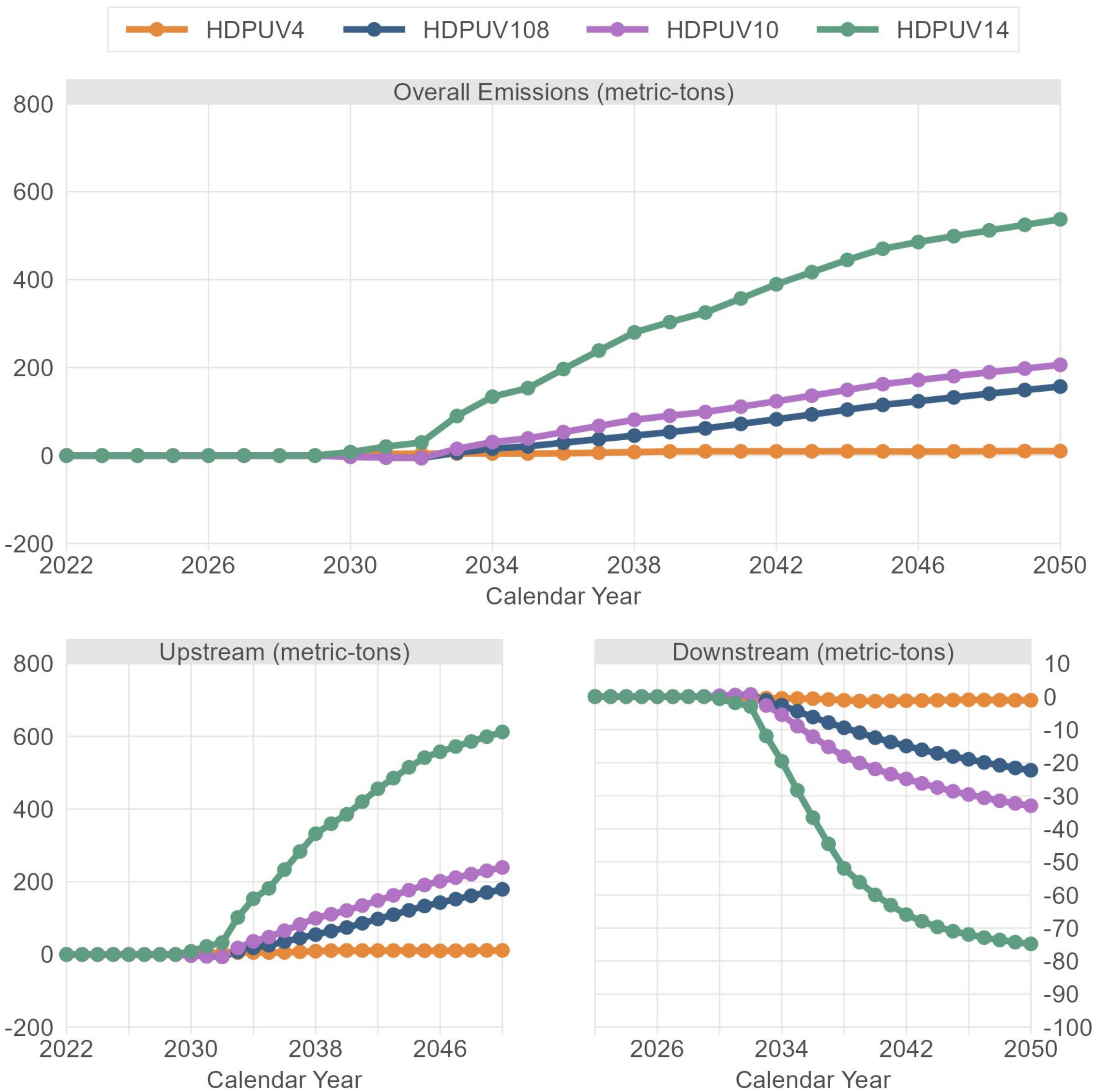


Figure 8-95 illustrates the incremental emission changes for SO_X for the action alternatives versus the reference baseline. As was noted earlier, the SO_X downstream emissions are measured based on the total consumption of fuel, rather than on a per-mile basis. Thus, the marginal to moderate reductions in fuel use in the action alternatives leads to proportionally marginal to moderate decreases of the downstream emissions when compared to the No-Action Alternative. However, as opposed to other pollutants, the inputs used in the CAFE model project electricity production to emit SO_X at a higher rate than gasoline production; therefore, the upstream emissions of SO_X are higher than the reference baseline as more electric vehicles are phased into the fleet in each action alternative. This also leads to a net increase in the overall SO_X emissions over the reference baseline.

Figure 8-95: Changes in SO_X Emissions Compared to Reference Baseline



8.3.5.4. 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 HDPUV fleet drops between CYs (and to a certain extent, between alternatives). Table 8-50 presents the number of incidents and proportions for each of the various emission health impacts, which were considered during this final rule, occurring during CY 2022. Since CY 2022 corresponds to the initial year evaluated for this analysis (MY 2022), and since the CAFE Model does not apply any fuel saving technologies during that initial year, the health impacts shown in the table are the same across all alternatives.

Table 8-50: Emission Health Impacts in CY 2022

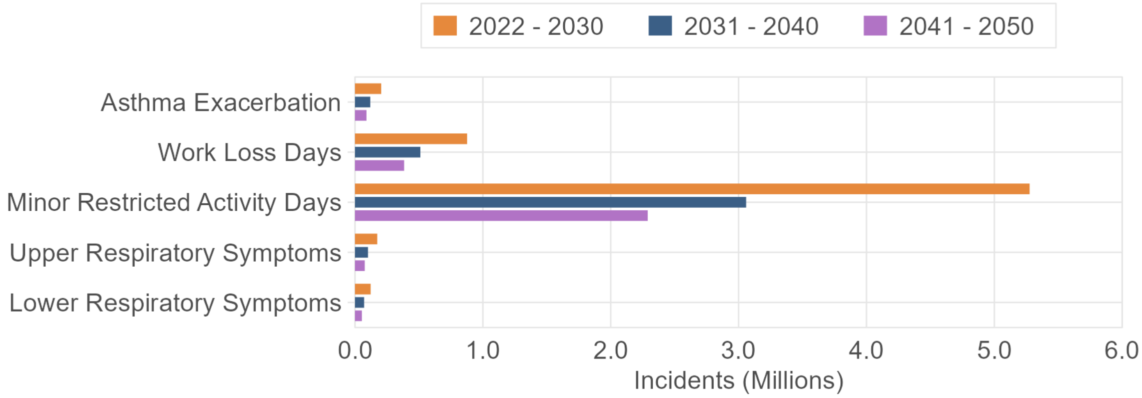
	Incidents (Units)	Share of Total
High Incident Counts		
Minor Restricted Activity Days	789,070	79.0%
Work Loss Days	130,951	13.1%

Asthma Exacerbation	30,563	3.1%
Upper Respiratory Symptoms	26,001	2.6%
Lower Respiratory Symptoms	18,301	1.8%
Low Incident Counts		
Non-Fatal Heart Attacks (Peters)	1,022	0.10%
Premature Deaths	989	0.10%
Respiratory Emergency Room Visits	553	0.06%
Cardiovascular Hospital Admissions	260	0.03%
Respiratory Hospital Admissions	247	0.02%
Non-Fatal Heart Attacks (All Others)	110	0.01%

As demonstrated by Table 8-50, 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 CY, although these proportions moderately decline with each subsequent year.

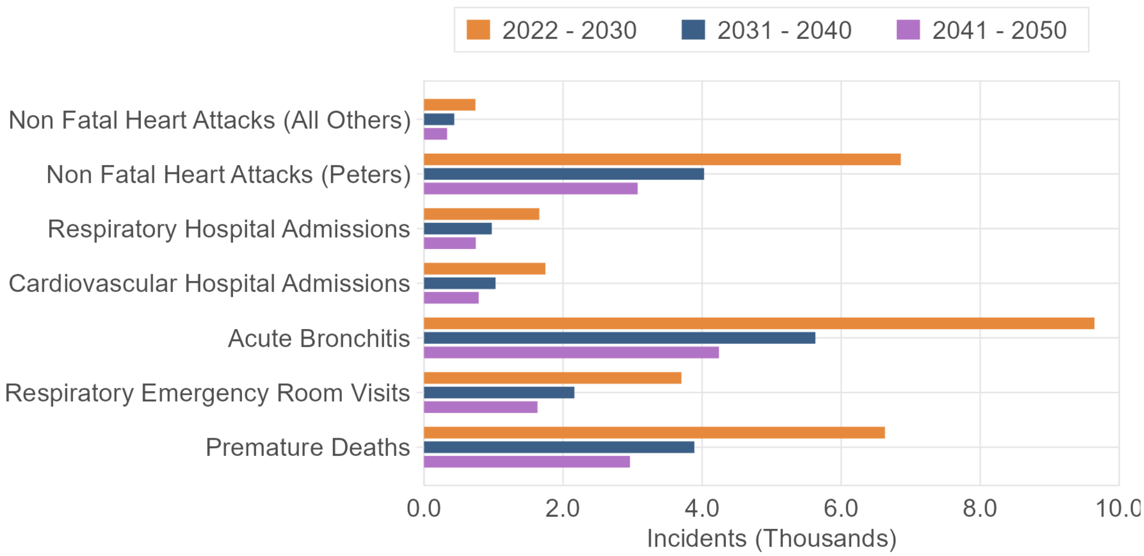
The emission health impacts attributed to the No-Action Alternative for the remainder of the CYs are presented as cumulative impacts over the next three decades in Figure 8-96 and Figure 8-97.[250] The figures were split into subsets of major incident counts (above ten thousand per year) and minor incident counts (below ten thousand) to aid with interpretation. As shown in 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 the NO_X and $PM_{2.5}$ pollutants (discussed in Chapter 8.3.5.3).

Figure 8-96: Cumulative Emission Health Impacts in the Reference Baseline Scenario (Part 1)



250 As discussed in the introduction to Chapter 8.3.5, the first decade in all figures presented by this chapter cover the range of calendar years between CYs 2022 and 2030, while the latter two encompass effects over the full ten-year period. While this marginally reduces the magnitude of cumulative incidents occurring during the first decade (as compared to the following ones), the figures still demonstrate the relative differences and a declining trend between the decades.

Figure 8-97: Cumulative Emission Health Impacts in the Reference Baseline Scenario (Part 2)



With increasing fuel efficiency standards under the action alternatives, health-related incidents are further decreased in response to an even greater reduction of fuel consumed. However, as was observed for criteria air pollutants, the least stringent alternative (HDPUV4) does not show any practical deviation from the reference baseline, while Alternatives HDPUV10 and HDPUV14 display marginal to moderate differences. Although the net emissions of SO_X increase in some action alternatives, the decreases in fine $PM_{2.5}$ and NO_X 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 8-98 and Figure 8-99 illustrate the incremental changes in emission health impacts for each alternative over the reference baseline scenario for the next three decades. However, considering that MY 2030 is the first year of regulatory action for the HDPUV fleet, the differences between all alternatives during the first decade (CY 2022-2030) are, therefore, virtually non-existent.

Figure 8-98: Changes in Cumulative Emission Health Impacts Compared to Reference Baseline (Part 1)

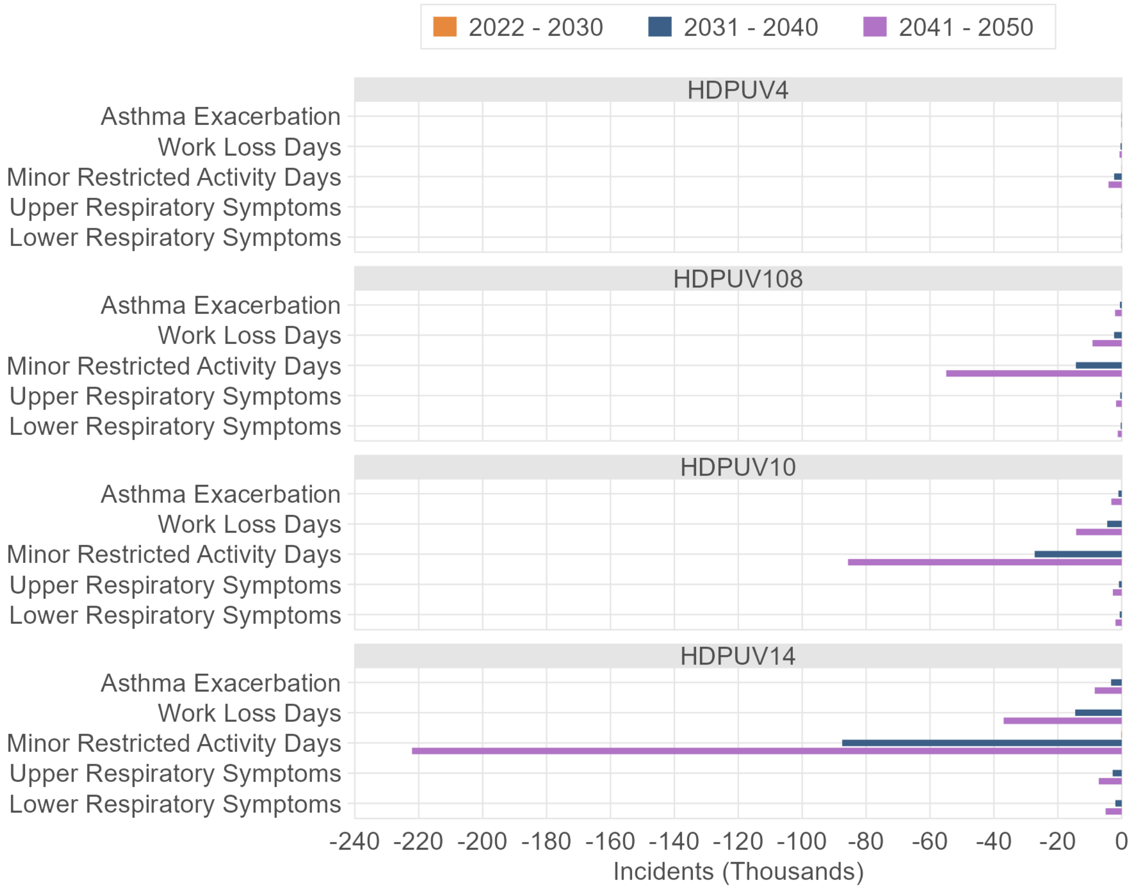
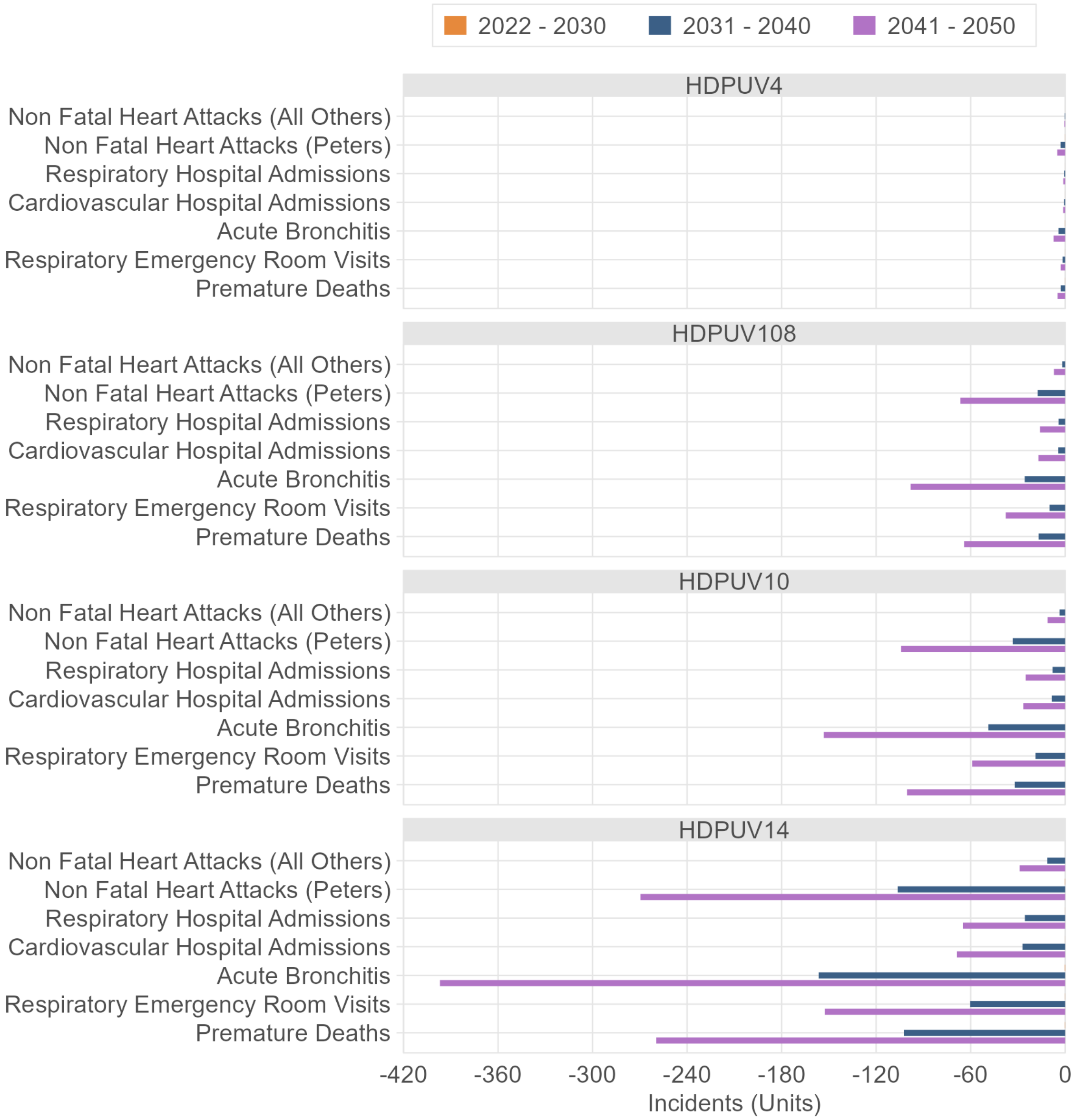


Figure 8-99: Changes in Cumulative Emission Health Impacts Compared to Reference Baseline (Part 2)



9. Alternative Baseline and Expanded Sensitivity Analysis

9.1. Description of the Alternative Baseline and Sensitivity Cases

CAFE Model Files Referenced in this Chapter

Below is a list of CAFE Model Files referenced in this chapter. See TSD Chapter 2.1.9 Where to Find the Internal NHTSA Files? for a full list of files referenced in this document and their respective file locations.

- Market Data Input File

Results presented in this analysis reflect the agency's best judgments regarding many different factors. As with all the past LD CAFE and HDPUV FE 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, and externality values, 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 are higher or lower due to deviation from the reference case cathode active material (CAM) cost assumptions, then incremental technology costs are affected slightly. By contrast, if oil prices are higher than the projections used in the reference baseline, technology adoption choices and incremental technology costs produce larger differences relative to the central analysis. In that respect, it might be said that the material cost projections for batteries turns out to exert less influence on the analysis, as technology costs, the primary metric affected by application of advanced powertrain technologies for the MY in question, are not as significantly affected by the alternative assumptions. By contrast, the high oil price case demonstrates that many different metrics are affected by these assumptions – market adoption of fuel economy-improving technologies in the reference baseline, new vehicle prices, sales of new vehicles and scrappage of used vehicles, and VMT. The sensitivity analysis thus demonstrates that oil prices can have significant effects on a number of relevant metrics (i.e., model results are sensitive to this assumption), and alternative assumptions can dramatically raise or lower the magnitude of 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 baseline 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 battery material costs 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. For a full discussion of how this information relates to NHTSA's determination of which regulatory alternatives would be maximum feasible, please see preamble Section VI.D.

Results of NHTSA's sensitivity analysis are summarized below, and detailed model inputs and outputs are available on the agency's website.[251] These are reported as incremental values for the rule relative to the reference baseline No-Action Alternative. They compare to the measures presented in the central analysis, above, using the reference baseline assumptions. The reference baseline values are also reported in the tables for easier comparison. It is important to note that results under both the No-Action Alternative and the Preferred Alternative (i.e., the final CAFE standards for LDVs and FE standards for HDPUVs) 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 Alternative. When interpreting the results of these sensitivity cases, this has implications for relative net benefits to the extent that the alternative assumptions alter the amount or pace of technology adoption within the reference baseline and action alternatives. For example, when technology adoption and fuel economy are greater in the reference baseline, this limits the additional costs required for manufacturers to comply with more stringent standards. However, since these technologies generate additional benefits to society, adopting them in the reference baseline both raises the reference baseline benefits, and lowers the incremental additional benefits generated in the action alternatives; when the technologies are net-beneficial to society, adopting them in the reference baseline lowers the additional net benefits generated in the action alternatives. This can sometimes lead to counterintuitive incremental impacts of changing some of the reference assumptions.

Table 9-1 lists and briefly describes the alternative baseline and the cases included in the sensitivity analysis. Some cases only apply to the LD fleet (e.g., scenarios altering assumptions about fleet share modeling) and others only affect the HDPUV FE analysis (e.g., commercial operator sales share), so the results tables only report results for relevant sensitivities by vehicle fleet. We may have simulated other unique and minor sensitivities, but we did not provide a write up in this chapter because the impacts are minimal. Those sensitives are discussed further in the relevant preamble section. For the LD analysis, all sensitivity cases with the exception of the Environmental Impact Statement (EIS) case are variants of the standard-setting reference baseline that includes statutory restrictions (e.g., treatment of dedicated AFVs). The same statutory restrictions do not apply to HDPUVs and so both the reference baseline and sensitivity analysis consider dedicated AFVs.

Table 9-1: Cases and Baselines Included in the Sensitivity Analysis

Case Name	Description
Reference baseline	Reference baseline
No ZEV alternative baseline (LD)	No BEVs added in response to ACC I or in response to expected manufacturer deployment at levels consistent with ACC II
EIS	Reference baseline for Environmental Impact Statement (EIS)
NPRM battery learning curve	Battery learning curve used for the NPRM.
Battery DMC high	Battery direct manufacturing cost (DMC) increased by 25 percent
Battery DMC low	Battery direct manufacturing cost (DMC) decreased by 15 percent
Battery CAM cost (high)	Highest projected battery cathode active material (CAM) costs (opposed to average projected CAM costs, used in the reference baseline)
Battery CAM cost (low)	Lowest projected battery cathode active material (CAM) costs (opposed to average projected CAM costs, used in the reference baseline)

[251] NHTSA. 2024. CAFE Compliance and Effects Modeling System: The Volpe Model. Last Revised: 2024. Available at: https://www.nhtsa.gov/corporate-average-fuel-economy/cafe-compliance-and-effects-modeling-system. (Accessed: Feb. 23, 2024).

Annual vehicle redesigns	Vehicles redesigned every model year
Limited HCR skips	Removes all HCR skips
AC/OC NPRM Cap Error No-Action Mod	NPRM run with incorrect OC cap of 15 g/mi instead of 10 g/mi in 2027, all AC for BEVs, and reduced OC for BEVs starts in 2023 and includes No-Action alternative
AC/OC NPRM Cap No-Action Mod	NPRM run with correct OC cap of 10 g/mi instead of 15 g/mi in 2027, all AC for BEVs, and reduced OC for BEVs starts in 2023 and includes No-Action alternative
AC/OC Mod	AC/OC identical to reference baseline except reduced OC for BEVs starts in 2023 and includes No-Action alternative
PHEV available MY 2030	Shifts initial HDPUV PHEV availability to MY 2030
Oil price (high)	Fuel prices from AEO 2023 High Oil Price case
Oil price (low)	Fuel prices from AEO 2023 Low Oil Price case
GDP (high)	GDP and sales based on AEO 2023 high economic growth case
GDP (low)	GDP and sales based on AEO 2023 low economic growth case
GDP + fuel (high)	GDP, fuel prices, and sales from AEO 2023 high economic growth case
GDP + fuel (low)	GDP, fuel prices, and sales from AEO 2023 low economic growth case
Oil market externalities (low)	Price shock component set to 10th percentile of estimates.
Oil market externalities (high)	Price shock component set to 90th percentile of estimates.
Fuel reduction import share (50%)	Assume 50 percent share of fuel consumption reduction supplied by imports
Fuel reduction import share (100%)	Assume 100 percent share of fuel consumption reduction supplied by imports
No payback period	Payback period set to 0 months
24-month payback period	Payback period set to 24 months
30-month/70k miles payback	Valuation of fuel savings at 30 months for technology application, 70,000 miles for sales and scrappage models
36-month payback period	Payback period set to 36 months
60-month payback period	Payback period set to 60 months
120-month payback period	Payback period set to 120 months
Implicit opportunity cost	Includes a measure that estimates possible opportunity cost of forgone vehicle attribute improvements that exceed the reference baseline 30-month payback period.
Rebound (5%)	Rebound effect set at 5 percent
Rebound (15%)	Rebound effect set at 15 percent
Sales-scrappage response (-0.1)	Sales-scrappage model with price elasticity multiplier of -0.1

Sales-scrappage response (-0.5)	Sales-scrappage model with price elasticity multiplier of -0.5
Sales-scrappage response (-1)	Sales-scrappage model with price elasticity multiplier of -1
LD sales (2022 FR)	LD sales model coefficients equal to those used in the 2022 CAFE Final Rule
LD sales (AEO 2023 levels)	LD sales levels consistent with AEO 2023 Reference baseline
LD sales (AEO 2023 growth)	LD sales rate of change consistent with AEO 2023 Reference baseline
No fleet share price response	Fleet share elasticity estimate set to 0 (i.e., no fleet share response across alternatives)
Fixed fleet share	Fleet share level fixed at 2023 value
Fixed fleet share, no price response	Fixed fleet share at 2023 level, fleet share elasticity set to zero
HDPUV sales (AEO reference)	HDPUV sales based on AEO 2023 Reference baseline (i.e., no initial sales ramp)
HDPUV sales (AEO low economic growth)	HDPUV sales based on AEO 2023 Low Economic Growth Case without initial sales ramp
HDPUV sales (AEO high economic growth)	HDPUV sales based on AEO 2023 High Economic Growth Case with initial sales ramp
Commercial operator sales share (100%)	Assume all HDPUV vehicles are purchased by commercial operators. Applies commercial operator private net benefit offset.
Commercial operator sales share (50%)	Assume half of all HDPUV vehicles are purchased by commercial operators. Applies commercial operator private net benefit offset.
Mass-size-safety (low)	The lower bound of the 95 percent confidence interval for all mass-size-safety model coefficients.
Mass-size-safety (high)	The upper bound of the 95 percent confidence interval for all mass-size-safety model coefficients.
Crash avoidance (low)	Lower-bound estimate of effectiveness of six current crash avoidance technologies at avoiding fatalities, injuries, and property damage
Crash avoidance (high)	Upper-bound estimate of effectiveness of six current crash avoidance technologies at avoiding fatalities, injuries, and property damage
2022 FR fatality rates	Fatality rates at 2022 CAFE Final Rule levels
AEO 2023 grid forecast	Upstream emissions factors based on AEO 2023 (GREET 2023 default)

EPA Post-IRA grid forecast	Upstream emission factors based on EPA's IPM Post-IRA 2022 reference baseline
MOVES3 downstream emissions	Downstream emissions factors from MOVES3
IWG SC-GHG	SC-GHG values at interim IWG levels[252]
Standard-setting conditions for MY 2027-2035	Applies standard-setting conditions for MY 2027-2035
Standard-setting conditions for MY 2027-2050	Applies standard-setting conditions for MY 2027-2050
Standard-setting conditions for MY 2023-2050	Applies standard-setting conditions for MY 2023-2050
Reduced ZEV compliance	Reduced ZEV percentage requirements prior to MY 2026 to model reduced ACC I compliance.
PEF (NPRM)	NOPR PEF value used for CAFE NPRM (23,160 Wh/gal)
PEF (2022 FR)	PEF value used in prior CAFE rulemakings (82,049 Wh/gal)
Social discount rate at 2%	Social costs and benefits discounted using 2% discount rate
No EV tax credits	All IRA EV tax credits removed
No AMPC	IRA Advanced Manufacturing Production tax credit (AMPC) removed
Consumer tax credit share 75%	Consumer tax credit share set to 75 percent (25 percent captured by manufacturers)
Consumer tax credit share 25%	Consumer tax credit share set to 25 percent (75 percent captured by manufacturers)
Linear CVC values	Clean vehicle credit (CVC) values assume a linear increase in nominal levels
Maximum CVC values	CVC values at maximum nominal levels
NPRM EV tax credits	CVC and AMPC at NPRM levels
HDPUV No ZEV	No BEVs added in response to California's ACT program

9.2. Summary of Sensitivity Results

9.2.1. Effect of Assumptions on Primary Cost and Benefit Measures

The sensitivity cases for this final rule can be grouped broadly into four categories based on the input parameter(s) they alter: technology, economics, social/environmental, and policy. This chapter includes figures that summarize the change in net benefits in each sensitivity case for the Preferred Alternative (Alternative PC2LT002 for LD and HDPUV108 for HDPUV) relative to the Reference baseline.[253] As stated previously, total social costs and benefits are computed on a model year basis for the LD fleet (MYs 1983-2031) and a CY basis for the HDPUV fleet (CYs 2022-2050).[254] Because fuel efficiency standards for HDPUV

[252] Note that the IWG SC-GHG values use different discount rates than all other sensitivity cases. IWG SC-GHG discount rates are presented as: 5%, 3%, and 2.5%.
[253] The differences in net benefits may increase or decrease in other alternatives or discount rate assumptions, depending on the specific input being adjusted. Complete model outputs for these sensitivity cases are included in the online documentation, available at https://www.nhtsa.gov/corporate-average-fuel-economy/cafe-compliance-and-effects-modeling-system.
[254] Chapter 5.3 outlines the differences between *model year* analysis and *calendar year* analysis for the purposes of this final rule and discusses the use of the two methods in presenting results for the CAFE and HDPUV fuel economy standards.

vehicles remain in place until new standards are set, HDPUV market benefits and costs are reported on a CY basis (i.e., CYs 2022-2050).

9.2.1.1. Light Duty

Figure 9-1 through Figure 9-6 illustrate the effect of varying an array of model input assumptions. The axis measuring net benefits is fixed across figures to ease comparison. The cases with some of the widest deviation in net benefits from the Reference baseline are those that modify payback period, social costs of GHGs, and policy assumptions.

Table 9-2 and Table 9-3 present the full suite of sensitivity case results and summarize key output measures including fuel consumption and associated emissions, consumer costs and benefits, and aggregate social benefits, costs, and net benefits. Table 9-4 includes reference baseline technology penetration rates for a set of modeled technologies alongside the change in technology penetration rates under the preferred alternative. In this table, note that the technology penetration rates in the No-Action Alternative are not identical across scenarios because the assumptions in the sensitivity case affects behavior both in the No-Action Alternative and action alternatives, so comparing sensitivity cases must account for these reference baseline adjustments *and* the changes produced by the preferred alternative. Table 9-5 concludes the chapter and presents a subset of the columns of the three preceding tables, but with a social discount rate of seven percent. Note that certain technology assumptions also produce large differences in benefits or costs, but—for reasons explained below—these scenarios test model logic more than represent likely real-world settings.

Figure 9-1: Net Social Benefits Over the Lifetime of Vehicles Through MY 2031 for the Preferred Alternative (PC2LT002), Technology Assumptions Sensitivity Cases (2021$, 3% Social Discount Rate, 2.0% SC-GHG Discount Rate)

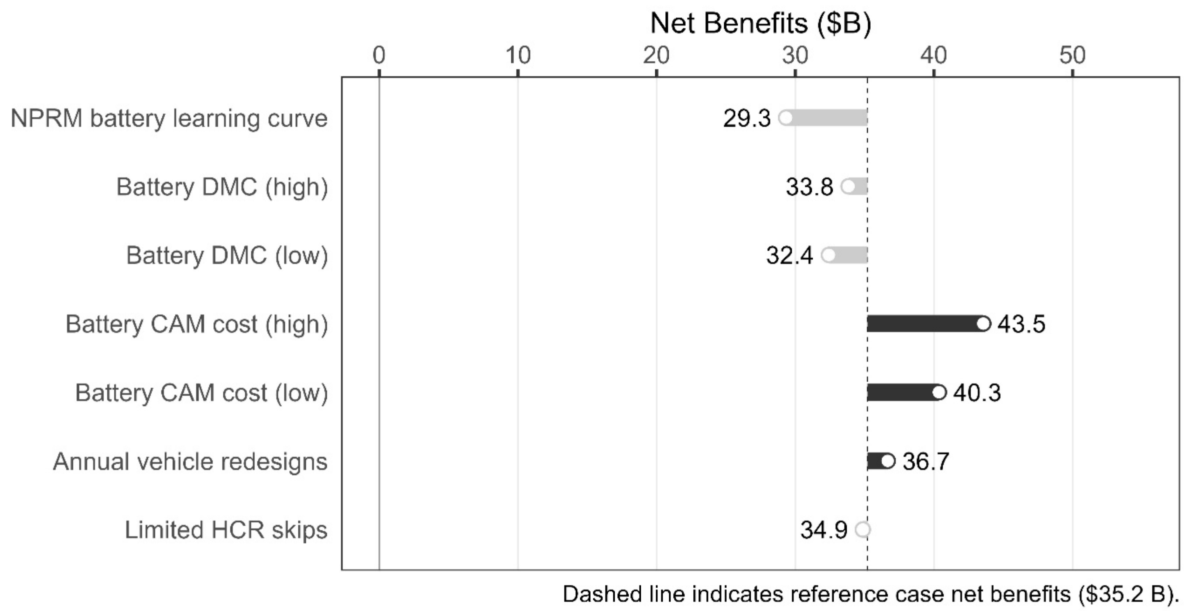


Figure 9-2: Net Social Benefits Over the Lifetime of Vehicles Through MY 2031 for the Preferred Alternative (PC2LT002), Macroeconomic Assumptions Sensitivity Cases (2021$, 3% Social Discount Rate, 2.0% SC-GHG Discount Rate)

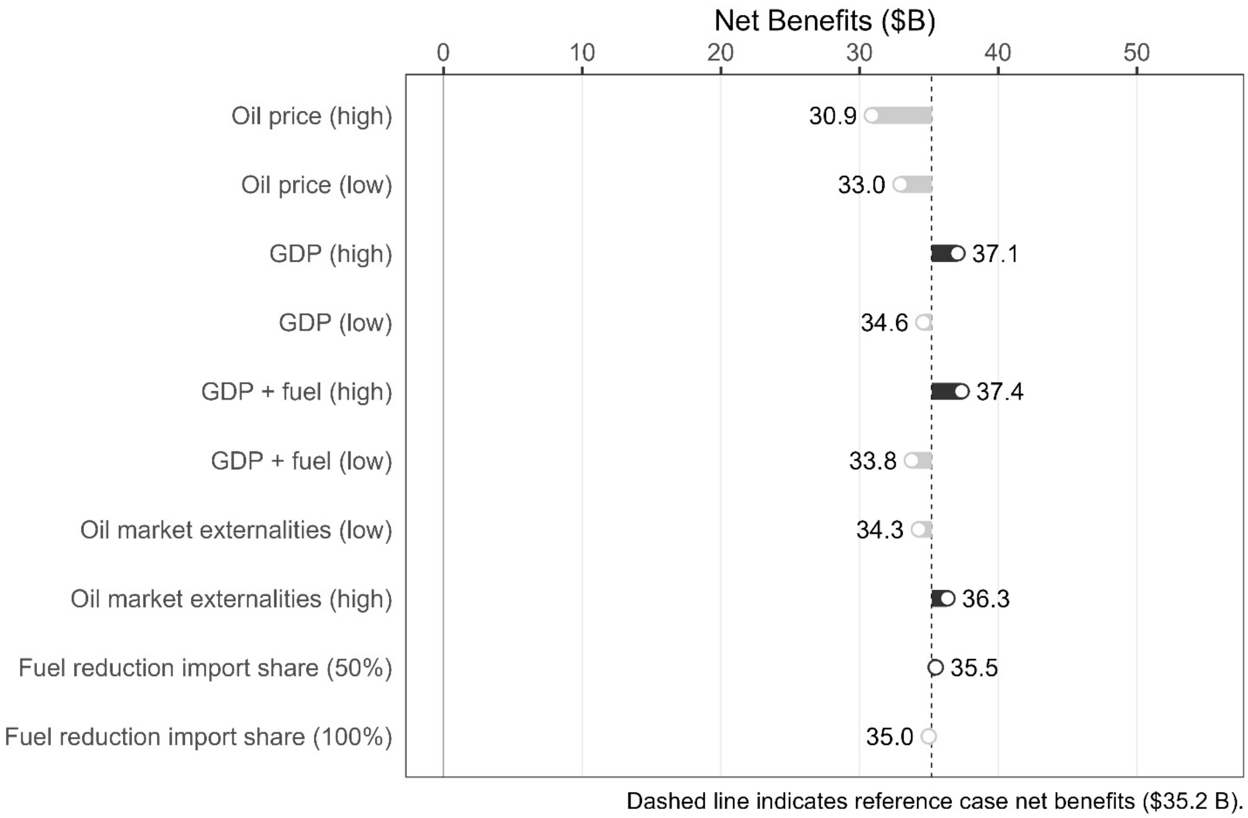
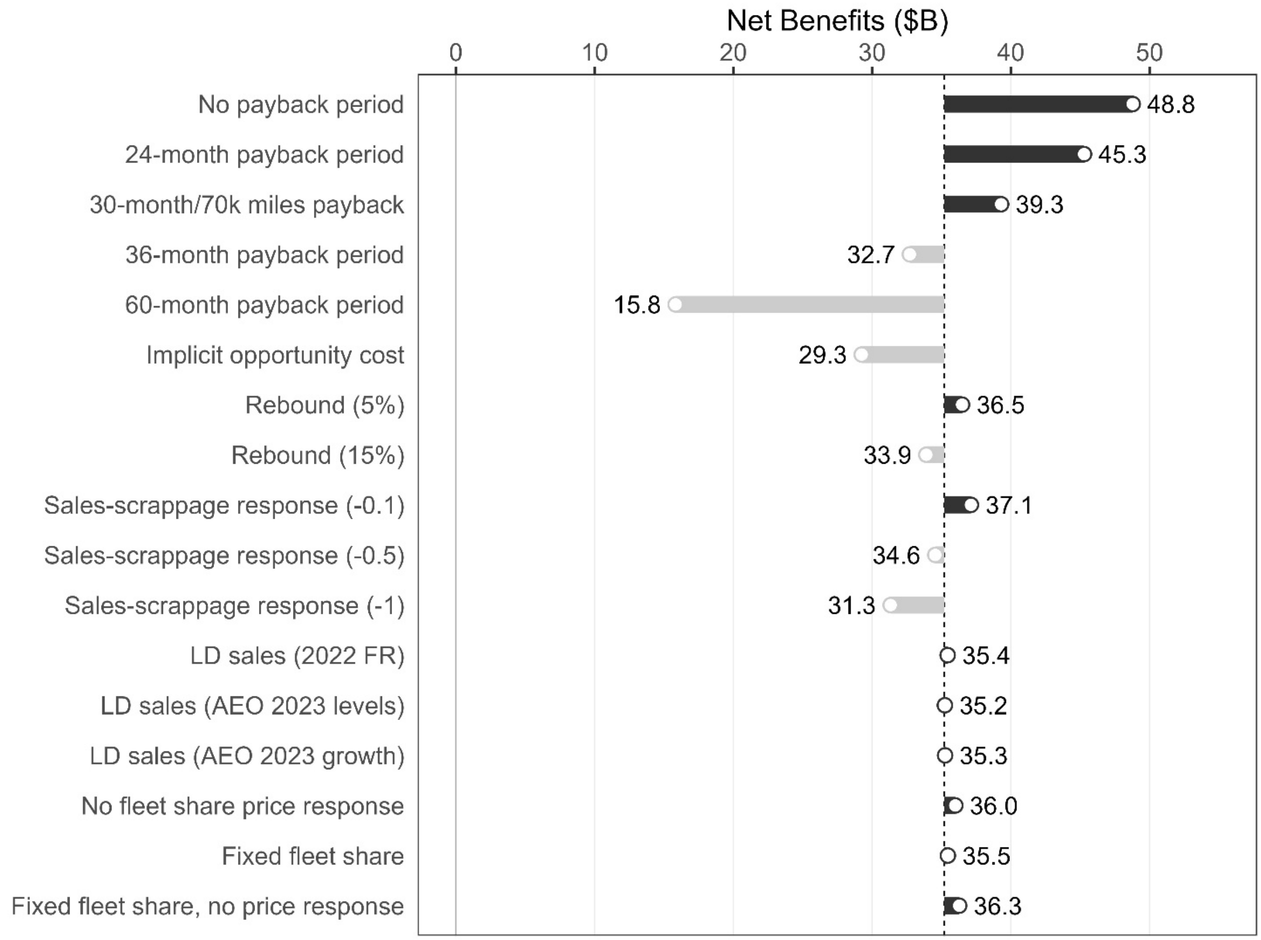
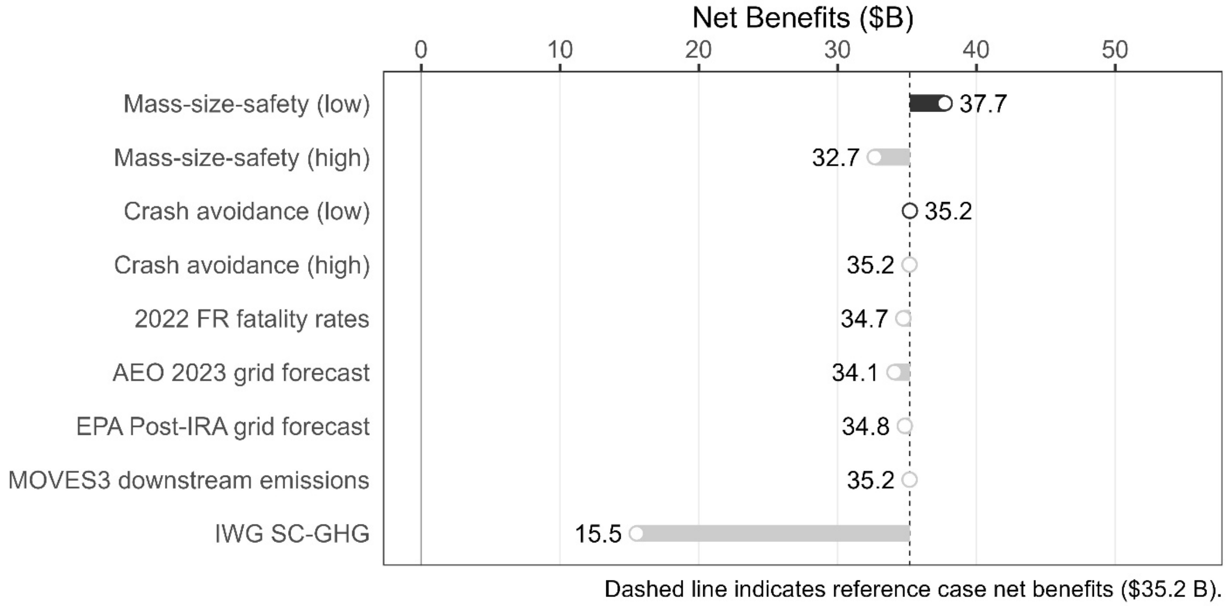


Figure 9-3: Net Social Benefits Over the Lifetime of Vehicles Through MY 2031 for the Preferred Alternative (PC2LT002), Payback and Sales Assumptions Sensitivity Cases (2021$, 3% Social Discount Rate, 2.0% SC-GHG Discount Rate)



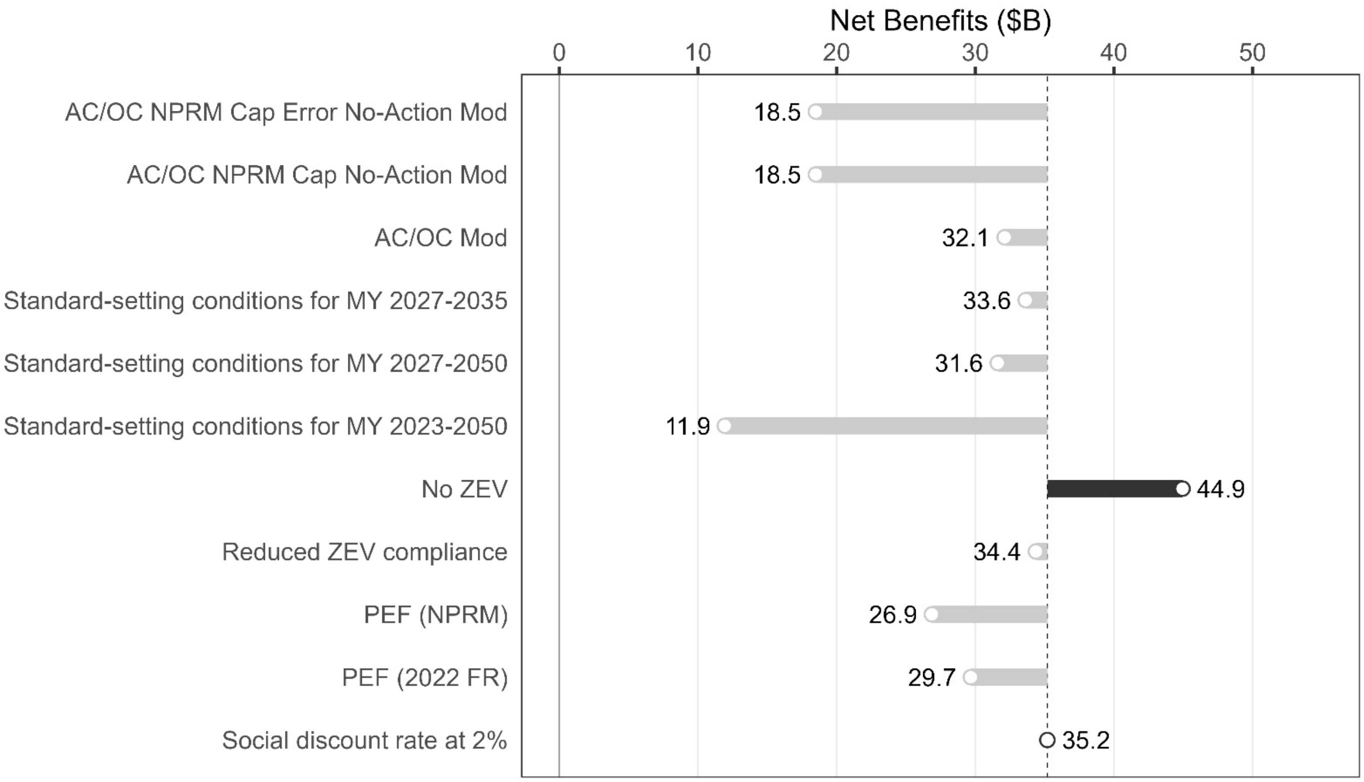
Dashed line indicates reference case net benefits ($35.2 B).

Figure 9-4: Net Social Benefits Over the Lifetime of Vehicles Through MY 2031 for the Preferred Alternative (PC2LT002), Safety and Environmental Assumptions Sensitivity Cases (2021$, 3% Social Discount Rate, 2.0% SC-GHG Discount Rate)[255]



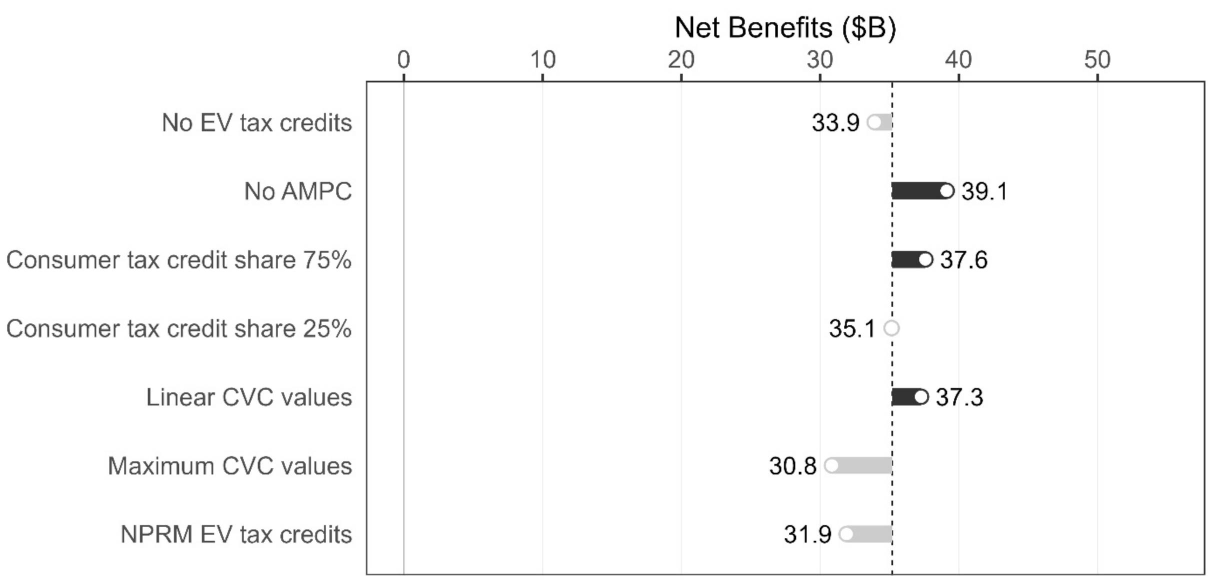
[255] IWG estimates assume SC-GHG discounted at 2.5%.

Figure 9-5: Net Social Benefits Over the Lifetime of Vehicles Through MY 2031 for the Preferred Alternative (PC2LT002), Alternative Baseline and Policy Assumptions Sensitivity Cases (2021$, 3% Social Discount Rate, 2.0% SC-GHG Discount Rate)



Dashed line indicates reference case net benefits ($35.2 B).

Figure 9-6: Net Social Benefits Over the Lifetime of Vehicles Through MY 2031 for the Preferred Alternative (PC2LT002), EV Tax Credit Assumptions Sensitivity Cases (2021$, 3% Social Discount Rate, 2.0% SC-GHG Discount Rate)



Dashed line indicates reference case net benefits ($35.2 B).

Table 9-2: Aggregate Light-Duty Fleet Costs and Benefits Over the Lifetime of Vehicles Through MY 2031 for the Preferred Alternative (PC2LT002), by Sensitivity Case (2021$, 3% Discount Rate, SC-GHG Discount Rate as Noted in Column Headings)

Sensitivity Case	Total Social Costs ($b)	Total Social Benefits ($b)			Net Social Benefits ($b)		
		2.5%	2.0%	1.5%	2.5%	2.0%	1.5%
Reference baseline	24.5	47.1	59.7	83.2	22.7	35.2	58.7
No ZEV alternative baseline	35.4	64.1	80.3	110.8	28.7	44.9	75.4
EIS	12.2	29.6	38.8	56.1	17.4	26.7	43.9
NPRM battery learning curve	21.0	39.7	50.3	70.2	18.7	29.3	49.2
Battery DMC high	25.8	46.9	59.6	83.5	21.1	33.8	57.7
Battery DMC low	15.4	38.0	47.9	66.3	22.6	32.4	50.8
Battery CAM cost (high)	26.8	55.5	70.3	98.2	28.7	43.5	71.4
Battery CAM cost (low)	21.8	49.0	62.1	86.7	27.3	40.3	64.9
Annual vehicle redesigns	17.5	43.6	54.2	74.1	26.1	36.7	56.6
Limited HCR skips	24.0	46.8	58.9	81.5	22.8	34.9	57.5
AC/OC NPRM Cap Error No-Action Mod	16.5	27.5	35.0	49.1	11.0	18.5	32.6
AC/OC NPRM Cap No-Action Mod	16.5	27.5	35.0	49.1	11.0	18.5	32.6
AC/OC Mod	25.5	45.5	57.6	80.4	20.0	32.1	54.9
Oil price (high)	11.7	36.0	42.6	55.1	24.3	30.9	43.4
Oil price (low)	27.3	45.4	60.3	88.1	18.1	33.0	60.8
GDP (high)	24.9	48.9	61.9	86.3	24.1	37.1	61.5
GDP (low)	24.2	46.4	58.8	81.9	22.3	34.6	57.8
GDP + fuel (high)	24.5	49.1	61.9	86.0	24.5	37.4	61.4
GDP + fuel (low)	24.3	45.6	58.1	81.5	21.3	33.8	57.1
Oil market externalities (low)	24.5	46.2	58.7	82.3	21.8	34.3	57.8
Oil market externalities (high)	24.5	48.3	60.8	84.3	23.8	36.3	59.9
Fuel reduction import share (50%)	24.5	47.4	60.0	83.5	23.0	35.5	59.0
Fuel reduction import share (100%)	24.5	46.9	59.5	83.0	22.5	35.0	58.5
No payback period	26.9	59.9	75.7	105.5	33.0	48.8	78.5
24-month payback period	24.2	54.9	69.5	96.8	30.7	45.3	72.6
30-month/70k miles payback	22.4	48.7	61.7	85.9	26.4	39.3	63.6
36-month payback period	18.6	40.6	51.3	71.4	22.0	32.7	52.9
60-month payback period	4.2	16.1	20.0	27.5	11.8	15.8	23.3
Implicit opportunity cost	30.4	47.1	59.7	83.2	16.7	29.3	52.8
Rebound (5%)	22.1	45.8	58.6	82.5	23.7	36.5	60.4

Sensitivity Case	Total Social Costs ($b)	Total Social Benefits ($b)			Net Social Benefits ($b)		
		2.5%	2.0%	1.5%	2.5%	2.0%	1.5%
Rebound (15%)	26.8	48.5	60.8	83.9	21.6	33.9	57.0
Sales-scrappage response (-0.1)	23.6	47.9	60.7	84.6	24.4	37.1	61.0
Sales-scrappage response (-0.5)	24.8	46.9	59.3	82.7	22.1	34.6	57.9
Sales-scrappage response (-1)	26.3	45.5	57.6	80.4	19.2	31.3	54.1
LD sales (2022 FR)	25.4	48.1	60.9	84.9	22.6	35.4	59.5
LD sales (AEO 2023 levels)	24.2	46.9	59.4	82.9	22.8	35.2	58.7
LD sales (AEO 2023 growth)	24.5	47.2	59.8	83.4	22.7	35.3	58.9
No fleet share price response	24.3	47.7	60.3	84.1	23.3	36.0	59.8
Fixed fleet share	25.0	47.8	60.4	84.1	22.8	35.5	59.2
Fixed fleet share, no price response	24.8	48.3	61.1	85.1	23.5	36.3	60.3
Mass-size-safety (low)	21.8	47.0	59.5	83.1	25.2	37.7	61.2
Mass-size-safety (high)	27.1	47.3	59.8	83.3	20.2	32.7	56.2
Crash avoidance (low)	24.6	47.3	59.8	83.4	22.7	35.2	58.7
Crash avoidance (high)	24.4	47.0	59.6	83.1	22.7	35.2	58.7
2022 FR fatality rates	24.1	46.4	58.9	82.4	22.2	34.7	58.3
AEO 2023 grid forecast	24.5	46.4	58.6	81.4	21.9	34.1	56.9
EPA Post-IRA grid forecast	24.5	46.9	59.3	82.6	22.5	34.8	58.1
MOVES3 downstream emissions	24.5	47.1	59.7	83.2	22.7	35.2	58.7
IWG SC-GHG[256]	24.5	30.6	36.1	40.0	6.2	11.6	15.5
Standard-setting conditions for MY 2027-2035	25.6	46.8	59.2	82.5	21.2	33.6	56.9
Standard-setting conditions for MY 2027-2050	26.7	46.1	58.3	81.3	19.4	31.6	54.6
Standard-setting conditions for MY 2023-2050	7.9	15.6	19.8	27.7	7.7	11.9	19.8
Reduced ZEV compliance	24.4	46.4	58.7	81.9	22.0	34.4	57.5
PEF (NPRM)	24.1	40.4	50.9	70.6	16.4	26.9	46.6
PEF (2022 FR)	14.9	35.0	44.5	62.6	20.1	29.7	47.7
Social discount rate at 2%	27.3	52.0	64.6	88.1	24.7	37.2	60.8
No EV tax credits	18.4	41.3	52.4	73.2	22.8	33.9	54.8
No AMPC	23.4	49.2	62.5	87.4	25.9	39.1	64.0

[256] Column headings for SC-GHG differ for this case. For ease of presentation, headings are retained but IWG SC-GHG discount rates are as follows (left to right across columns): 5%, 3%, 2.5%.

Sensitivity Case	Total Social Costs ($b)	Total Social Benefits ($b)			Net Social Benefits ($b)		
		2.5%	2.0%	1.5%	2.5%	2.0%	1.5%
Consumer tax credit share 75%	21.3	46.7	58.9	81.8	25.4	37.6	60.5
Consumer tax credit share 25%	20.9	44.2	56.1	78.3	23.3	35.1	57.4
Linear CVC values	25.3	49.3	62.6	87.5	24.0	37.3	62.2
Maximum CVC values	14.3	36.1	45.1	62.1	21.8	30.8	47.8
NPRM EV tax credits	17.3	39.3	49.2	67.9	21.9	31.9	50.6

Table 9-3: Selected Light-Duty Fleet Model Metrics for the Preferred Alternative (PC2LT002), by Sensitivity Case (2021$, 3% Discount Rate)

Sensitivity Case	Gasoline Consumption (b.gal)	Electricity Consumption (TWh)	CO_2 Emissions (MMT)	Fatalities	Criteria Emissions Deaths	MY 2031 Regulatory Cost ($/vehicle)	MY 2031 Lifetime Retail Fuel Expenditure ($/vehicle)	MY 2031 Sales	MY 2031 Jobs
Reference baseline	-64	333	-659	442	-670	392	-639	-23,702	5,832
No ZEV	-115	493	-1,207	836	-1,203	661	-1,061	-50,888	7,322
EIS	-19	143	-186	107	-226	81	-208	2,745	1,621
NPRM battery learning curve	-76	409	-781	501	-650	336	-582	-18,495	4,797
Battery DMC high	-98	634	-992	597	-949	382	-600	-23,038	6,063
Battery DMC low	-49	146	-519	323	-366	294	-635	-14,436	5,069
Battery CAM cost (high)	-91	541	-934	569	-929	415	-736	-23,237	6,898
Battery CAM cost (low)	-66	340	-689	449	-639	370	-716	-18,669	6,129
Annual vehicle redesigns	-37	86	-400	377	-389	227	-547	-13,360	3,659
Limited HCR skips	-61	267	-642	449	-601	390	-686	-23,001	5,766
AC/OC NPRM Cap Error No-Action Mod	-49	304	-503	300	-471	323	-469	-21,784	4,447
AC/OC NPRM Cap No-Action Mod	-49	304	-503	300	-471	323	-469	-21,784	4,447
AC/OC Mod	-60	316	-623	418	-581	413	-626	-27,131	6,031
Oil price (high)	-29	52	-311	362	-254	194	-569	-6,086	2,335
Oil price (low)	-149	993	-1,508	689	-1,613	376	-514	-25,963	5,376
GDP (high)	-67	349	-690	462	-704	392	-665	-23,946	5,786
GDP (low)	-64	341	-658	441	-674	389	-625	-24,092	5,785
GDP + fuel (high)	-65	347	-677	485	-693	388	-675	-23,142	5,789
GDP + fuel (low)	-74	427	-757	465	-799	390	-602	-24,578	5,785
Oil market externalities (low)	-64	333	-659	442	-670	392	-639	-23,702	5,832

Sensitivity Case	Gasoline Consumption (b.gal)	Electricity Consumption (TWh)	CO_2 Emissions (MMT)	Fatalities	Criteria Emissions Deaths	MY 2031 Regulatory Cost ($/vehicle)	MY 2031 Lifetime Retail Fuel Expenditure ($/vehicle)	MY 2031 Sales	MY 2031 Jobs
Oil market externalities (high)	-64	333	-659	442	-670	392	-639	-23,702	5,832
Fuel reduction import share (50%)	-64	333	-659	442	-873	392	-639	-23,702	5,832
Fuel reduction import share (100%)	-64	333	-659	442	-535	392	-639	-23,702	5,832
No payback period	-129	754	-1,318	706	-1,284	418	-789	-22,598	6,039
24-month payback period	-105	658	-1,075	594	-1,114	381	-743	-19,220	5,984
30-month/70k miles payback	-64	334	-662	429	-678	392	-644	-5,631	7,007
36-month payback period	-50	233	-522	385	-471	321	-580	-18,133	4,763
60-month payback period	-11	-5	-120	75	-68	80	-213	-4,922	1,068
Implicit opportunity cost	-64	333	-659	442	-670	392	-639	-23,702	5,832
Rebound (5%)	-64	327	-667	222	-691	392	-654	-23,702	5,832
Rebound (15%)	-63	340	-651	663	-650	392	-625	-23,702	5,832
Sales-scrappage response (-0.1)	-64	334	-660	436	-673	392	-647	-5,940	6,957
Sales-scrappage response (-0.5)	-64	333	-659	444	-669	392	-637	-29,622	5,455
Sales-scrappage response (-1)	-63	333	-657	454	-665	392	-624	-59,203	3,579
LD sales (2022 FR)	-64	337	-662	445	-675	391	-612	-25,527	6,198
LD sales (AEO 2023 levels)	-63	335	-654	434	-654	388	-638	-24,145	5,712
LD sales (AEO 2023 growth)	-63	331	-653	440	-664	390	-634	-24,308	5,889
No fleet share price response	-64	334	-658	441	-668	392	-642	-23,578	5,735

Sensitivity Case	Gasoline Consumption (b.gal)	Electricity Consumption (TWh)	CO_2 Emissions (MMT)	Fatalities	Criteria Emissions Deaths	MY 2031 Regulatory Cost ($/vehicle)	MY 2031 Lifetime Retail Fuel Expenditure ($/vehicle)	MY 2031 Sales	MY 2031 Jobs
Fixed fleet share	-71	396	-729	489	-800	397	-638	-25,328	5,442
Fixed fleet share, no price response	-71	397	-729	489	-799	396	-642	-25,191	5,327
Mass-size-safety (low)	-64	333	-659	-203	-670	392	-639	-23,702	5,832
Mass-size-safety (high)	-64	333	-659	1,086	-670	392	-639	-23,702	5,832
Crash avoidance (low)	-64	333	-659	460	-670	392	-639	-23,702	5,832
Crash avoidance (high)	-64	333	-659	416	-670	392	-639	-23,702	5,832
2022 FR fatality rates	-64	333	-659	500	-670	392	-639	-23,702	5,832
AEO 2023 grid forecast	-64	333	-638	442	-559	392	-639	-23,702	5,832
EPA Post-IRA grid forecast	-64	333	-660	442	-724	392	-639	-23,702	5,832
MOVES3 downstream emissions	-64	333	-659	442	-666	392	-639	-23,702	5,832
IWG SC-GHG	-64	333	-659	442	-670	392	-639	-23,702	5,832
Standard-setting conditions for MY 2027-2035	-70	374	-728	443	-599	396	-645	-23,961	5,863
Standard-setting conditions for MY 2027-2050	-78	328	-821	597	-575	396	-643	-23,961	5,863
Standard-setting conditions for MY 2023-2050	-23	92	-250	197	-153	107	-195	-6,673	1,382
Reduced ZEV compliance	-66	349	-678	475	-686	389	-636	-23,670	5,754
PEF (NPRM)	-61	328	-636	452	-641	407	-596	-29,806	4,757
PEF (2022 FR)	-49	311	-501	279	-528	224	-448	-7,790	4,637
Social discount rate at 2%	-64	333	-659	442	-670	392	-639	-23,702	5,832
No EV tax credits	-65	397	-668	403	-656	312	-580	-26,399	4,052

Sensitivity Case	Gasoline Consumption (b.gal)	Electricity Consumption (TWh)	CO_2 Emissions (MMT)	Fatalities	Criteria Emissions Deaths	MY 2031 Regulatory Cost ($/vehicle)	MY 2031 Lifetime Retail Fuel Expenditure ($/vehicle)	MY 2031 Sales	MY 2031 Jobs
No AMPC	-70	393	-722	447	-693	372	-666	-21,085	6,050
Consumer tax credit share 75%	-57	258	-597	420	-503	313	-626	-14,082	4,981
Consumer tax credit share 25%	-71	391	-728	507	-943	431	-616	-32,454	3,478
Linear CVC values	-66	370	-685	440	-685	403	-667	-23,462	6,131
Maximum CVC values	-42	134	-447	362	-473	230	-469	-13,669	2,122
NPRM EV tax credits	-57	237	-600	410	-527	312	-610	-17,346	4,723

Table 9-4: Light-Duty Fleet Penetration Rates of Selected Technologies for the Preferred Alternative (PC2LT002), by Sensitivity Case (Percent, MY 2031)

Sensitivity Case	HCR		SHEV		PHEV		BEV[257]	
	No Action	Change	No Action	Change	No Action	Change	No Action	Change
Reference baseline	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
No ZEV alternative baseline	26.0	-7.3	26.8	+17.9	2.9	+3.3	19.0	0
EIS	18.0	+0.1	14.3	-0.2	0.6	0	45.3	+1.5
NPRM battery learning curve	21.6	-2.3	25.0	+4.3	1.9	+3.5	28.1	0
Battery DMC high	19.9	-1.3	25.8	+3.4	1.7	+4.1	28.1	0
Battery DMC low	22.8	-3.3	20.4	+6.4	1.6	+2.7	30.0	0
Battery CAM cost (high)	22.8	-2.8	22.2	+6.0	0.7	+4.3	28.4	0
Battery CAM cost (low)	22.7	-2.9	20.6	+5.9	0.5	+3.8	29.0	0
Annual vehicle redesigns	22.1	-2.6	22.7	+11.5	0.8	+0.8	28.0	0
Limited HCR skips	31.7	-4.5	19.5	+8.8	2.7	+3.2	28.1	0
AC/OC NPRM Cap Error No-Action Mod	22.1	-1.8	23.4	+1.4	1.8	+3.1	28.2	0

[257] Due to EPCA provisions, during our standard-setting years, the CAFE Model does not consider BEVs as a compliance strategy to achieve fuel economy standards.

Sensitivity Case	HCR		SHEV		PHEV		BEV[257]	
	No Action	Change	No Action	Change	No Action	Change	No Action	Change
AC/OC NPRM Cap No-Action Mod	22.1	-1.8	23.4	+1.4	1.8	+3.1	28.2	0
AC/OC Mod	22.1	-2.3	23.4	+4.6	1.8	+3.9	28.2	0
Oil price (high)	21.3	-2.2	18.9	+6.5	7.4	+1.0	30.3	0
Oil price (low)	21.8	-2.6	21.5	+7.6	1.0	+3.8	28.3	0
GDP (high)	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
GDP (low)	22.1	-2.4	23.5	+4.9	1.8	+3.9	28.1	0
GDP + fuel (high)	22.1	-2.4	23.5	+4.7	1.8	+3.9	28.1	0
GDP + fuel (low)	22.2	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
Oil market externalities (low)	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
Oil market externalities (high)	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
Fuel reduction import share (50%)	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
Fuel reduction import share (100%)	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
No payback period	22.3	-2.7	18.7	+6.4	3.6	+4.2	28.3	0
24-month payback period	22.0	-2.5	21.4	+7.6	0.9	+3.9	28.4	0
30-month/70k miles payback	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
36-month payback period	22.5	-2.8	22.4	+5.6	2.0	+3.2	28.2	0
60-month payback period	21.3	-1.0	28.3	+4.1	5.2	+0.2	30.0	0
Implicit opportunity cost	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
Rebound (5%)	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
Rebound (15%)	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
Sales-scrappage response (-0.1)	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
Sales-scrappage response (-0.5)	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
Sales-scrappage response (-1)	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
LD sales (2022 FR)	22.1	-2.4	23.4	+5.0	1.8	+3.9	28.1	0
LD sales (AEO 2023 levels)	22.1	-2.4	23.4	+4.8	1.8	+3.9	28.1	0

Sensitivity Case	HCR		SHEV		PHEV		BEV[257]	
	No Action	Change	No Action	Change	No Action	Change	No Action	Change
LD sales (AEO 2023 growth)	22.1	-2.4	23.4	+5.0	1.8	+3.9	28.1	0
No fleet share price response	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
Fixed fleet share	22.8	-2.9	22.4	+5.9	1.6	+3.7	28.5	0
Fixed fleet share, no price response	22.8	-2.9	22.4	+5.9	1.6	+3.7	28.5	0
Mass-size-safety (low)	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
Mass-size-safety (high)	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
Crash avoidance (low)	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
Crash avoidance (high)	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
2022 FR fatality rates	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
AEO 2023 grid forecast	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
EPA Post-IRA grid forecast	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
MOVES3 downstream emissions	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
IWG SC-GHG	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
Standard-setting conditions for MY 2027-2035	22.1	-2.4	23.3	+5.4	1.8	+3.9	28.1	0
Standard-setting conditions for MY 2027-2050	22.1	-2.4	23.3	+5.4	1.8	+3.9	28.1	0
Standard-setting conditions for MY 2023-2050	16.5	-0.3	30.5	+2.5	7.9	+0.9	27.8	0
Reduced ZEV compliance	22.1	-2.4	23.2	+4.9	1.8	+3.8	28.2	0
PEF (NPRM)	20.6	-2.7	29.3	+6.4	2.0	+3.0	28.1	0
PEF (2022 FR)	22.2	-1.1	21.4	+1.9	1.8	+3.3	28.1	0
Social discount rate at 2%	22.1	-2.4	23.3	+5.0	1.8	+3.9	28.1	0
No EV tax credits	20.7	-1.9	28.0	+5.0	0	+3.4	28.0	0
No AMPC	21.9	-2.3	24.6	+5.8	0.9	+4.1	28.1	0
Consumer tax credit share 75%	22.0	-2.4	23.1	+8.5	0.4	+2.4	28.3	0
Consumer tax credit share 25%	22.1	-3.4	12.7	+4.3	10.9	+5.8	28.9	0

Sensitivity Case	HCR		SHEV		PHEV		BEV[257]	
	No Action	Change	No Action	Change	No Action	Change	No Action	Change
Linear CVC values	22.2	-2.4	23.4	+5.4	1.1	+4.2	28.1	0
Maximum CVC values	22.7	-3.4	16.2	+9.1	7.8	+1.3	28.5	0
NPRM EV tax credits	21.8	-2.6	20.9	+8.2	2.9	+2.5	28.3	0

Table 9-5: Aggregate Light-Duty Fleet Costs and Benefits Over the Lifetime of Vehicles Through MY 2031 for the Preferred Alternative (PC2LT002), by Sensitivity Case (2021$, 7% Discount Rate, SC-GHG Discount Rate as Noted in Column Headings)

Sensitivity Case	Total Social Costs ($b)	Total Social Benefits ($b)			Net Social Benefits ($b)			MY 2031 Regulatory Cost ($/vehicle)	MY 2031 Lifetime Retail Fuel Expenditure ($/vehicle)
		2.5%	2.0%	1.5%	2.5%	2.0%	1.5%		
Reference baseline	16.2	34.5	47.0	70.5	18.2	30.8	54.3	392	-496
No ZEV	22.6	46.2	62.4	92.9	23.5	39.8	70.3	661	-826
EIS	8.4	22.6	31.8	49.1	14.1	23.4	40.7	81	-161
NPRM battery learning curve	13.6	29.0	39.6	59.5	15.4	26.0	45.9	336	-451
Battery DMC high	17.0	34.5	47.2	71.1	17.5	30.2	54.0	382	-465
Battery DMC low	9.9	27.5	37.3	55.7	17.6	27.4	45.8	294	-492
Battery CAM cost (high)	17.8	40.6	55.5	83.3	22.9	37.7	65.5	415	-571
Battery CAM cost (low)	14.3	35.8	48.9	73.5	21.5	34.6	59.2	370	-555
Annual vehicle redesigns	11.5	31.2	41.8	61.7	19.7	30.3	50.2	227	-425
Limited HCR skips	15.8	33.9	46.0	68.6	18.1	30.2	52.8	390	-532
AC/OC NPRM Cap Error No-Action Mod	10.6	20.2	27.7	41.8	9.6	17.1	31.2	323	-364
AC/OC NPRM Cap No-Action Mod	10.6	20.2	27.7	41.8	9.6	17.1	31.2	323	-364
AC/OC Mod	16.7	33.3	45.4	68.2	16.6	28.7	51.4	413	-486
Oil price (high)	7.6	24.4	31.0	43.5	16.8	23.4	35.9	194	-443
Oil price (low)	17.3	35.1	49.9	77.8	17.8	32.6	60.5	376	-400
GDP (high)	16.4	35.7	48.7	73.2	19.3	32.3	56.7	392	-515

Sensitivity Case	**Total Social Costs ($b)**	**Total Social Benefits ($b)**			**Net Social Benefits ($b)**			**MY 2031 Regulatory Cost ($/vehicle)**	**MY 2031 Lifetime Retail Fuel Expenditure ($/vehicle)**
		2.5%	**2.0%**	**1.5%**	**2.5%**	**2.0%**	**1.5%**		
GDP (low)	16.0	33.9	46.3	69.4	17.9	30.2	53.4	389	-485
GDP + fuel (high)	16.2	35.7	48.5	72.6	19.4	32.2	56.3	388	-522
GDP + fuel (low)	16.1	33.6	46.0	69.4	17.5	29.9	53.3	390	-469
Oil market externalities (low)	16.2	33.9	46.5	70.0	17.7	30.2	53.8	392	-496
Oil market externalities (high)	16.2	35.1	47.6	71.1	18.9	31.4	54.9	392	-496
Fuel reduction import share (50%)	16.2	34.6	47.1	70.7	18.4	30.9	54.4	392	-496
Fuel reduction import share (100%)	16.2	34.4	46.9	70.4	18.1	30.7	54.2	392	-496
No payback period	18.0	43.6	59.4	89.1	25.6	41.4	71.2	418	-609
24-month payback period	15.9	40.1	54.6	81.9	24.2	38.7	66.0	381	-576
30-month/70k miles payback	15.0	35.6	48.5	72.8	20.6	33.5	57.8	392	-500
36-month payback period	12.2	29.6	40.3	60.4	17.3	28.1	48.2	321	-450
60-month payback period	2.8	11.5	15.5	23.0	8.7	12.7	20.2	80	-165
Implicit opportunity cost	19.9	34.5	47.0	70.5	14.6	27.1	50.7	392	-496
Rebound (5%)	14.9	33.9	46.6	70.6	19.0	31.7	55.7	392	-508
Rebound (15%)	17.6	35.0	47.3	70.5	17.5	29.8	52.9	392	-485
Sales-scrappage response (-0.1)	15.7	35.1	47.8	71.7	19.4	32.1	56.0	392	-502
Sales-scrappage response (-0.5)	16.4	34.3	46.7	70.1	17.9	30.3	53.7	392	-494
Sales-scrappage response (-1)	17.3	33.3	45.4	68.1	15.9	28.0	50.8	392	-484
LD sales (2022 FR)	16.9	35.1	47.9	72.0	18.2	31.0	55.1	391	-473
LD sales (AEO 2023 levels)	16.0	34.3	46.8	70.3	18.3	30.8	54.2	388	-494
LD sales (AEO 2023 growth)	16.3	34.5	47.1	70.7	18.3	30.8	54.4	390	-491
No fleet share price response	16.2	34.8	47.5	71.3	18.7	31.3	55.1	392	-498
Fixed fleet share	16.6	34.9	47.5	71.2	18.3	31.0	54.7	397	-495
Fixed fleet share, no price response	16.5	35.3	48.1	72.0	18.8	31.5	55.5	396	-498
Mass-size-safety (low)	14.8	34.4	46.9	70.4	19.6	32.1	55.7	392	-496

Sensitivity Case	Total Social Costs ($b)	Total Social Benefits ($b)			Net Social Benefits ($b)			MY 2031 Regulatory Cost ($/vehicle)	MY 2031 Lifetime Retail Fuel Expenditure ($/vehicle)
		2.5%	2.0%	1.5%	2.5%	2.0%	1.5%		
Mass-size-safety (high)	17.7	34.5	47.1	70.6	16.9	29.4	52.9	392	-496
Crash avoidance (low)	16.3	34.6	47.1	70.6	18.2	30.8	54.3	392	-496
Crash avoidance (high)	16.2	34.4	46.9	70.4	18.2	30.8	54.3	392	-496
2022 FR fatality rates	16.0	34.0	46.5	70.0	18.0	30.5	54.0	392	-496
AEO 2023 grid forecast	16.2	33.8	46.0	68.8	17.6	29.7	52.6	392	-496
EPA Post-IRA grid forecast	16.2	34.2	46.6	69.9	18.0	30.4	53.7	392	-496
MOVES3 downstream emissions	16.2	34.5	47.0	70.5	18.2	30.8	54.3	392	-496
IWG SC-GHG[258]	16.2	17.9	23.4	27.3	1.7	7.2	11.1	392	-496
Standard-setting conditions for MY 2027-2035	16.8	34.2	46.6	69.9	17.5	29.9	53.2	396	-501
Standard-setting conditions for MY 2027-2050	17.2	33.8	46.0	68.9	16.6	28.8	51.7	396	-500
Standard-setting conditions for MY 2023-2050	5.0	11.5	15.7	23.6	6.5	10.7	18.6	107	-152
Reduced ZEV compliance	16.1	33.9	46.2	69.4	17.8	30.1	53.3	389	-493
PEF (NPRM)	15.9	29.4	39.8	59.6	13.5	24.0	43.7	407	-463
PEF (2022 FR)	10.0	25.7	35.3	53.3	15.7	25.3	43.3	224	-346
No EV tax credits	12.4	30.1	41.3	62.1	17.7	28.8	49.7	312	-449
No AMPC	15.5	36.1	49.3	74.2	20.6	33.9	58.8	372	-517
Consumer tax credit share 75%	14.0	34.0	46.2	69.2	20.0	32.2	55.2	313	-486
Consumer tax credit share 25%	13.9	32.2	44.0	66.3	18.3	30.1	52.4	431	-480
Linear CVC values	16.8	36.2	49.4	74.4	19.3	32.6	57.5	403	-518
Maximum CVC values	9.4	26.0	35.0	51.9	16.6	25.6	42.6	230	-365
NPRM EV tax credits	11.3	28.3	38.3	57.0	17.0	27.0	45.7	312	-473

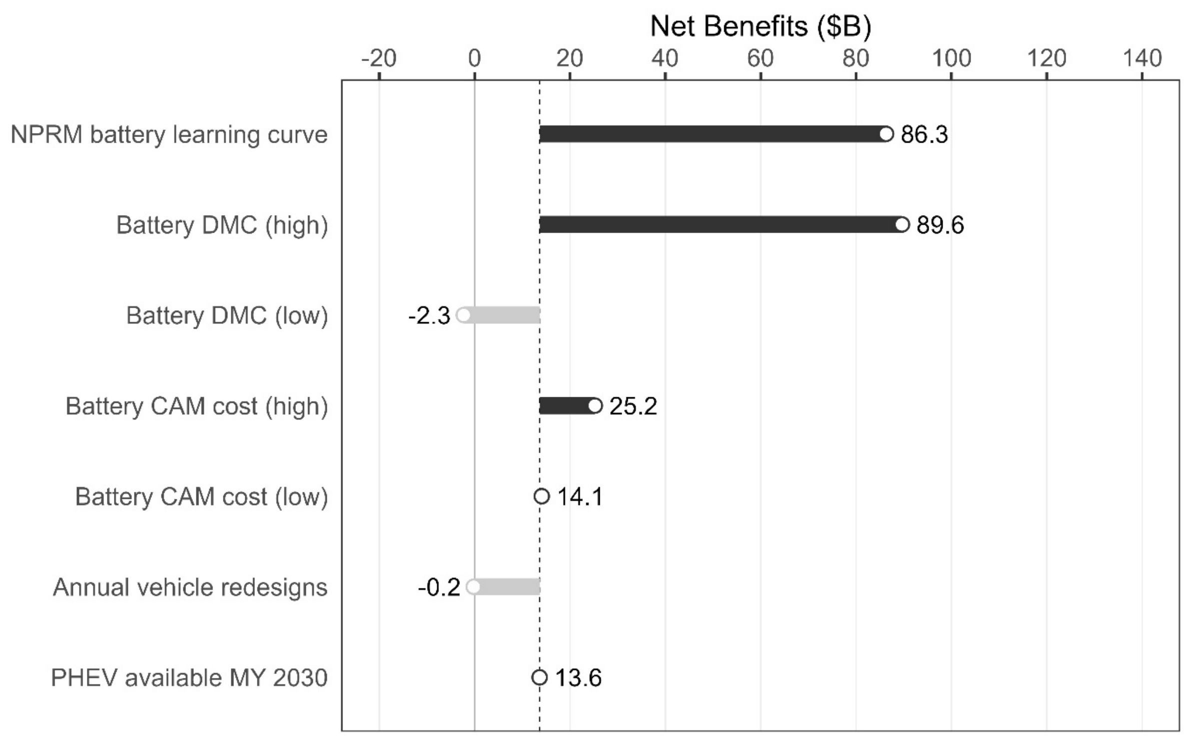
[258] Column headings for SC-GHG differ for this case. For ease of presentation, headings are retained but IWG SC-GHG discount rates are as follows (left to right across columns): 5%, 3%, 2.5%.

9.2.1.2. HDPUV

As in the chapter immediately below, Figure 9-7 through Figure 9-12 illustrate the effect of varying an array of model input assumptions. The axis measuring net benefits is fixed across figures to ease comparison. In the HDPUV context, input assumptions broadly fall into two groupings: those that produce large effects on net benefit estimates and those that result in rather muted outcomes. This differs from the sensitivity analysis outcomes in the light duty fleet. Most of the bimodal nature of these sensitivity case outcomes is the result of the smaller size of the HDPUV fleet and fact that large portions of the fleet respond together. As expected, the scenarios that produce the largest change in net benefits are those that alter determinants of BEV adoption (e.g., battery costs, tax credits, payback period) or those that affect electrification benefits (e.g., oil price forecasts).

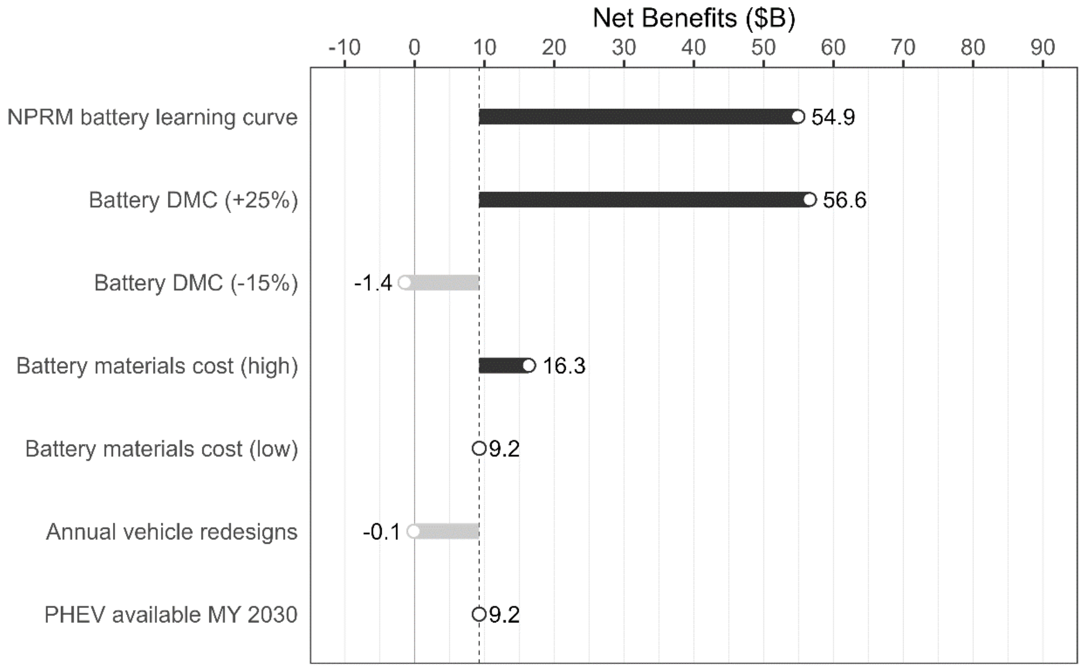
The remaining tables in this chapter mirror those included in the LD chapter above. Table 9-6 and Table 9-7 present the full suite of sensitivity case results and summarize key output measures including fuel consumption and associated emissions, consumer costs and benefits, and aggregate social benefits, costs, and net benefits. Table 9-8 includes reference baseline technology penetration rates for a set of modeled technologies alongside the change in technology penetration rates under the preferred alternative. The table includes some technologies that are more prevalent in the HDPUV fleet and were therefore not included in the LD sensitivity summary. In this table, note that the technology penetration rates for MY 2038 vehicles in the No-Action Alternative are not identical across sensitivity cases because the assumptions in the sensitivity case affects behavior both in the No-Action Alternative and action alternatives, so comparing across scenarios must account for these differences *and* the changes produced by the preferred alternative. Table 9-9 concludes the chapter and presents a subset of the columns of the three preceding tables, but with a social discount rate of seven percent.

Figure 9-7: Net Social Benefits in CY 2022-2050 for the Preferred Alternative (HDPUV108), Technology Assumptions Sensitivity Cases (2021$, 3% Social Discount Rate, 2.0% SC-GHG Discount Rate)



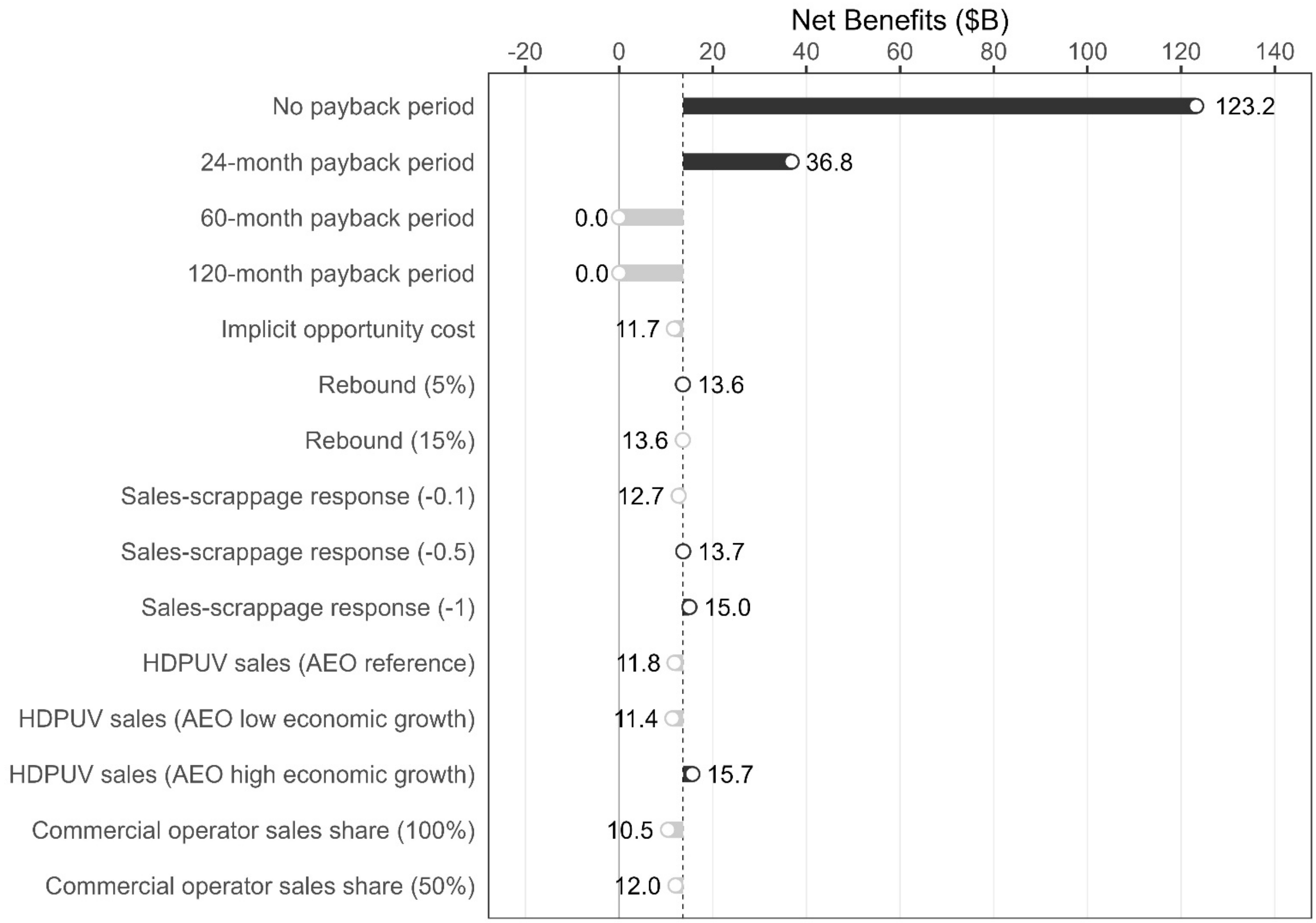
Dashed line indicates reference case net benefits ($13.6 B).

Figure 9-8: Net Social Benefits in CY 2022-2050 for the Preferred Alternative (HDPUV108), Macroeconomic Assumptions Sensitivity Cases (2021$, 3% Social Discount Rate, 2% SC-GHG Discount Rate)



Dashed line indicates reference case net benefits ($9.2 B).

Figure 9-9: Net Social Benefits in CY 2022-2050 for the Preferred Alternative (HDPUV108), Sales and Payback Assumptions Sensitivity Cases (2021$, 3% Social Discount Rate, 2.0% SC-GHG Discount Rate)



Dashed line indicates reference case net benefits ($13.6 B).

Figure 9-10: Net Social Benefits in CY 2022-2050 for the Preferred Alternative (HDPUV108), Social and Environmental Assumptions Sensitivity Cases (2021$, 3% Social Discount Rate, 2.0% SC-GHG Discount Rate)[259]

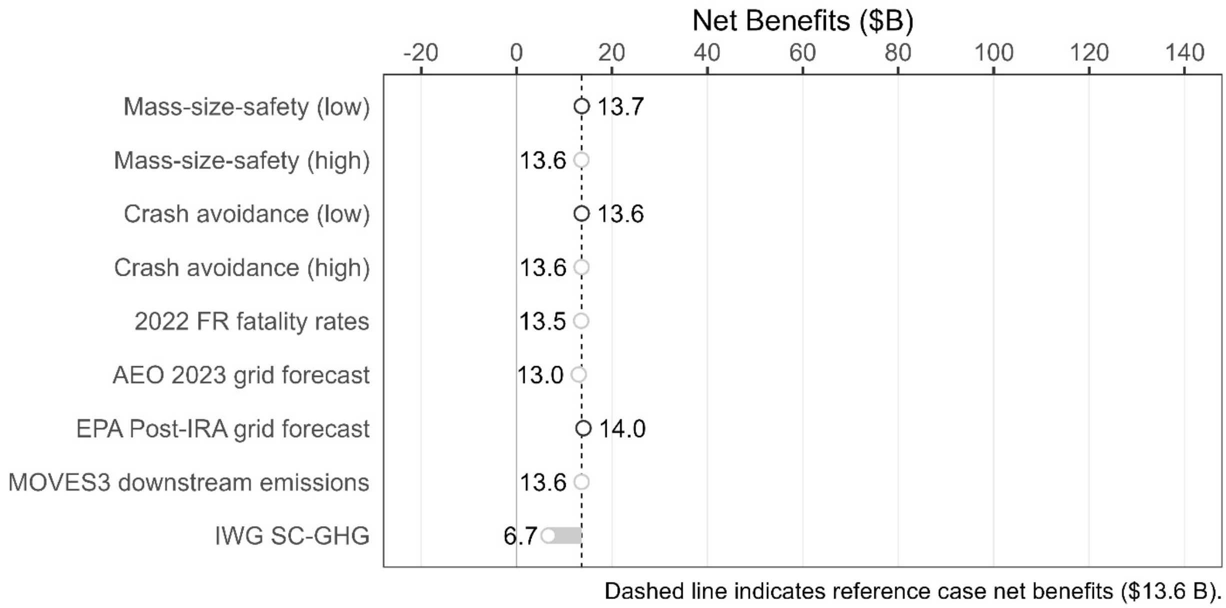
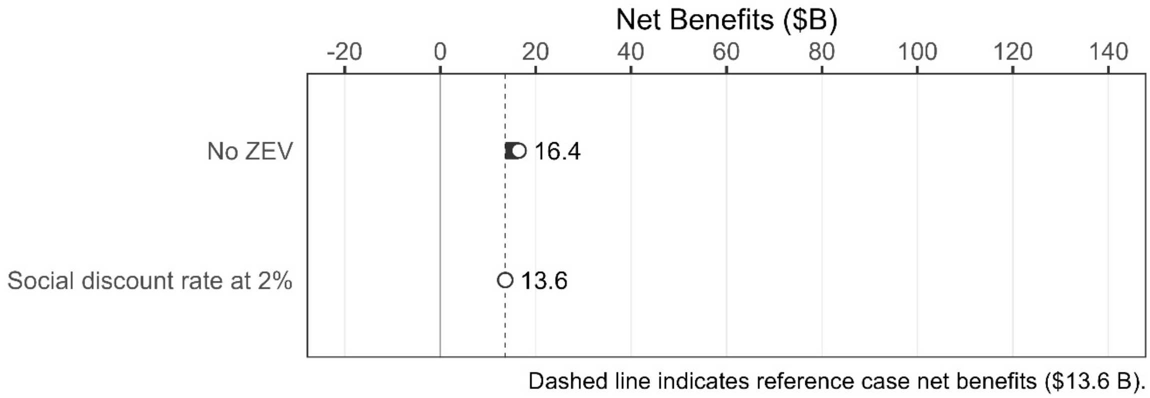
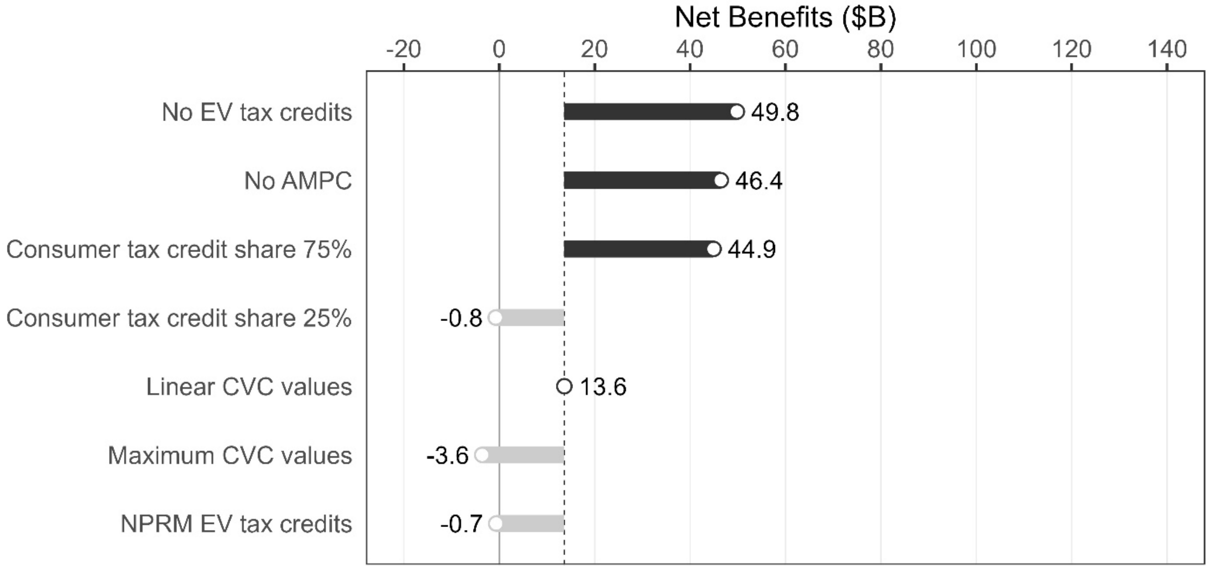


Figure 9-11: Net Social Benefits in CY 2022-2050 for the Preferred Alternative (HDPUV108), Policy Assumptions Sensitivity Cases (2021$, 3% Social Discount Rate, 2.0% SC-GHG Discount Rate)



[259] IWG SC-GHG results based on a 2.5% SC-GHG discount rate.

Figure 9-12: Net Social Benefits in CY 2022-2050 for the Preferred Alternative (HDPUV108), EV Tax Credit Assumptions Sensitivity Cases (2021$, 3% Social Discount Rate, 2.0% SC-GHG Discount Rate)



Dashed line indicates reference case net benefits ($13.6 B).

Table 9-6: Aggregate HDPUV Fleet Costs and Benefits in CY 2022-2050 for the Preferred Alternative (HDPUV108), by Sensitivity Case (2021$, 3% Discount Rate, SC-GHG Discount Rate as Noted in Column Headings)

Sensitivity Case	Total Social Costs ($b)	Total Social Benefits ($b)			Net Social Benefits ($b)		
		2.5%	2.0%	1.5%	2.5%	2.0%	1.5%
Reference baseline	3.40	12.64	17.03	25.31	9.24	13.62	21.91
NPRM battery learning curve	23.63	78.53	109.93	169.19	54.90	86.30	145.56
Battery DMC high	24.80	81.36	114.44	176.88	56.55	89.64	152.07
Battery DMC low	-0.58	-1.98	-2.87	-4.55	-1.40	-2.29	-3.97
Battery CAM cost (high)	6.66	22.98	31.87	48.63	16.32	25.21	41.97
Battery CAM cost (low)	3.50	12.75	17.58	26.69	9.25	14.08	23.18
Annual vehicle redesigns	-0.09	-0.21	-0.29	-0.45	-0.12	-0.20	-0.36
PHEV available MY 2030	3.40	12.64	17.03	25.31	9.24	13.62	21.91
Oil price (high)	0.21	0.60	0.98	1.69	0.38	0.76	1.48
Oil price (low)	22.08	74.17	115.64	193.91	52.09	93.56	171.84
GDP (high)	3.97	14.50	19.61	29.25	10.53	15.64	25.28
GDP (low)	2.84	10.63	14.24	21.07	7.79	11.41	18.24
GDP + fuel (high)	3.89	14.28	19.09	28.18	10.38	15.20	24.29
GDP + fuel (low)	3.48	12.64	17.34	26.22	9.17	13.86	22.74
Oil market externalities (low)	3.40	12.34	16.72	25.01	8.93	13.32	21.60
Oil market externalities (high)	3.40	13.03	17.41	25.70	9.62	14.01	22.29
Fuel reduction import share (50%)	3.40	12.74	17.12	25.41	9.33	13.72	22.00
Fuel reduction import share (100%)	3.40	12.58	16.97	25.25	9.18	13.56	21.85
No payback period	30.44	109.26	153.65	237.45	78.82	123.21	207.01
24-month payback period	9.17	33.11	46.01	70.33	23.94	36.84	61.16
60-month payback period	-0.01	0.00	-0.04	-0.10	0.01	-0.03	-0.10
120-month payback period	0.03	0.04	0.06	0.10	0.02	0.04	0.07
Implicit opportunity cost	5.33	12.64	17.03	25.31	7.31	11.70	19.98

Sensitivity Case	Total Social Costs ($b)	Total Social Benefits ($b)			Net Social Benefits ($b)		
		2.5%	2.0%	1.5%	2.5%	2.0%	1.5%
Rebound (5%)	3.31	12.56	16.94	25.23	9.25	13.64	21.92
Rebound (15%)	3.50	12.73	17.11	25.40	9.23	13.61	21.89
Sales-scrappage response (-0.1)	3.68	12.17	16.41	24.41	8.49	12.73	20.73
Sales-scrappage response (-0.5)	3.24	12.57	16.95	25.23	9.33	13.71	21.98
Sales-scrappage response (-1)	2.72	13.22	17.74	26.29	10.50	15.02	23.57
HDPUV sales (AEO reference)	2.97	10.99	14.81	22.02	8.02	11.84	19.05
HDPUV sales (AEO low economic growth)	2.84	10.62	14.23	21.05	7.78	11.39	18.21
HDPUV sales (AEO high economic growth)	3.97	14.52	19.63	29.28	10.55	15.66	25.31
Commercial operator sales share (100%)	6.58	12.64	17.03	25.31	6.07	10.45	18.74
Commercial operator sales share (50%)	4.99	12.64	17.03	25.31	7.65	12.04	20.32
Mass-size-safety (low)	3.38	12.66	17.04	25.33	9.28	13.66	21.95
Mass-size-safety (high)	3.43	12.63	17.02	25.30	9.20	13.59	21.87
Crash avoidance (low)	3.39	12.65	17.04	25.32	9.26	13.64	21.93
Crash avoidance (high)	3.41	12.64	17.02	25.31	9.23	13.61	21.90
2022 FR fatality rates	3.46	12.61	16.99	25.28	9.15	13.53	21.82
AEO 2023 grid forecast	3.40	12.26	16.43	24.32	8.85	13.03	20.92
EPA Post-IRA grid forecast	3.40	12.91	17.43	25.97	9.50	14.02	22.56
MOVES3 downstream emissions	3.40	12.64	17.03	25.31	9.24	13.62	21.90
IWG SC-GHG[260]	3.40	6.94	8.77	10.10	3.53	5.37	6.69
No ZEV	4.24	15.29	20.68	30.85	11.05	16.44	26.61
Social discount rate at 2%	4.17	14.22	18.60	26.89	10.05	14.44	22.72
No EV tax credits	12.45	44.51	62.26	95.71	32.06	49.81	83.26
No AMPC	12.22	41.39	58.65	91.14	29.17	46.43	78.92

[260] Column headings for SC-GHG differ for this case. For ease of presentation, headings are retained but IWG SC-GHG discount rates are as follows (left to right across columns): 5%, 3%, 2.5%.

Sensitivity Case	Total Social Costs ($b)	Total Social Benefits ($b)			Net Social Benefits ($b)		
		2.5%	2.0%	1.5%	2.5%	2.0%	1.5%
Consumer tax credit share 75%	12.05	40.25	56.97	88.45	28.20	44.92	76.40
Consumer tax credit share 25%	-0.28	-0.76	-1.04	-1.57	-0.48	-0.76	-1.29
Linear CVC values	3.40	12.64	17.03	25.31	9.24	13.62	21.91
Maximum CVC values	-1.01	-3.17	-4.60	-7.28	-2.16	-3.59	-6.27
NPRM EV tax credits	-0.25	-0.63	-0.91	-1.44	-0.38	-0.66	-1.19

Table 9-7: Selected HDPUV Fleet Model Metrics for the Preferred Alternative (HDPUV108), by Sensitivity Case (2021$, 3% Discount Rate)[261]

Sensitivity Case	Gasoline Consumption (b.gal)	Electricity Consumption (TWh)	CO_2 Emissions (MMT)	Fatalities	Criteria Emissions Deaths	MY 2038 Regulatory Cost ($/vehicle)	MY 2038 Lifetime Retail Fuel Expenditure ($/vehicle)	MY 2038 Sales	MY 2038 Jobs
Reference baseline	-6	56	-55	-6	-81	226	-717	-1,124	-36
NPRM battery learning curve	-40	382	-393	-47	-600	1,582	-5,092	-7,983	-251
Battery DMC high	-42	411	-414	-47	-629	1,537	-5,078	-7,479	-235
Battery DMC low	1	-12	11	-1	19	-26	172	-3	0
Battery CAM cost (high)	-11	111	-111	-8	-171	273	-944	-1,216	-40
Battery CAM cost (low)	-6	63	-60	-5	-90	205	-718	-902	-29
Annual vehicle redesigns	0	-1	1	0	2	2	-9	-13	-1
PHEV available MY 2030	-6	56	-55	-6	-81	226	-717	-1,124	-36
Oil price (high)	0	6	-5	6	-9	-19	-160	410	13
Oil price (low)	-53	466	-519	-139	-766	1,203	-3,255	-7,347	-231
GDP (high)	-7	65	-64	-6	-95	223	-708	-1,204	-38
GDP (low)	-5	46	-45	-5	-66	207	-627	-919	-29

[261] Values for CY 2022-2050 unless otherwise noted.

Sensitivity Case	Gasoline Consumption (b.gal)	Electricity Consumption (TWh)	CO_2 Emissions (MMT)	Fatalities	Criteria Emissions Deaths	MY 2038 Regulatory Cost ($/vehicle)	MY 2038 Lifetime Retail Fuel Expenditure ($/vehicle)	MY 2038 Sales	MY 2038 Jobs
GDP + fuel (high)	-6	58	-60	-4	-85	237	-768	-1,078	-35
GDP + fuel (low)	-6	60	-59	-6	-88	227	-702	-1,012	-32
Oil market externalities (low)	-6	56	-55	-6	-81	226	-717	-1,124	-36
Oil market externalities (high)	-6	56	-55	-6	-81	226	-717	-1,124	-36
Fuel reduction import share (50%)	-6	56	-55	-6	-99	226	-717	-1,124	-36
Fuel reduction import share (100%)	-6	56	-55	-6	-69	226	-717	-1,124	-36
No payback period	-57	504	-556	55	-785	1,243	-6,486	-2,314	-73
24-month payback period	-16	149	-161	-11	-245	531	-2,244	-1,616	-52
60-month payback period	0	-1	0	0	1	-2	-14	51	2
120-month payback period	0	0	0	0	-1	5	2	-57	-2
Implicit opportunity cost	-6	56	-55	-6	-81	226	-717	-1,124	-36
Rebound (5%)	-6	55	-55	-9	-81	226	-720	-1,124	-36
Rebound (15%)	-6	56	-55	-3	-81	226	-713	-1,124	-36
Sales-scrappage response (-0.1)	-5	55	-53	4	-77	226	-719	-274	-9
Sales-scrappage response (-0.5)	-6	56	-55	-10	-81	224	-714	-1,384	-45
Sales-scrappage response (-1)	-6	54	-57	-26	-85	226	-715	-2,808	-90
HDPUV sales (AEO reference)	-5	49	-48	-5	-71	224	-712	-965	-32
HDPUV sales (AEO low economic growth)	-5	46	-45	-5	-66	207	-625	-919	-29
HDPUV sales (AEO high economic growth)	-7	65	-64	-6	-96	223	-709	-1,204	-38
Commercial operator sales share (100%)	-6	56	-55	-6	-81	226	-717	-1,124	-36
Commercial operator sales share (50%)	-6	56	-55	-6	-81	226	-717	-1,124	-36

Sensitivity Case	Gasoline Consumption (b.gal)	Electricity Consumption (TWh)	CO_2 Emissions (MMT)	Fatalities	Criteria Emissions Deaths	MY 2038 Regulatory Cost ($/vehicle)	MY 2038 Lifetime Retail Fuel Expenditure ($/vehicle)	MY 2038 Sales	MY 2038 Jobs
Mass-size-safety (low)	-6	56	-55	-7	-81	226	-717	-1,124	-36
Mass-size-safety (high)	-6	56	-55	-5	-81	226	-717	-1,124	-36
Crash avoidance (low)	-6	56	-55	-6	-81	226	-717	-1,124	-36
Crash avoidance (high)	-6	56	-55	-6	-81	226	-717	-1,124	-36
2022 FR fatality rates	-6	56	-55	-4	-81	226	-717	-1,124	-36
AEO 2023 grid forecast	-6	56	-52	-6	-66	226	-717	-1,124	-36
EPA Post-IRA grid forecast	-6	56	-57	-6	-96	226	-717	-1,124	-36
MOVES3 downstream emissions	-6	56	-55	-6	-82	226	-717	-1,124	-36
IWG SC-GHG	-6	56	-55	-6	-81	226	-717	-1,124	-36
No ZEV	-7	65	-68	-5	-98	267	-874	-1,277	-41
Social discount rate at 2%	-6	56	-55	-6	-81	226	-717	-1,124	-36
No EV tax credits	-23	218	-221	-12	-337	471	-2,032	-1,418	-46
No AMPC	-22	218	-215	-8	-350	246	-1,080	-735	-23
Consumer tax credit share 75%	-21	212	-208	4	-326	374	-1,731	-894	-28
Consumer tax credit share 25%	0	-4	3	0	7	-8	18	17	1
Linear CVC values	-6	56	-55	-6	-81	226	-717	-1,124	-36
Maximum CVC values	2	-19	18	0	31	-46	234	100	4
NPRM EV tax credits	0	-4	3	0	6	-3	10	-6	0

Table 9-8: HDPUV Fleet Penetration Rates of Selected Technologies for the Preferred Alternative (HDPUV108), by Sensitivity Case (Percent, MY 2038)

Sensitivity Case	Advanced Transmissions		Advanced Gas Engines		Mild Hybrid		SHEV		PHEV		BEV	
	No Action	Change	No Action	Change	No Action	Change	No Action	Change	No Action	Change	No Action	Change
Reference baseline	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
NPRM battery learning curve	48.8	-24.1	48.8	-24.1	1.2	+4.4	39.1	+1.7	0.1	+9.5	12.0	+12.8
Battery DMC high	48.8	-21.0	48.8	-21.0	1.4	+6.3	38.3	-1.8	0.1	+8.8	12.8	+14.0
Battery DMC low	10.4	+0.6	10.4	+0.6	1.2	0	13.5	+0.2	29.1	0	47.0	-0.7
Battery CAM cost (high)	24.0	-3.7	24.0	-3.7	1.2	+4.9	36.8	-1.0	0.2	+3.9	39.0	+0.9
Battery CAM cost (low)	21.9	-2.8	21.9	-2.8	1.2	-0.9	29.4	-1.0	7.1	+2.9	41.6	+0.9
Annual vehicle redesigns	18.0	0	18.0	0	0	0	27.3	0	9.7	0	45.0	0
PHEV available MY 2030	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
Oil price (high)	0.1	-0.1	0.1	-0.1	0	0	0	0	53.8	-1.1	46.0	+1.2
Oil price (low)	48.8	-21.6	14.8	+4.8	8.0	+5.7	38.3	-1.1	0	+4.7	12.9	+18.0
GDP (high)	22.8	-3.1	22.8	-3.1	1.2	-0.9	36.8	-1.0	0.3	+4.1	40.1	0
GDP (low)	22.5	-2.7	22.5	-2.7	1.2	-1.0	36.8	-1.0	0.2	+4.1	40.5	-0.4
GDP + fuel (high)	22.8	-2.8	22.8	-2.8	1.2	+5.0	36.4	-1.0	0.3	+3.8	40.4	+0.1
GDP + fuel (low)	23.1	-3.2	23.1	-3.2	1.2	-1.0	36.8	-1.0	0.2	+4.1	39.8	+0.1
Oil market externalities (low)	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
Oil market externalities (high)	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
Fuel reduction import share (50%)	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
Fuel reduction import share (100%)	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0

Sensitivity Case	Advanced Transmissions		Advanced Gas Engines		Mild Hybrid		SHEV		PHEV		BEV	
	No Action	Change	No Action	Change	No Action	Change	No Action	Change	No Action	Change	No Action	Change
No payback period	30.8	-4.1	11.5	-5.6	12.6	-4.7	38.6	-3.0	0.1	+7.8	11.3	+17.6
24-month payback period	28.7	-8.4	17.6	+2.7	6.0	-0.4	37.0	-1.0	0.1	+3.8	34.2	+5.6
60-month payback period	0.1	0	0.1	0	0	0	0.2	0	53.5	-0.2	46.1	+0.2
120-month payback period	0	0	0	0	0	0	0	0	55.4	0	44.6	0
Implicit opportunity cost	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
Rebound (5%)	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
Rebound (15%)	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
Sales-scrappage response (-0.1)	22.9	-3.1	22.9	-3.1	1.2	-0.4	36.8	-1.0	0.3	+4.1	40.1	0
Sales-scrappage response (-0.5)	22.9	-3.1	22.9	-3.1	1.2	-1.0	36.8	-1.0	0.3	+4.0	40.1	+0.1
Sales-scrappage response (-1)	22.9	-3.1	22.9	-3.1	1.2	-0.5	36.8	-1.0	0.3	+4.1	40.1	0
HDPUV sales (AEO reference)	22.9	-3.1	22.9	-3.1	1.2	-1.0	36.8	-1.0	0.3	+4.1	40.1	0
HDPUV sales (AEO low economic growth)	22.5	-2.7	22.5	-2.7	1.2	-1.0	36.8	-1.0	0.2	+4.1	40.5	-0.4
HDPUV sales (AEO high economic growth)	22.8	-3.1	22.8	-3.1	1.2	-0.9	36.8	-1.0	0.3	+4.1	40.1	0
Commercial operator sales share (100%)	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
Commercial operator sales share (50%)	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
Mass-size-safety (low)	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
Mass-size-safety (high)	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0

Sensitivity Case	Advanced Transmissions		Advanced Gas Engines		Mild Hybrid		SHEV		PHEV		BEV	
	No Action	Change	No Action	Change	No Action	Change	No Action	Change	No Action	Change	No Action	Change
Crash avoidance (low)	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
Crash avoidance (high)	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
2022 FR fatality rates	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
AEO 2023 grid forecast	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
EPA Post-IRA grid forecast	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
MOVES3 downstream emissions	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
IWG SC-GHG	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
No ZEV	23.4	-3.6	23.4	-3.6	1.2	+4.6	36.8	-1.0	0.2	+4.2	39.6	+0.3
Social discount rate at 2%	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
No EV tax credits	22.8	-8.1	22.8	-8.1	1.2	+3.6	36.9	-1.0	0.2	+5.2	40.1	+3.8
No AMPC	22.9	-4.4	22.9	-4.4	1.2	+3.9	36.7	-1.0	0.2	+3.9	40.2	+1.5
Consumer tax credit share 75%	23.1	-6.7	23.1	-6.7	1.2	+5.0	36.7	-1.0	0.2	+3.8	40.0	+3.8
Consumer tax credit share 25%	8.9	+0.1	8.9	+0.1	0	0	5.7	+0.1	39.7	-0.2	45.8	0
Linear CVC values	22.9	-3.1	22.9	-3.1	1.2	-0.3	36.8	-1.0	0.3	+4.1	40.1	0
Maximum CVC values	12.8	+1.0	12.8	+1.0	1.2	0	13.9	+0.2	28.9	0	44.4	-1.1
NPRM EV tax credits	18.6	0	18.6	0	1.2	0	14.0	+0.1	22.8	0	44.6	-0.1

Table 9-9: Aggregate HDPUV Fleet Costs and Benefits in CY 2022-2050 for the Preferred Alternative (HDPUV108), by Sensitivity Case (2021$, 7% Discount Rate, SC-GHG Discount Rate as Noted in Column Headings)

Sensitivity Case	Total Social Costs ($b)	Total Social Benefits ($b)			Net Social Benefits ($b)			MY 2038 Regulatory Cost ($/vehicle)	MY 2038 Lifetime Retail Fuel Expenditure ($/vehicle)
		2.5%	2.0%	1.5%	2.5%	2.0%	1.5%		
Reference baseline	1.58	8.99	13.38	21.66	7.41	11.80	20.08	226	-552
NPRM battery learning curve	12.02	59.93	91.34	150.59	47.91	79.31	138.57	1,582	-3,923
Battery DMC high	12.43	62.41	95.49	157.93	49.99	83.07	145.51	1,537	-3,911
Battery DMC low	-0.32	-1.63	-2.52	-4.20	-1.31	-2.20	-3.87	-26	132
Battery CAM cost (high)	3.40	17.36	26.24	43.00	13.96	22.84	39.60	273	-727
Battery CAM cost (low)	1.73	9.49	14.31	23.42	7.76	12.58	21.69	205	-553
Annual vehicle redesigns	-0.06	-0.17	-0.26	-0.42	-0.11	-0.20	-0.36	2	-7
PHEV available MY 2030	1.58	8.99	13.38	21.66	7.41	11.80	20.08	226	-552
Oil price (high)	0.09	0.57	0.95	1.67	0.48	0.86	1.57	-19	-124
Oil price (low)	11.11	65.82	107.30	185.57	54.71	96.18	174.46	1,203	-2,501
GDP (high)	1.88	10.40	15.51	25.15	8.53	13.63	23.27	223	-545
GDP (low)	1.31	7.50	11.11	17.94	6.19	9.80	16.63	207	-483
GDP + fuel (high)	1.81	10.06	14.88	23.97	8.25	13.06	22.16	237	-594
GDP + fuel (low)	1.66	9.29	13.99	22.86	7.63	12.33	21.20	227	-544
Oil market externalities (low)	1.58	8.86	13.25	21.53	7.28	11.66	19.95	226	-552
Oil market externalities (high)	1.58	9.16	13.54	21.83	7.57	11.96	20.24	226	-552
Fuel reduction import share (50%)	1.58	9.03	13.41	21.70	7.45	11.83	20.12	226	-552
Fuel reduction import share (100%)	1.58	8.97	13.36	21.64	7.39	11.77	20.06	226	-552
No payback period	14.80	83.90	128.30	212.09	69.10	113.50	197.29	1,243	-4,999
24-month payback period	4.64	25.06	37.95	62.28	20.42	33.32	57.64	531	-1,730
60-month payback period	0.00	-0.02	-0.06	-0.12	-0.02	-0.05	-0.12	-2	-11
120-month payback period	0.01	0.03	0.05	0.09	0.02	0.04	0.07	5	2

Sensitivity Case	Total Social Costs ($b)	Total Social Benefits ($b)			Net Social Benefits ($b)			MY 2038 Regulatory Cost ($/vehicle)	MY 2038 Lifetime Retail Fuel Expenditure ($/vehicle)
		2.5%	2.0%	1.5%	2.5%	2.0%	1.5%		
Implicit opportunity cost	2.34	8.99	13.38	21.66	6.65	11.04	19.32	226	-552
Rebound (5%)	1.54	8.96	13.34	21.63	7.42	11.80	20.09	226	-555
Rebound (15%)	1.62	9.03	13.41	21.70	7.41	11.79	20.07	226	-549
Sales-scrappage response (-0.1)	1.69	8.66	12.89	20.90	6.97	11.20	19.20	226	-554
Sales-scrappage response (-0.5)	1.51	8.96	13.34	21.62	7.45	11.83	20.10	224	-550
Sales-scrappage response (-1)	1.28	9.36	13.88	22.43	8.08	12.60	21.15	226	-551
HDPUV sales (AEO reference)	1.39	7.83	11.65	18.86	6.44	10.26	17.48	224	-549
HDPUV sales (AEO low economic growth)	1.31	7.49	11.10	17.92	6.18	9.79	16.61	207	-482
HDPUV sales (AEO high economic growth)	1.88	10.42	15.53	25.18	8.54	13.65	23.30	223	-546
Commercial operator sales share (100%)	2.84	8.99	13.38	21.66	6.16	10.54	18.83	226	-552
Commercial operator sales share (50%)	2.21	8.99	13.38	21.66	6.78	11.17	19.45	226	-552
Mass-size-safety (low)	1.57	9.00	13.38	21.67	7.43	11.81	20.10	226	-552
Mass-size-safety (high)	1.59	8.99	13.37	21.66	7.39	11.78	20.06	226	-552
Crash avoidance (low)	1.58	9.00	13.38	21.67	7.42	11.80	20.09	226	-552
Crash avoidance (high)	1.58	8.99	13.38	21.66	7.41	11.79	20.08	226	-552
2022 FR fatality rates	1.61	8.98	13.36	21.65	7.37	11.76	20.04	226	-552
AEO 2023 grid forecast	1.58	8.66	12.83	20.72	7.07	11.25	19.14	226	-552
EPA Post-IRA grid forecast	1.58	9.21	13.73	22.26	7.63	12.14	20.68	226	-552
MOVES3 downstream emissions	1.58	8.99	13.37	21.65	7.41	11.79	20.07	226	-552
IWG SC-GHG[262]	1.58	3.29	5.12	6.45	1.70	3.54	4.86	226	-552

[262] Column headings for SC-GHG differ for this case. For ease of presentation, headings are retained but IWG SC-GHG discount rates are as follows (left to right across columns): 5%, 3%, 2.5%.

Sensitivity Case	Total Social Costs ($b)	Total Social Benefits ($b)			Net Social Benefits ($b)			MY 2038 Regulatory Cost ($/vehicle)	MY 2038 Lifetime Retail Fuel Expenditure ($/vehicle)
		2.5%	2.0%	1.5%	2.5%	2.0%	1.5%		
No ZEV	2.01	10.98	16.37	26.54	8.97	14.35	24.53	267	-674
No EV tax credits	6.62	34.38	52.14	85.58	27.76	45.51	78.96	471	-1,566
No AMPC	6.79	32.81	50.07	82.56	26.02	43.28	75.77	246	-832
Consumer tax credit share 75%	6.53	31.74	48.46	79.94	25.21	41.93	73.41	374	-1,334
Consumer tax credit share 25%	-0.17	-0.59	-0.87	-1.40	-0.42	-0.70	-1.23	-8	14
Linear CVC values	1.58	8.99	13.38	21.66	7.41	11.80	20.08	226	-552
Maximum CVC values	-0.58	-2.61	-4.04	-6.73	-2.03	-3.46	-6.15	-46	180
NPRM EV tax credits	-0.16	-0.53	-0.82	-1.34	-0.37	-0.65	-1.18	-3	8

9.2.2. Effect of Technology-Related Parameters

9.2.2.1. Redesign Schedules

Vehicle manufacturers establish redesign schedules for their vehicles by considering the availability of capital and other resources, competitive position in certain market segments, the sales volume for each vehicle model, and the influence of regulatory requirements. As discussed in preamble Section III.C and in Chapter 9.1 in this FRIA, NHTSA used an informed, historical review of redesign and refresh intervals to estimate 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, supply change disruption as observed by COVID-19, or a manufacturer's capital availability, among other factors. To test an extreme case of redesign flexibility, one sensitivity allowed for annual vehicle redesigns, meaning each vehicle in the analysis fleet could be redesigned in each model year. In this setting, the pool of available vehicle and technology combinations is significantly greater for each manufacturer because there are more opportunities for vehicle redesigns than in the reference baseline. This increases the likelihood that the CAFE Model optimizes technology solutions for a given set of parameters in each model year. More rapid redesigns therefore allow manufacturers to hew closer to the regulatory requirements. In reality, manufacturers must overshoot compliance by applying more expensive technology with the knowledge that they will be unable to apply new technology for several years until the next refresh or redesign. The CAFE Model simulates this behavior by considering technology candidates from the most recent redesign, thus retroactively applying technology if it is determined to be the most cost-effective way to reach compliance (See CAFE Model Documentation S5.3.2).

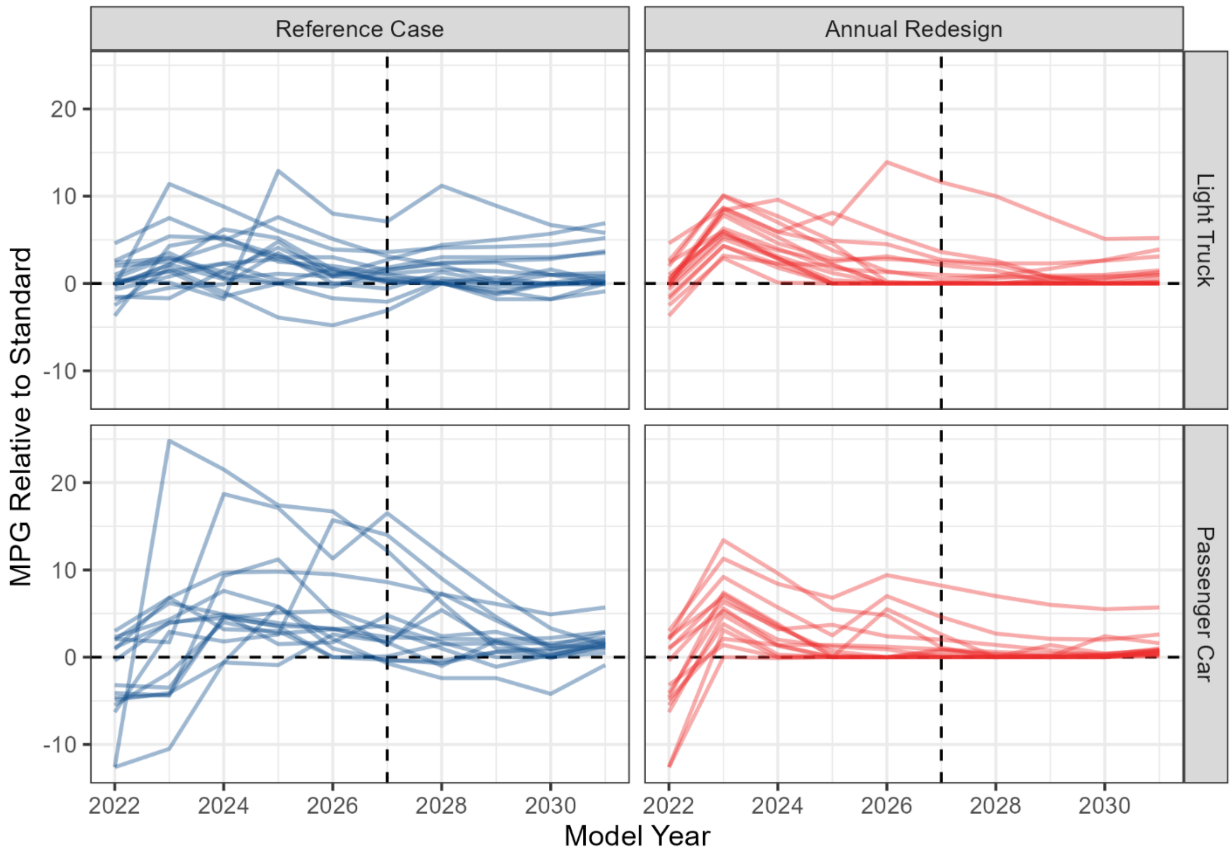
However, we caution that this sensitivity is a narrowly-focused test of model logic and that the underlying assumption of rapid redesign in this sensitivity case is unrealistic; manufacturers have historically required multiple years of development between redesigns and refreshes. Additionally, this case does not account for the costs of stranded capital from such high frequency redesigns, 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. Manufacturers control the redesign schedules for their own vehicles and the fact that they still require multiple years despite the potential benefits points to there being real technical, practical, and economic obstacles to doing so.

The impact of annual redesign compared to the RB results in a:

- $7.0 billion dollar decrease in Social Costs, a $5.5 billion dollar decrease in social benefits, and a $1.5 billion dollar increase in net social benefits.
- 3.4 percent increase in the number of SHEVs and PHEVs in MY 2031.
- $165 reduction in regulatory costs per vehicle.

Figure 9-13 below shows the compliance status for each manufacturer by model year across regulatory classes. The left panels show the reference baseline, and the right panels show the annual redesign sensitivity case. In the reference baseline, manufacturers will over or under-comply with the standard as they deplete, bank, or spend credits prior to the standard-setting years. Overall, most manufacturers must over-comply ahead of increases in the CAFE standard. In contrast, for the annual redesigns, most manufacturers are extremely close to the MPG standard, with no manufacturers failing to meet the standard (and thus paying fines). Thus, for regulatory years where the CAFE standard increases, annual redesigns predict lower (but still compliant) fuel economy as manufacturers apply the bare minimum of technology every year to meet the standard. All of the changes in results from the reference baseline are expected for this unrealistic sensitivity.

Figure 9-13: Compliance Paths for Reference and Annual Redesign Sensitivity Cases



Each line represents a manufacturer's compliance path.
Presentation omits instances of high overcompliance:
Tesla, Rivian, Lucid, and Karma for PC and LT, Subaru and Volvo for PC.

9.2.2.2. Battery Costs

Sensitivity results in Table 9-1 and Table 9-2 include several battery cost-related cases: direct costs of batteries, battery costs that consider high and low values of cathode active material costs, as well as battery learning rate assumptions from the NPRM. Note that for this final rule, unlike the NPRM, our battery learning curve is based on a battery cost study/report by DOE/Argonne,[263] which stems from interagency coordination between NHTSA, EPA, and DOE/Argonne. For more information on our reference baseline learning curve, please see TSD Chapter 3.3.5.3 and preamble Section III.D.3 (Electrification).

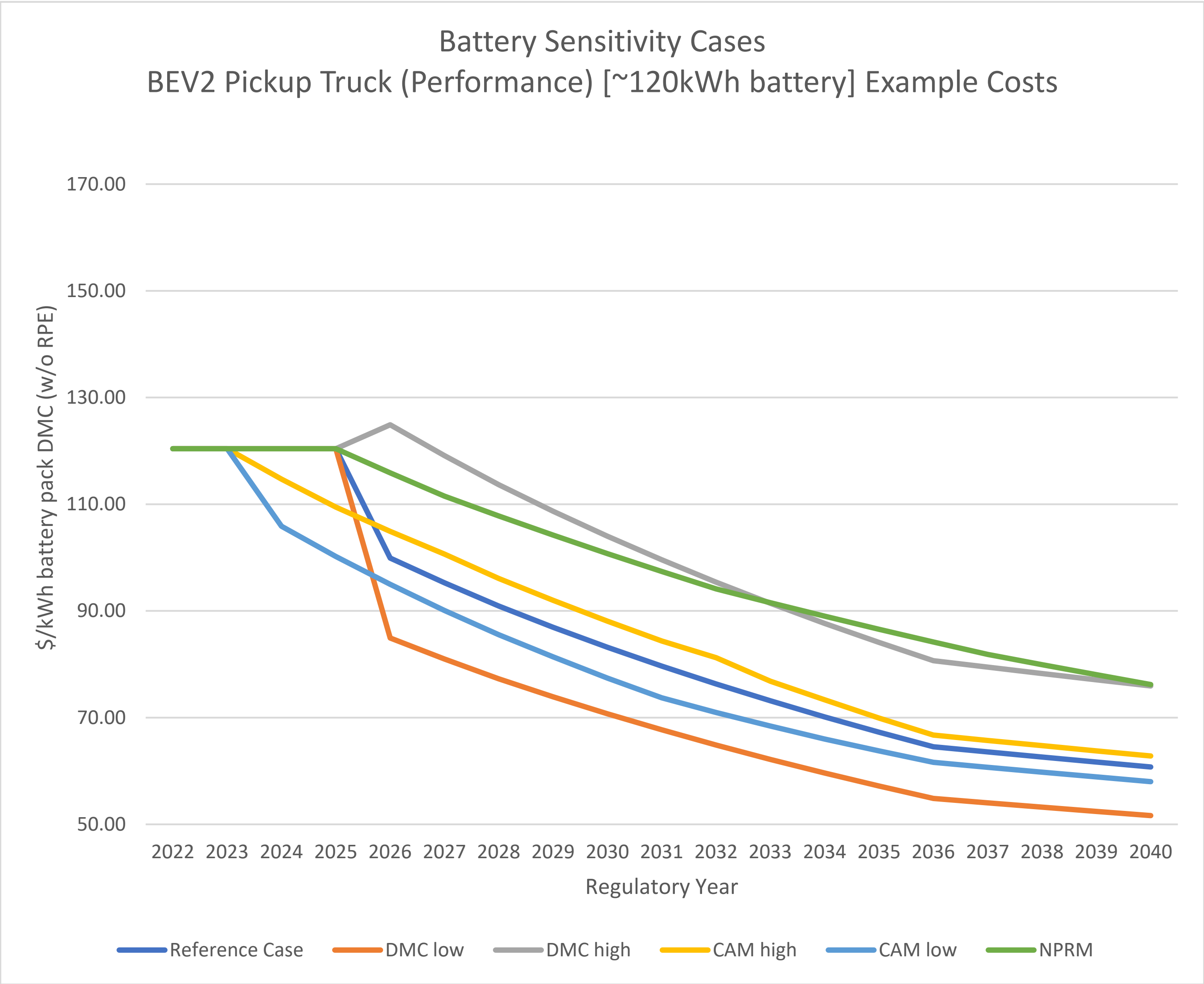
Based on our literature review of projected battery pack costs from other sources, discussed in TSD Chapter 3.3.5.3, in addition to comments from stakeholders and interagency discussions with DOE and EPA, we determined that exploring sensitivity cases to examine the impacts of increasing and decreasing the direct manufacturing cost (DMC) of batteries (by +25/-15 percent) as well as high and low cathode active material (CAM) cost values (in contrast from their average levels in the reference baseline) was reasonable.

Figure 9-14 below includes indexed cost values for battery cost trajectories under all battery cost sensitivity scenarios along with the Reference Baseline (RB) for a non-performance midsize passenger car BEV2 with a 120-kWh battery-pack. The measure presented in the figure is BEV3 battery cost, equivalent to the MY 2022 battery pack cost (produced in CY 2021). The curves in the graph illustrate the differences in the battery cases over time. The sensitivities related to battery direct costs (+25/-15 percent – referenced further as DMC high and DMC low, respectively) are a fixed ratio of the reference cost values. Cost ratio is not fixed, however, for the CAM high/low-cost cases; the mineral costs (per kWh), provided by Argonne and based on

[263] ANL. 2024. Cost Analysis and Projections for U.S.-Manufactured Automotive Lithium-ion Batteries. ANL/CSE-24/1. Available at: https://publications.anl.gov/anlpubs/2024/01/187177.pdf. (Accessed: March 12, 2024).

expert projections,[264] are distinct for NMC battery packs and LFP battery packs and are unique for each year between MY 2023 and MY 2035. Also, since the NMC/LFP market mix changes over the course of the rulemaking, so does the contributing mineral cost for a specific pack. Learning cost scenarios, as with the NPRM battery learning curve (BLC) case, gradually deviate from the reference level.

Figure 9-14: Battery Cost Sensitivity Cases



Technology Penetration - In the LD fleet, across battery sensitivity cases (and the RB), the DMC high case resulted in highest PHEV penetration under the Preferred Alternative at 5.8% of the fleet; the DMC high case also resulted in 1.7% PHEV penetration under No Action. The highest PHEV penetration case under No Action was the NPRM BLC at 1.9% penetration, and 5.4% penetration under the Preferred Alternative. In contrast, the CAM low case reduced PHEVs to 0.5% of the LD fleet under No Action and 4.3% under the Preferred Alternative. Similarly, the DMC low case resulted in 4.3% PHEV penetration under the Preferred Alternative with a No Action penetration of 1.6%. The RB resulted in 1.8% PHEV penetration under No Action and 5.7% penetration under the Preferred Alternative. The CAM high case PHEV penetration values are nested within the values above, showing 0.7% PHEV penetration under No Action and 5.0% PHEV penetration under the Preferred Alternative.

Both the DMC low case and CAM low resulted in the least SHEV technology penetration; under the No-Action Alternative, the DMC low case resulted in SHEV penetration of 20.4% and the CAM low case resulted in

[264] Final Rule Battery Costs Docket Memo.

20.6% SHEV penetration. Under the Preferred Alternative, the DMC low case resulted in SHEV penetration of 26.8% and the CAM low case resulted in 26.5% penetration. Conversely, the two sensitivity cases with SHEV penetration higher than the RB (23.3% No-Action Alternative, 28.3% Preferred Alternative) were the DMC high case and the NPRM BLC case. The NPRM BLC case resulted in 25.0% SHEV penetration under No Action and 29.3% under the Preferred Alternative. The DMC high case resulted in 25.8% SHEV penetration under No Action and 29.2% penetration under the Preferred Alternative. The remaining battery sensitivity case (CAM high) resulted in SHEV penetration that did not deviate greatly from the RB – 22.2% under No Action and 28.2% under the Preferred Alternative.

For the HDPUV fleet, electrification technology application greatly varied between battery sensitivity cases; this is due to the HDPUV fleet having greater diversity of vehicle use-cases as well as having a smaller fleet, compared to LD. For instance, HD vans that are used on specific delivery routes maybe easier to electrify compared to HD pickup trucks, whose applications and routes are more sporadic. Unlike the LD fleet, in the HDPUV modeling those vehicles are allowed to apply BEV technology in the standard setting years, so any significant change in electrification costs will have larger effects on the technology penetration rates. For instance, for the RB, BEVs make up 40.1% of the fleet under both the No Action and under the Preferred Alternative; BEV penetration was significantly lower, in contrast, under the DMC high case and the NPRM BLC case – resulting in 12.8% and 12.0% BEV penetration in the HDPUV under No Action and 26.8% and 24.8% of the HDPUV fleet under the Preferred Alternative, respectively. The CAM high case yielded similar BEV penetration compared to the RB, with BEVs making up 39.0% of the fleet under No Action and 39.9% of the fleet under the Preferred Alternative. The DMC low case and the CAM low case yielded the highest BEV penetration – 47.0% BEV penetration of the fleet under No Action and 46.3% under the Preferred Alternative for the DMC low case and 41.6% BEV penetration of the fleet under No Action and 42.5% under the Preferred Alternative for the CAM low case.

Under the RB, 0.3% of the fleet is comprised of PHEVs under No Action; under the Preferred Alternative, the RB HDPUV fleet resulted in 4.4% PHEVs. The DMC low case resulted in the highest PHEV penetrations across all battery sensitivity cases – 29.1% of the fleet under both the No Action and Preferred Alternatives. The lowest PHEV penetration under No Action resulted from the NPRM BLC case and the DMC high case – both with 0.1% penetration; under the Preferred Alternative, the NPRM BLC case resulted in 9.6% PHEV penetration and the DMC high case resulted in 8.9% fleet penetration. The lowest under the Preferred Alternative was the CAM high case at 4.1% PHEV penetration; this case also showed low penetration under No Action at 0.2% penetration of the fleet. The CAM low case PHEV penetration values are nested within the values above, showing 7.1% penetration under No Action and 10.0% penetration under the Preferred Alternative.

The DMC low case resulted in the lowest SHEV penetration – 13.5% and 13.7% in the HDPUV fleet, under the No Action and the Preferred Alternative, respectively. The NPRM BLC case resulted in the highest SHEV penetration, at 39.1% and 40.8% under the No Action and Preferred Alternatives, respectively. Notably, both the reference baseline and the CAM high resulted in 36.8% under No Action and 35.8% under the Preferred Alternative. Similarly, the DMC high case resulted in 38.3% penetration under No Action and 36.5% under the Preferred Alternative. The CAM low case SHEV penetration values are nested within the values above, showing 29.4% penetration under No Action and 28.4% penetration under the Preferred Alternative.

The CAM low case resulted in the lowest BISG mild hybrid penetration in the HDPUV fleet – 1.2% under No-Action Alternative and 0.3% under the Preferred Alternative; the RB and all remaining sensitivity cases under No Action also resulted in 1.2% BISG penetration except the DMC high case, which resulted in 1.4% under No Action. The RB resulted in 0.9% under the Preferred Alternative; similarly, the DMC low case resulted in BISG penetration of 1.2% under the Preferred Alternative. The DMC high case resulted in the greatest BISG penetration – 7.7% under the Preferred Alternative; similarly, the CAM high case resulted in 6.1% mild hybrid penetration of the HDPUV fleet under the Preferred Alternative, and the NPRM BLC case resulted in 5.6% penetration under the Preferred Alternative.

For the HDPUV fleet, outside of electrified powertrain technology, the conventional technology application for advanced engine technology was also analyzed under the battery sensitivities. The DMC low case resulted in the least advanced engine technology penetration – 10.4% and 11.0% penetration for No-Action Alternative and the Preferred Alternative, respectively. The highest advanced engine technology penetration was a result of No Action with the DMC high case and NPRM BLC case at 48.8% penetration; under the Preferred Alternative, the DMC high case resulted in 27.8% fleet penetration and the NPRM BLC case resulted in 24.7% penetration. The RB showed 22.9% penetration under No Action and 19.8% penetration under the Preferred Alternative; similarly, the CAM high case resulted in 24.0% under No Action and 20.3% penetration under the Preferred Alternative. The CAM low case resulted in 21.9% advanced engine technology penetration under No Action and 19.1% under the Preferred Alternative.

See Table 9-4 and Table 9-8 for changes in technology penetrations for all sensitivity cases (light duty and HDPUV, respectively) and further discussion of the results in Chapter 9.2.1.

Net Benefits - In the LD fleet, there was a variance in net benefits (the difference between total SCs and total social benefits) across all battery cost scenarios;[265] compared to the RB ($35.2B net benefit over No-Action Alternative), the CAM high case increased net benefits $43.5B and the CAM low case increased benefits $40.3B. The DMC low case decreased net benefits to $32.4B and the DMC high case decreased benefits to $33.8B compared to the RB. The NPRM BLC case resulted in the lowest net benefits of $29.3B compared to the RB.

The impact on consumers (the difference between regulatory cost and retail fuel expenditure) between the RB and all battery sensitivity cases ranged as low as $218 savings per-vehicle under the Preferred Alternative (over No-Action Alternative, $29 more than RB – with the RB saving $247 per vehicle) with the DMC high case and as high as $346 savings per-vehicle (saving $99 over the RB) with the CAM low case. The NPRM BLC case proved to have very similar consumer effects as the RB at $246 savings. The remaining cases resulted in relatively high savings: the DMC low case yielded $341 savings and the CAM high case yielded $321 savings per-vehicle.

The HDPUV fleet, which is much smaller than the LD fleet, still shows variance in net social benefits between battery cost cases. Under the Preferred Alternative, the RB results in a $13.62B benefit over No Action; similarly, the CAM low case resulted in $14.08B benefit over No Action. The DMC low case did not show benefit over No Action, resulting in a $2.29B net loss. The remaining battery sensitivity cases, however, show significant improvements over No Action; the DMC low case results in a $89.64B benefit, the NPRM BLC case results in a $86.30B benefit, and the CAM high case yields a $25.21B benefit – all under the Preferred Alternative over No Action. The increased benefits in action alternatives results from technologies getting applied in the standard setting years instead of reference baseline years (again, because the EPCA restrictions do not apply in the HDPUV context).

There is a stark contrast in consumer effects in the HDPUV fleet between battery sensitivity cases. The RB yields a $491/vehicle savings under the Preferred Alternative, compared to No-Action Alternative. Similarly, the CAM low case yields in a $513/vehicle savings, and the CAM high case results in a $671/vehicle savings under the Preferred Alternative, compared to No Action Alternative. The DMC low case resulted in a $146/vehicle loss under the Preferred Alternative compared to the No Action Alternative.

The remaining cases yield a significant savings over No-Action Alternative; the DMC high case results in a $3,541 savings, and the NPRM BLC case results in a $3,510 savings per-vehicle. As discussed before, any change in battery costs has a significant impact on sensitivities results considered for this analysis. If battery technology is less expensive than NHTSA currently forecasts, the benefits in the HDPUV are observed in the reference baseline as it is quickly adopted because the technology is cost effective, regardless of new standards. Alternatively, if the battery technology is more expensive, the benefits are observed to occur in the standard setting years, as manufacturers would adopt electrification to meet standards.

Other Metrics - In the LD fleet, between battery sensitivity cases, there are notable differences in additional metrics, such as gasoline and electricity consumption as well as CO_2 emissions avoided. The RB saved 64 billion gallons of gasoline under the Preferred Alternative over No Action; similarly, the low CAM case resulted in 66 billion gallons saved. Only one of the sensitivity cases saved less gasoline than the RB – the DMC low case resulted in 49 billion gallons saved over No Action. The remaining cases saved significantly more gasoline; the NPRM BLC case saved 76 gallons of gasoline under the Preferred Alternative over No Action,

[265] 3% discount rate was used.

the CAM high case resulted in 91 billion gallons of gasoline saved, and the DMC high case saved the most gasoline at 98 billion gallons.

Among all battery sensitivity cases, the DMC high case contributed to the largest difference in electricity consumption between the preferred alternative and No-Action Alternative – consuming 634 TWh more energy (over double the energy difference in most other cases, including the RB at 333 TWh under the Preferred Alternative compared to No-Action Alternative); the CAM high case similarly consumed electricity at 541 TWh over No Action. The CAM low case and the NPRM BLC case yielded similar electricity consumption values; CAM low consumed 340 TWh over No Action and NPRM BLC consumed 409 TWh more electricity over No Action. The DMC low case resulted in the lowest electricity consumption at 146 TWh more under the Preferred Alternative over No Action.

Carbon dioxide prevention is an additional, measurable metric used to compare sensitivity studies. In the RB, we estimate 659 million metric tons (MMT) less CO_2 compared to the No-Action Alternative; similarly, the Preferred Alternative under the CAM low case results in 689 MMT CO_2 less than No Action, and the NPRM BLC case results in 781 MMT CO_2 less than No Action. The DMC low case resulted in the least CO_2 prevented – 519 MMT CO_2 less than No Action. The remaining battery sensitivity cases yield greater differences between the Preferred Alternative and No-Action Alternative – the greatest difference being under the DMC high case with 992 MMT CO_2 less with the Preferred Alternative compared to No-Action Alternative; similarly, the CAM high case yields 934 MMT CO_2 less under the Preferred Alternative compared to No-Action Alternative.

In the HDPUV fleet, additional metrics were also analyzed between battery sensitivity cases. Gasoline consumption did not change significantly between the No Action Alternative and Preferred Alternative for the DMC low case; however, it should be noted that with this case, gasoline consumption was *increased* by 1 billion gallons. With both the RB and CAM low case, 6 billion gallons of gasoline were saved over No Action. The greatest contrast under regulatory action is shown under the remaining cases. The DMC high case saved 42 billion gallons of gasoline under the Preferred Alternative over No Action Alternative; similarly, the NPRM BLC case saved 40 billion gallons of gasoline under the Preferred Alternative over No Action Alternative. The CAM high case values are nested between the cases above, resulting in 11 billion gallons of gasoline saved under the Preferred Alternative over No Action Alternative.

There was a small difference in electricity consumption between the Preferred Alternative and No Action Alternative with the DMC low case – consuming 12 TWh *less* electricity under the Preferred Alternative over the No Action Alternative. The RB consumed 56 TWh more electricity over No Action; similarly, the CAM low case consumed 63 TWh more electricity under the Preferred Alternative over No Action. The largest difference in electricity consumption was displayed under the remaining battery sensitivity cases. The DMC high case consumed 411 TWh more under the Preferred Alternative over No Action Alternative; similarly, the NPRM BLC case resulted in an additional 382 TWh of electricity consumption under the Preferred Alternative over No Action Alternative. The CAM high case resulted in 111 TWh of additional electricity consumption over No Action.

The DMC low case was unique in that it resulted in 11 MMT *more* CO_2 under the Preferred Alternative over No Action. In contrast, the DMC high case resulted in the largest difference between the Preferred Alternative and No Action Alternative, yielding 414 MMT less CO_2 under regulatory action; similarly, the NPRM BLC case yielded 393 MMT less CO_2 under the Preferred Alternative compared to No Action. The RB resulted in 55 MMT less CO_2 than No Action; similarly, the CAM low case yielded 60 MMT less CO_2 than No Action. The CAM high case resulted in 111 MMT less CO_2 under the Preferred Alternative compared to No Action.

These results are expected as increases and decreases in electrification costs influenced manufacturers to adopt other types of technologies. See Chapter 9.2.1 for these cost metrics.

9.2.2.3. Off-Cycle and Air Conditioning Efficiency

AC and OC efficiency technologies can provide fuel economy benefits in real-world vehicle operation. NHTSA accounts for these benefits by adding fuel consumption improvement values (FCIVs) to a vehicle's fuel economy value. AC and OC FCIVs are based on an ICEs fuel economy difference not captured on the two-cycle regulatory compliance cycle and a test cycle that can capture those benefits. As discussed in TSD

Chapter 3.7, our analysis considers manufacturers adopting AC and OC technologies as a part of their compliance strategies.

Existing AC and OC FCIVs – based on ICE technologies – do not represent improvements in BEV fuel efficiency because BEVs have no ICE or transmission, and so cannot take advantage of engine or transmission-specific technology improvements. We represent this in the reference baseline modeling by limiting the amount of AC and OC technologies that BEVs can adopt. In working to align with EPA on recently finalized rules for FCIVs, we made minor errors in the NPRM and FRN inputs. These errors and the sensitivity cases we ran to assess their effect are discussed below.

NPRM Sensitivities - For the NPRM, we had two errors in setting up our AC and OC FCIV caps. First, we incorrectly had the OC cap for LT ICE vehicles set to 15 g/mi for MY2027 and beyond, which should have been set to 10 g/mi for MY2027 on. Secondly, we left the OC caps in the reference baseline the same for ICE vehicles and BEVs when we should have reduced the OC caps for BEVs to 5 g/mi for PC and 9 g/mi for LTs from MY2023 to MY2026. To better understand the impact these errors had on the NPRM analysis we ran two sensitivities titled AC/OC NPRM Cap Error No-Action Mod and AC/OC NPRM Cap No-Action Mod.

The sensitivity titled AC/OC NPRM Cap Error No-Action Mod is set up just like the NPRM run with the LT OC cap set to 15 g/mi and we corrected the MY2023-2026 BEV OC cap to 5 g/mi for PC and 9 g/mi for LT. This scenario represents what we did in the NPRM. The sensitivity titled AC/OC NPRM Cap No-Action Mod reflects what we should have done in the NPRM with the LT OC cap set to 10 g/mi for MY2027 and reflect the corrected MY2023-2026 BEV OC cap to 5 g/mi for PC and 9 g/mi for LT. Comparing the results between these two sensitivities in Table 9-2, Table 9-3, and Table 9-4 in Chapter 9.2.1 shows no difference and that the input error had no significant impact on the analysis.

AC/OC Mod – For the final rule, we made an error to reduce the BEV OC cap to 5 g/mi for PC and 9 g/mi for LT for MY2023-2026 and instead kept it the same as the ICE vehicles. This sensitivity corrects the BEV OC cap and applies it to the reference baseline No Action scenario and all other alternatives. If we look back to tables in Chapter 9.2.1, by MY2031 there is little difference between the impacts of this sensitivity and the reference baseline. Since we lowered the OC cap for BEVs between MY2023-2026, we have effectively removed some of the FCIVs that would have been generated by BEVs. As a result, in the AC/OC Mod sensitivity we see total social costs increase slightly by MY 2031 to $25.5B stemming from a small increase in gasoline consumed and a corresponding increase in CO2 emissions than seen in the reference baseline. We also see small changes in technology application and a $21 per vehicle increase in regulatory costs, but less lifetime retail fuel savings with this sensitivity. Consequently, the net social benefit shown in Table 9-2 is also reduced slightly by MY 2031 to $32.1B for this sensitivity than in the reference baseline. The small changes that can be seen in Table 9-2, Table 9-3, and Table 9-4 in Chapter 9.2.1 are not significant enough for us to change our preferred alternative.

9.2.2.4. Engine Technologies

We ran one sensitivity case to further inform our decisions concerning constraints we apply to the application of HCR engine technologies (HCR, HCRE, and HCRD) in the standard setting analysis. Preamble Section III.D and TSD Chapter 3 discuss the constraints we apply to the application of HCR engine technologies, in particular to proxy capital that a manufacturer would lose by switching from manufacturing one type of engine technology to HCR engine technology (i.e., “stranded capital”), and to represent what we believe is an appropriate restriction of the technology to vehicles that have higher load requirements, based on feedback from the automotive industry and our engineering judgment. A discussion of these engine technologies and a discussion of the SKIPs we applied in the reference baseline is located in Chapter 3.1 of the TSD and the application of SKIPs in the reference baseline is located in the Market Data Input File.

Limited HCR skips – We removed all adoption constraints for the HCR, HCRE, and HCRD engine technologies.

When we removed the constraints on application of HCR technology, fleetwide HCR technology penetration increased by approximately 9.6% in MY31, from 22.1% to 31.7% in the no action alternative. We see that HCR penetration for the limited HCR skip sensitivity is 7.5% higher fleetwide than in the reference baseline for the preferred alternative. Initial HCR technology penetration increased between the reference baseline no-action alternative and the sensitivity case no-action alternative because more vehicles can adopt this technology. From a technology perspective, more of the basic engines can and do select the HCR technology along the way. Fines are also lower in the sensitivity case because more vehicles like the Camaro, Ram 1500, F-150, Silverado, Mustang, etc. adopt HCR engines. However, while these results look positive, they are misleading, as we do not believe that HCR technology could be applied to these vehicles while maintaining important performance metrics like towing in the case of the pickup trucks. Additionally, as discussed below, the CAFE Model does not account for the cost of stranded capital that a manufacturer would incur from switching from one engine technology to an HCR engine technology.

The average regulatory cost on a per vehicle basis for the preferred alternative in MY2031 is $392 in the reference baseline and decreased by approximately $2 in the sensitivity case to $390. The net social benefits slightly decreased by $0.3 billion for the sensitivity case compared to the reference baseline in the preferred alternative. The reference baseline saves 3 billion gallons of gasoline and 17 million metric tons of CO2 while using 66 TWh more electricity compared to the sensitivity case. However, we believe that in the real world, manufacturers would incur significantly more costs from applying HCR technology to these vehicles and that would vastly outweigh the additional, slight increase in societal benefit. As discussed in the preamble Section III.C.3 and TSD Chapter 3, it costs approximately $1 billion for a manufacturer to design, build, and deploy a new engine. Just one manufacturer that incurs the costs to switch to HCR technology under the limited HCR skips case would incur costs that significantly outweigh the limited increased social benefits.

The data shown in more detail in Chapter 9.2.1 shows the minimal impact of the HCR adoption constraint for this rule.

9.2.2.5. HDPUV PHEV Availability

The “PHEV available MY 2030” sensitivity case was run to look at the impacts of the assumption that HDPUV manufacturers would likely not introduce any PHEVs into their lineups until MY 2030. Unlike the LD PHEV technologies that include three powertrain options and two range options, our analysis limits the HDPUV PHEV technologies to one powertrain option and one range option. There are no PHEVs in the reference baseline HDPUV fleet, and there are no announcements from major manufacturers that indicate this is a pathway that they will pursue in the short term.[266] Further discussion on electrification technologies and how these are applied to our analysis are located in preamble Section III and TSD Chapter 3.

For the Preferred Alternative, the HDPUV fleet shows no variance in total social costs, total social benefits, or net social benefits between the RB and PHEV availability case.

Similarly, there are no differences between the RB and PHEV availability case in select metrics for the Preferred Alternative, including gasoline consumption, electricity consumption, CO_2 emissions, fatalities, criteria emission deaths, regulatory costs, lifetime retail fuel expenditure, sales, and jobs.

Especially worth noting is that for this sensitivity, PHEV penetration is unchanged compared to the RB for both the No-Action Alternative and the Preferred Alternative at 0.3% and 4.1%, respectively. As mentioned previously, no PHEVs are expected to enter the HDPUV fleet in the near future. NHTSA believes this is in part because PHEVs, which are essentially two separate powertrains combined, can decrease HDPUV capability by increasing the curb weight of the vehicle, thereby reducing cargo capacity. A manufacturer’s ability to use PHEVs in the HDPUV segment is highly dependent on the load requirements and the duty cycle of the vehicle.[267,268,269]

Therefore, even if PHEVs are available earlier or later, we still believe the Preferred Alternative is appropriate and reflects what HDPUV manufacturers may do during the rulemaking timeframe.

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[266] We recognize that there are some third-party companies that have converted HDPUVs into PHEVs, however, HDPUV incomplete vehicles that are retrofitted with electrification technology in the aftermarket are not regulated under this rule unless the manufacturer optionally chooses to certify them as a complete vehicle. *See* 49 CFR 523.7.

[267] National Renewable Energy Laboratory. 2023. Electric and Plug-in Hybrid Electric Vehicle Publications. Transportation & Mobility Research. Available at: https://www.nrel.gov/transportation/fleettest-publications-electric.html. (Accessed: Feb. 9, 2024)

[268] For the purpose of the Fuel Efficiency regulation, HDPUVs are assessed on the 2-cycle test procedure similar to the LD vehicles. The GVWR does not exceed 14,000 lbs in this segment.

[269] Birky, A. et al. 2017. Electrification Beyond Light Duty: Class 2b-3 Commercial Vehicles. Final Report. Dec. 2017. Oak Ridge National Laboratory. pp 1-47. Available at: https://info.ornl.gov/sites/publications/Files/Pub106416.pdf. (Accessed: Feb. 9, 2024).

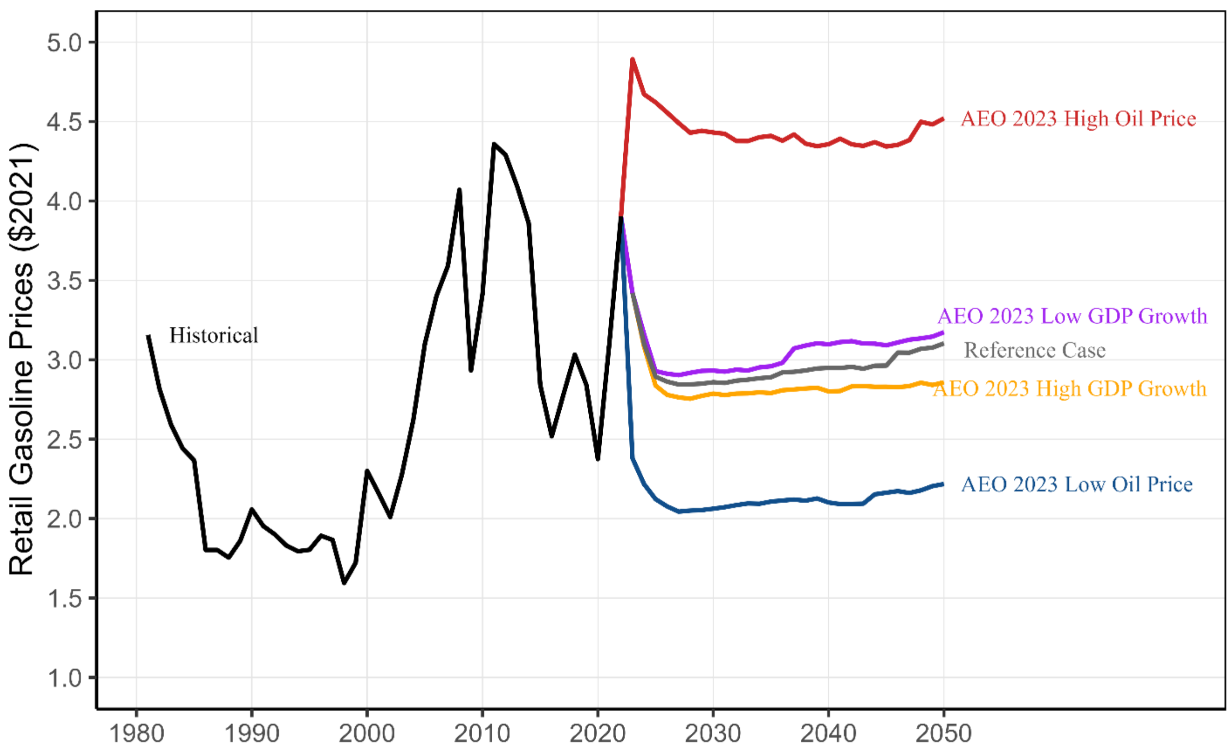
9.2.3. Effect of Economic Parameters

9.2.3.1. 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 9-15 presents the fuel price time series for the Reference baseline and sensitivity cases alongside historical fuel price levels in 2021 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 four price projections: high- and low-oil price projections, and high- and low-economic growth oil price projections from AEO 2023 that rely on EIA assumptions about future oil price trajectories. In broad terms, the AEO 2023 high oil price, low oil price, and reference case price projections represent high, low, and moderate growth trends in fuel prices. The low economic growth series falls between the reference case and high oil price projection, while the high economic growth series lies below the reference case but above the low oil price series.

Figure 9-15: Fuel Price Sensitivity Cases



In the case of increasing fuel prices—especially the rapid increase in the high oil price scenario—consumers demand more fuel economy in the new vehicle market because each gallon of fuel saved during the 30-month payback period is worth more. In the high oil price scenario, manufacturers adopt more expensive technologies that yield larger improvements in fuel economy in both the No-Action Alternative and the action alternatives. Increasing the reference baseline fuel savings limits the incremental effect of the change in regulation on the overall quantity of fuel consumption; however, the increase in fuel costs raises the overall value of any fuel savings under the final standards. In Table 9-3 we find that for MY 2031 the incremental fuel cost savings under the final standards in the high oil price scenario are about $70 per vehicle lower than the Reference baseline and the total gasoline consumption reduction is about 35 billion gallons lower. Additional costs imposed under the final standards are about $200 per vehicle lower in the high oil price scenario than under the final standards in the Reference baseline, meaning that the net effect of the alternative stringency is less costly for consumers, and sales of new vehicles are thus expected to be higher than in the Reference baseline. The effects of lower oil prices act in the reverse direction, meaning that consumers will value fuel economy gains less, and manufacturers will adopt fewer expensive technologies for this purpose. On balance this will lower the level of tech adoption in the No-Action Alternative, raising the incremental effects of changes in the regulation on the quantity of fuel consumed. However, the value of these effects on costs will be diminished by the lower price of fuel. Our results align with this outcome. Overall, in the low fuel price case the final standards increase the incremental reduction in gasoline consumption by almost 90 billion gallons, but the associated fuel cost savings is about $115 lower than in the Reference baseline. The increase in technology costs is on par with what we find in the Reference baseline, meaning that the net effect of the final standards is less beneficial to the consumer. Results for the economic growth cases align closely with the Reference baseline, as the magnitude of the effect on fuel price projections is significantly smaller.

we find that for the CAFE fleet, the high oil price case results in net benefits of approximately $30.9 billion relative to the No-Action Alternative under a 3 percent discount rate. This is only slightly higher than in the Reference baseline. Net benefits in the low oil price case are around $33.0 billion. Results for the two economic growth cases (GDP + fuel (high) and GDP + fuel (low)) both yield results with slightly higher (lower) net benefits compared to the Reference baseline respectively.

When we examine results for MY 2038 HDPUVs in Table 9-8, we find that, under the high oil price scenario, technology adoption in the No-Action Alternative is much higher than in the Reference baseline. Incremental technology adoption in BEVs is also higher under the final standards in this case. However, in the low oil price scenario, less BEV technology is adopted in the No-Action Alternative, meaning that the more stringent standards require more technology adoption. As a result, significantly more incremental BEV technology adoption takes place and incremental fuel efficiency improvements are larger in the alternatives. Additional technology costs in this scenario rise to over $1,000 per vehicle, while fuel savings are significantly higher, at just above $3,000 per vehicle. The incremental reduction in gasoline consumption under the final standards is significantly larger in the low oil price case than in the Reference baseline, at around 53 billion gallons. Results under the GDP growth cases fall between the two and are close to the Reference baseline. In Table 9-6, we find that in the high oil price scenario the additional net benefits under the final standards are minimal. On the other hand, net social benefits rise to around $93.56 billion in the low oil price case and are close to the Reference baseline levels in the GDP growth cases.

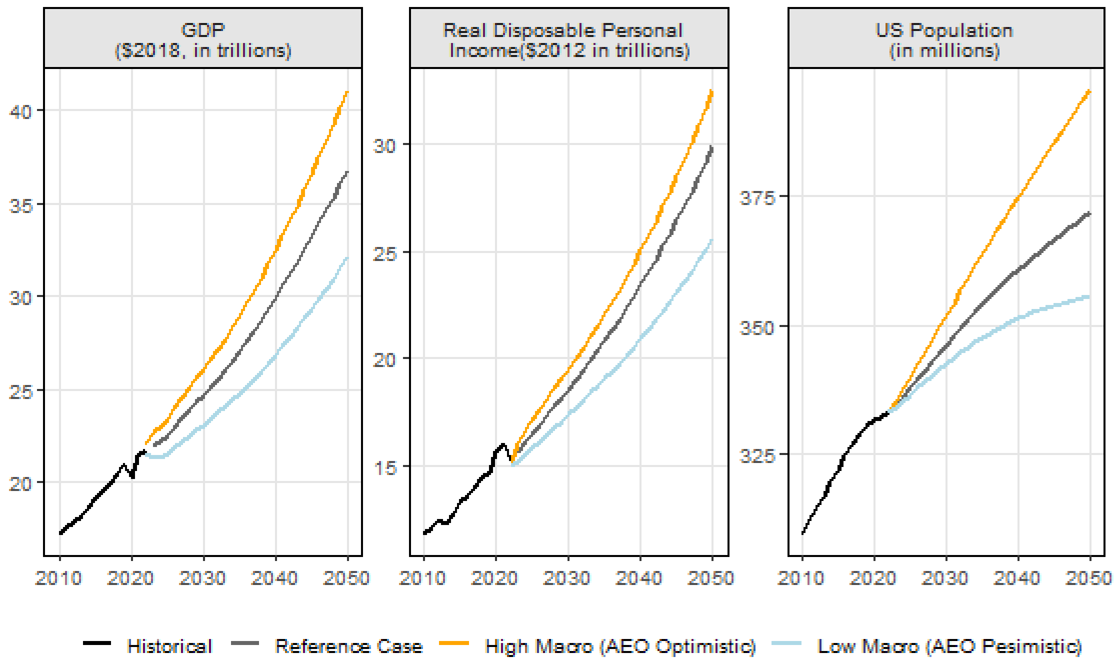
The results of these oil price sensitivities lead to a fairly narrow range of potential net benefit outcomes from the final standards. This is the product of two important factors. First, the price of fuel is one of the most significant determinants of the value of avoided fuel consumption. Large differences 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. Higher oil prices lead to higher values of fuel cost savings per gallon of gasoline saved, but also lead to greater technology adoption under the No-Action Alternative which acts to limit the incremental effects of a change in the standards. Further, the price series used in this sensitivity analysis (especially the EIA high and low oil price forecasts) represent extremes of potential future price paths in both the near and long-term, with prices ranging from just over $2 per gallon to more than $4.50 per gallon in 2021 dollars. We also note that while they are not considered in this sensitivity case, changes in the projection of oil market conditions will also affect our estimates of the value of reductions in energy security externalities caused by higher standards. The model's sensitivity to these estimates is explored in Chapter 9.5.1.3. Finally, it is important to note that differences in our net benefit results between light duty vehicles and HDPUVs are due in part to the restrictions placed on technology adoption by the standard-setting conditions.

For the final rule, NHTSA also revised its assumption that 100 percent of the reduction in fuel consumption was accounted for by reductions in fuel imports. NHTSA instead assumes that the share is 80 percent, which was calibrated using a simple model of the global fuel market described in TSD Chapter 6.2.4.3. NHTSA also assesses two alternative effects of a reduction in fuel consumption as sensitivity cases: (1) the assumption that 50% of the reduction in fuel consumption leads to reduced fuel imports; and (2) the assumption that 100% of the reduction in fuel consumption leads to reduced imports (rather than effects on domestic production). The primary channel through which this assumption affects net benefits is through the quantity by which domestic upstream emissions are reduced. Impacts on societal net benefits are small in each case, with net benefits falling by $200 million in the 100 percent case and rising by $300 million in the 50 percent case. Results are similar but smaller in magnitude for HDPUVs. We conclude that our results are not sensitive to this assumption.

9.2.3.2. Macroeconomic Forecasts

The CAFE Model relies on a set of macroeconomic assumptions related to 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 light duty vehicle market, the rate at which the on-road fleet turns over, and the total demand for travel. In this analysis, the Reference baseline assumptions come from the EIA 2023 AEO and the S&P Global GI September 2022 Macroeconomic Outlook base case. Along with the case used in this reference baseline, NHTSA uses AEO's high- and low-GDP growth cases' estimates of GDP, population, and real disposable income as sensitivity cases. The "GDP (low)" and "GDP (high)" sensitivity cases in the tables and figures of Chapter 9.2.1 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 baseline level. Two additional cases include the corresponding fuel price series for gasoline, diesel, and electricity. Projected macroeconomic variables from each of these cases are shown in Figure 9-16.

Figure 9-16: Parameter Input Values for Macroeconomic Sensitivity Cases



The lingering consequences of the COVID-19 pandemic, disruptions to the supply chain, the Russia-Ukraine War, and inflation 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 the CAFE Model the macroeconomic variables highlighted in this case affect the size and composition of the fleet as well as vehicle usage. As a result, their effect on technology adoption is minimal. Table 9-3 indicates that sales impacts are small as well; however, there are also corresponding impacts on traffic fatalities and criteria emission deaths due to changes in the makeup and usage of the fleet. Overall net benefits differ by about $2.5 billion between the high and low growth cases, with the Reference baseline closer to the low growth case. When we also incorporate the corresponding fuel price projections from the AEO we find that net benefits are slightly higher or lower for each case, and make the difference grow to about $3 billion between the two cases.

We simulate the same set of sensitivity cases for HDPUVs and summarize net-benefit results in Table 9-6. We find that for the GDP sensitivities, net-benefits in the high GDP case are about $2 billion higher than the

Reference baseline, while in the low GDP case they are about $2.2 billion lower. When we vary the macro variables and oil prices, results are closer to the Reference baseline. This is partly due to a smaller difference in criteria emission deaths driven by a smaller difference in electricity consumption.

9.2.3.3. Oil Market Externalities

For this final rule analysis, NHTSA estimated the value of externalities from fuel consumption related to energy security in oil markets. As explained in TSD Chapter 6.2.4, these quantities depend on the short run elasticities of global and domestic petroleum supply and demand, as well as the elasticity of U.S. GDP with respect to global oil prices. There are a range of estimates for these quantities in the literature, and thus a range of potential values for the estimates of energy security externalities. In the Reference baseline, NHTSA uses the mean estimates produced from the full set of possible elasticity parameterizations.[270] To evaluate the sensitivity of the CAFE Model results to this parameter, the agency ran two additional cases in which value of oil market externalities was set to the lower 10th percentile value, and the upper 90th percentile value.

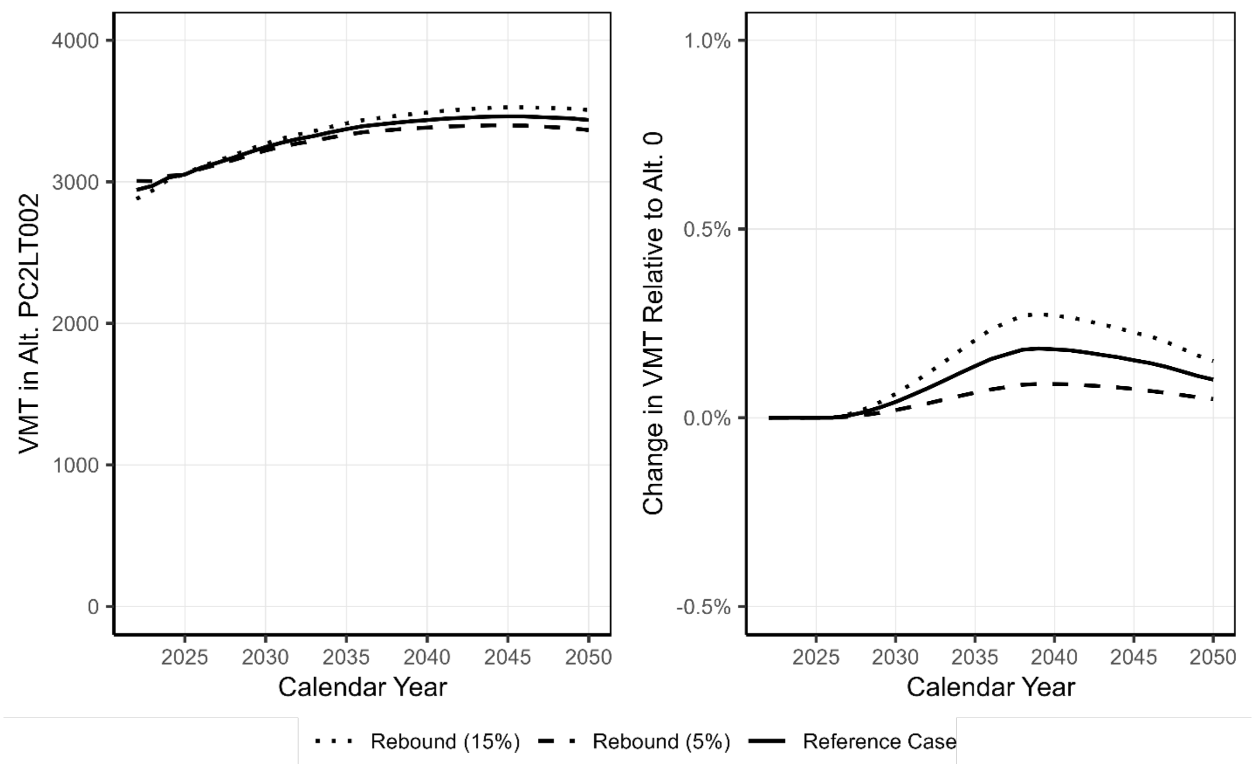
Since this quantity measures the value of a societal effect that is not internalized by vehicle owners or manufacturers, there are no effects on the compliance behavior of manufacturers or on the driving behavior of owners. Instead, this parameter simply scales up or down the societal effect of a change in the quantity of oil consumption induced by a regulatory alternative, and thus only affects the overall benefits from a change in regulation and not the costs. In Table 9-2 we find that for CAFE fleet, using the high estimate for the externality adds about $1 billion dollars of additional benefits, while using the low value lowers benefits by around $1 billion. For HDPUVs, as shown in Table 9-6, the effects on both costs and benefits are less than $500 million compared to the Reference baseline.

9.2.3.4. Rebound Effect

The CAFE Model results are less sensitive to some parameters than others. As seen in Table 9-6, changing the rebound effect in either direction has a moderate impact on net benefits under the final standards. The central analysis uses a rebound effect of 10 percent, and the two sensitivity cases assume 5 percent rebound and 15 percent rebound. Changing the rebound effect increases or decreases the amount of fuel cost savings by about $15 per vehicle (increase when rebound is lowered, decrease when rebound is increased), but the foregone fuel savings are due to changes in travel that provide corresponding mobility benefits that offset the change in fuel savings. The difference in net benefits between the sensitivity cases and Reference baseline is attributable to the externalities associated with the change in travel. The effect of these sensitivity cases on VMT under the final standards relative to the No-Action Alternative is displayed in Figure 9-17. The range of the sensitivities is a little over 0.25 percent of total light duty VMT at its peak.

[270] NHTSA took its estimates for these elasticities from the distribution of elasticity estimates listed in Brown (2018). This set includes both recent and older estimates of these elasticities.

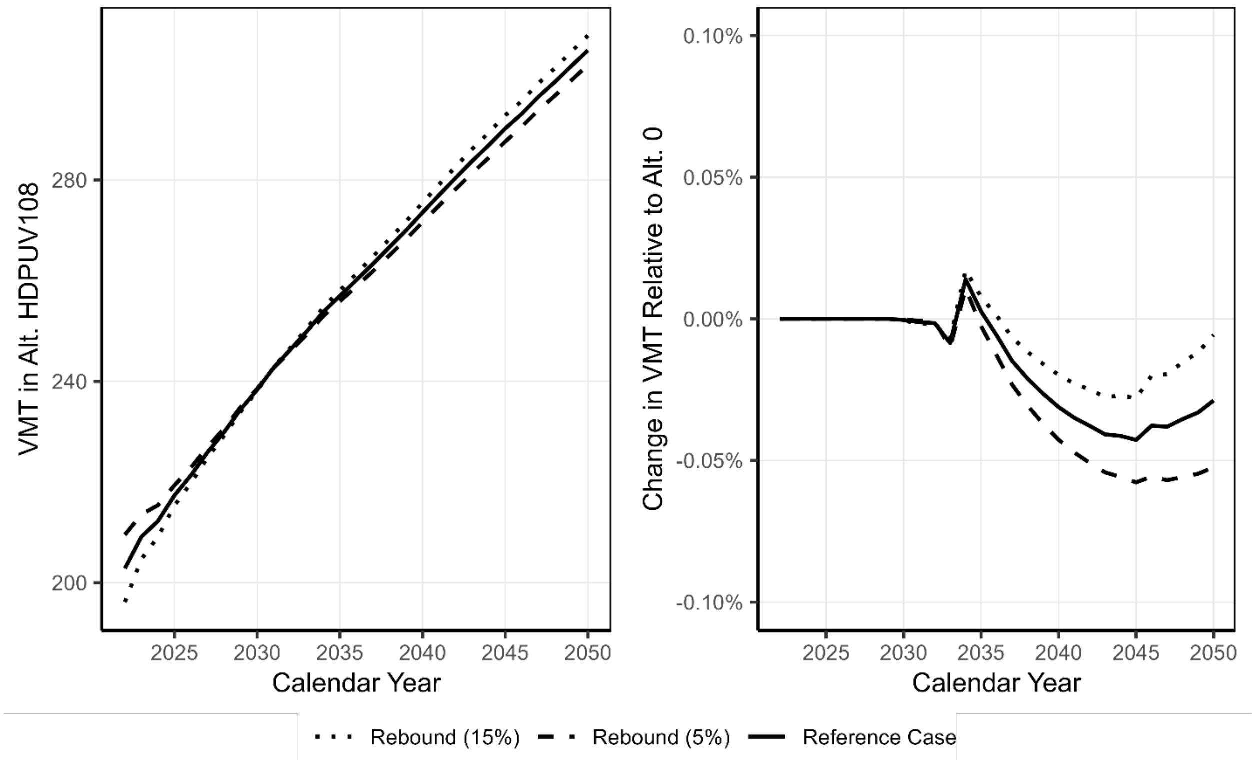
Figure 9-17: Light-Duty Vehicle Miles Traveled in Alternative Rebound Cases



Using a 3 percent discount rate, assuming a rebound effect of 5 percent results in slightly lower costs and benefits, relative to the Reference baseline, and an increase in net benefits. Assuming a rebound effect of 15 percent leads to higher cost and benefit values and a decrease in net benefits relative to the Reference baseline. In both cases, net benefits change by a magnitude of about $1 billion.

When we turn to HDPUVs we see that changes are even more modest. In Figure 9-18 we see that the rebound VMT range is now well under 0.1 percent of total HDPUV VMT. As shown in Table 9-6, social costs and social benefits both increase with the rebound effect. Compared to the Reference baseline, net social benefits increase by about $20 million per year with a 5 percent rebound effect and decrease by about $10 million per year with a 15 percent rebound effect.

Figure 9-18: HDPUV Vehicle Miles Traveled in Alternative Rebound Cases



9.2.3.5. Sales Forecasts

The CAFE Model uses a nominal forecast to project total CAFE fleet sales and a projection based on year-to-year AEO growth rates to project HDPUV sales. To test the sensitivity of the model to these modeling choices, NHTSA runs three sensitivity cases each for the total vehicle sales projections of CAFE fleet vehicles and HDPUVs. Here it is important to note that these side cases deal specifically with either methodological or input choices that directly impact the No-Action Alternative sales projections. However, sensitivities that adjust macroeconomic variables will also affect the projected level of sales for light duty vehicles in the No-Action Alternative and the regulatory alternatives. Thus, sensitivity to changes in No-Action Alternative sales can be seen as being embedded in these additional sensitivity cases as well.

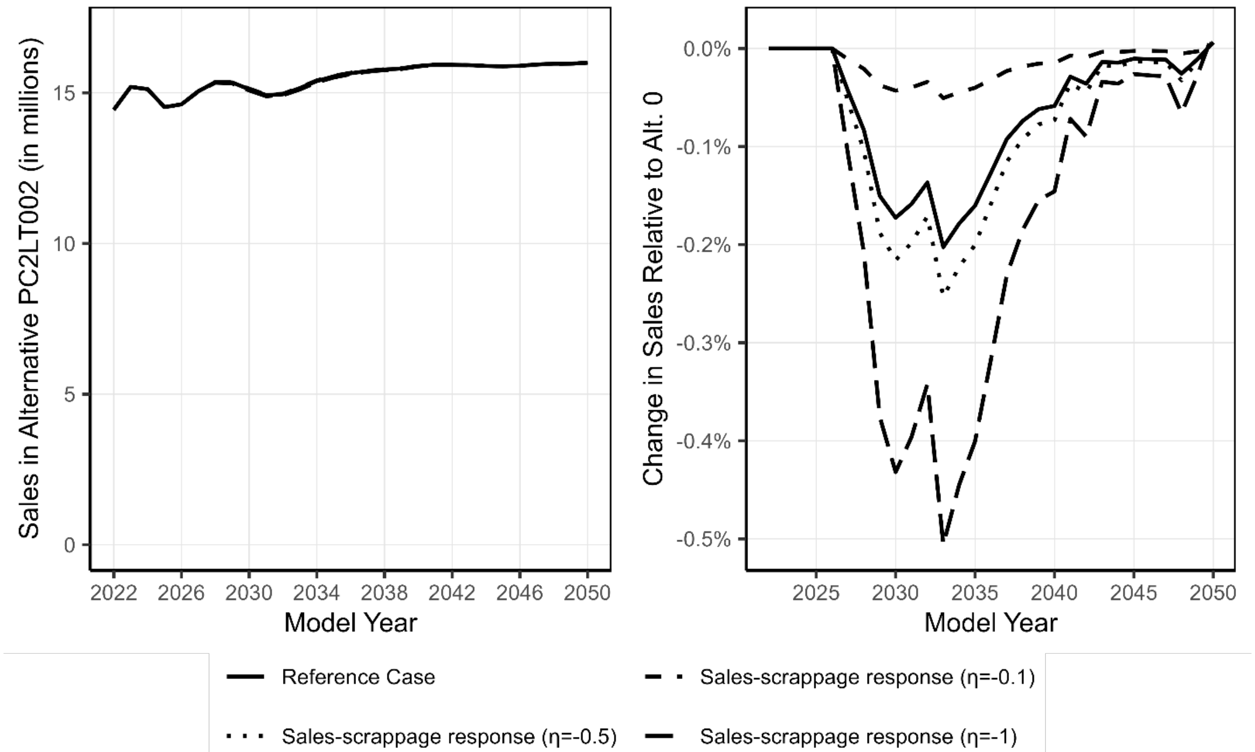
For CAFE fleet vehicles we project sales using: 1) the 2022 final rule projection of sales, 2) the AEO 2023 Reference baseline projection for total light duty sales, and 3) the AEO 2023 year-to-year light duty sales growth rates applied to the initial compliance fleet used in the CAFE Model. Since these changes do not affect the costs or benefits of technology adoption for an individual vehicle, they should just tend to amplify or decrease the levels of net benefits that we observe in the Reference baseline. Examining their effect on costs and benefits in Table 9-2 we find that this is the case. Costs and benefits are highest in the 2022 final rule model case and lowest in the 2023 AEO sales levels case. Net benefits under a 3 percent discount rate are within $1 billion of the Reference baseline in each sensitivity case. Overall, the model is not relatively sensitive to these changes.

For HDPUVs, we modify our sales model by first removing the early period sales growth rate adjustment described in TSD Chapter 4.2 and then basing sales growth rates on: 1) the 2023 AEO's reference case projection of sales for this class of vehicles, 2) the projection of sales in the 2023 AEO's "High Economic Growth" case, and 3) the projection of sales from the 2023 AEO's "Low Economic Growth" case. We find that costs and benefits are both higher in the high growth case, and lower in the low growth case. Net benefits in the low growth case are about $0.6 billion lower than the Reference baseline while in the high growth case they are about $1.9 billion higher.

9.2.3.6. Sales Elasticity

Sensitivity cases with adjusted sales and scrappage responses produce only modest changes in costs and benefits. We include three cases with different sales-scrappage responses, which vary the price elasticity around the reference baseline. The high elasticity case uses a price elasticity of -1, the middle sets it equal to -0.5 and the low elasticity case uses -0.1. Sales effects for light duty vehicles under the final standards in each of these sensitivities are presented in Figure 9-19.

Figure 9-19: Light-Duty Sales Effects of Alternative Price Elasticity Estimates



The effects of this variation on social net benefits are modest. As shown in Table 9-2 net social benefits in the low elasticity case for light duty vehicles are higher by about $1.9 billion, while they are lower by about $3.9 billion in the high elasticity case, and about $600 million lower in the middle case. A more elastic consumer response depresses sales when technology costs are passed through to consumers, meaning that the additional benefits of the new technology are somewhat muted by their lower overall penetration into the fleet.

Sales in the HDPUV case do not vary significantly from the No-Action Alternative in the Reference baseline. As a result, adjusting the elasticity has only minimal effects on sales as shown in Table 9-7. When we examine costs and benefits in Table 9-6 for each of the price elasticity cases, we find that total additional net social benefits under a 3 percent discount rate only vary from the Reference baseline by less than $1 billion in the low elasticity case, and about $1.4 billion in the high elasticity case.

9.2.3.7. Fleet Share

In this analysis, NHTSA chose to project reference baseline fleet share forward from the 2022 initial fleet using the year-to-year growth rate projections implied by the 2023 AEO. This is similar to the approach used in the NPRM but incorporates more recent projections. To account for the influence of relative price changes between PCs and LTs across regulatory alternatives, NHTSA used a parameterized binomial logit model which is described in further detail in TSD Chapter 4.2 and in a docket memo.[271] To test the sensitivity of the CAFE Model's results to these modeling choices, the agency ran three additional cases: 1) using the AEO-based share projection but excluding the price-based adjustment between regulatory alternatives, 2) keeping

[271] See "Calibrated Estimates for Projecting Light-Duty Fleet Share in the CAFE Model." In Docket No. NHTSA-2023-0022.

the No-Action Alternative fleet share fixed at initial levels but allowing price-based adjustments in the alternatives, and 3) keeping fleet shares in each alternative fixed at the initial levels.

As shown in Table 9-2 excluding the price-based adjustment has little influence on the incremental costs and benefits of the Preferred Alternative. Social net benefits increase by about $800 million under a 3 percent discount rate. Removing this adjustment limits the reallocation of non-rebound VMT, and thus safety costs between cars and trucks as described in TSD Chapter 4.3. In Table 9-10 we find that in this case incremental net benefits to society are highest under the final standards PC2LT002 for passenger cars at around $9.8 billion under a 3 percent discount rate. Net benefits for passenger cars decrease with the overall stringency of the alternatives, though the cause for this differs for PC1LT3 as compared with the three most stringent alternatives, PC2LT4, PC3LT5, and PC6LT8. For PC1LT3 incremental social costs for passenger cars are lower than in the preferred alternative, but social benefits are reduced by an even greater degree. On the other hand, for the three more stringent alternatives incremental social costs, especially external costs are significantly higher than in the preferred alternative, and this more than cancels out the additional private and external benefits.

Table 9-10: No Fleet Share Price Response, Incremental Societal Costs and Benefits, Passenger Cars, Model Years Produced Through 2031 (2021$ Billions, 3% Discount Rate, SC-GHG 2.0 Percent Discount Rate)

	PC2LT002	PC1LT3	PC2LT4	PC3LT5	PC6LT8
Private Costs	6.6	2.1	5.4	8.7	16.1
External Costs	3.3	2.9	5.5	9.1	15.7
Social Costs	9.9	4.9	11.0	17.8	31.8
Private Benefits	9.6	5.1	7.8	10.0	16.2
External Benefits	10.2	4.8	7.3	9.1	14.4
Social Benefits	19.7	9.9	15.1	19.1	30.6
Net Social Benefits	9.8	5.0	4.1	1.3	-1.2

When we keep r the No-Action Alternative fleet shares at their 2022 values, we find only a slight increase in social costs and benefits, leading to a slight increase in social net benefits relative to the Reference baseline. When we turn off price response and fix the fleet share at 2022 levels, we find a slightly larger effect in the same direction. Net benefits in this case are about $1.1 billion higher than the Reference baseline.

9.2.3.8. Payback Period

New vehicle buyers have a variety of preferences for vehicle attributes (e.g., seating capacity, interior volume, drive type, 0 to 60 mph time 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, 2020, and 2022 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 eliminates 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 to both manufacturers and consumers. More effective technologies will have higher monthly savings but, with shorter assumed payback periods, there still may not be enough time to accumulate sufficient fuel savings to offset the higher initial cost.

Sensitivity cases that vary payback period lengths for the light-duty fleet produce results that are mostly consistent with expectations. For example, in the 60-month payback period scenario, incremental average vehicle costs, lifetime fuel savings, social benefits, and social costs (relative to the No-Action Alternative) all decrease in magnitude when compared to the Reference baseline. Longer payback periods mean consumers are more willing to pay for technology that improves fuel efficiency, which, depending on the stringency of the CAFE and CO_2 standards, may result in consumers being willing to pay for technology that is beyond that necessitated by CAFE and CO_2 standards. We see this predominantly in the No-Action Alternative, and as a result, the estimated incremental impacts, benefits, and costs of more stringent standards are reduced. Eliminating the payback period means 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. This means that their technology adoption will be driven entirely by the standards, thus increasing the importance of changes in the standards. Net benefits move as expected in these two most extreme cases, increasing to $48.8 billion when we eliminate the payback period entirely and decreasing to $15.8 billion in the 60-month payback period case.

When we slightly shorten the payback period to 24 months, we find that manufacturers produce fewer vehicles with more expensive technology (e.g., PHEVs) in both the No-Action Alternative and the action alternatives. This keeps the incremental change in PHEV penetration in this case similar to what we find in the Reference baseline. Net benefits under the final standards are higher than the Reference baseline, which is primarily due to significantly lower SHEV penetration in the No-Action Alternative, and much higher incremental SHEV penetration in the preferred alternative.

The 36-month payback period produces somewhat lower incremental social costs and social benefits than the Reference baseline. In MY 2031 the No-Action Alternative PHEV adoption is slightly higher than in the Reference baseline, and incremental adoption is lower. The incremental adoption of SHEVs is slightly higher than in the Reference baseline. In this case, incremental environmental benefits and fuel savings are both somewhat lower than in the Reference baseline, but sales effects are more moderate and safety costs are much lower.

When we analyze results for HDPUVs in Table 9-6, we find the same overall pattern for incremental social costs, social benefits, and social net-benefits. The HDPUV fleet is significantly smaller than the light duty fleet, meaning that changes to the payback period in some cases change technology adoption decisions for much larger shares of the overall fleet. As a result, assumptions within our HDPUV analysis can appear to have a larger impact in the results than observed in the light duty fleet. For HDPUVs we also run one additional case in which we assume a 120-month payback period. Results are similar to the 60-month payback period case, where we find only minimal societal costs and benefits from changing the standards.

Each of the payback sensitivity results should be interpreted keeping in mind an important reality about model assumptions: they only affect the simulated decisions about which technology manufacturers will apply; the current sales and scrappage modules do not respond to changes in this payback period assumption, but rather to separate payback assumptions (the Reference baseline payback period) specified when running the model.

To test the sensitivity of the assumptions used in the sales and scrappage models for the light-duty vehicles, NHTSA also included a scenario in which fuel savings for technology application were valued at 30-months (as in the reference baseline), but 70,000 miles for the valuation in the sales and scrappage models (twice as long as the 35,000 miles in the reference baseline) representing approximately 5 years of consumer value for fuel economy improvements. We find that social costs decrease by $2.1 billion, while social benefits increase by $2.0 billion. The incremental fuel cost savings and technology costs differ only slightly in this case, although the effect of these costs on sales is much smaller than in the Reference baseline. In this sensitivity case, the regulation has less of an effect on fleet turnover, allowing more of the fleet to transition to new vehicles.

9.2.3.9. Implicit Opportunity Cost

In the central analysis for the light duty fleet, NHTSA's analysis suggests that buyers' perceived reluctance to purchase higher-mpg models is due to the consumer's undervaluation of the expected savings in fuel costs and due to potential market failures including informational asymmetries between consumers, dealerships, and manufacturers; market power; first-mover disadvantages for both consumers and manufacturers, or status quo biases; split incentives between vehicle purchasers and vehicle drivers; behavioral patterns like myopia and loss aversion; and other failures that may prevent consumers from purchasing the optimal level of fuel economy in an unregulated market as discussed in Chapter 2.1.4 of the FRIA.

Another potential explanation for why buyers have in the past been reluctant to purchase fuel-saving technologies is the potential for tradeoffs between vehicle fuel economy and other vehicle attributes including performance. In the absence of standards, a vehicle producer may adopt a set of technologies that improve fuel economy as well as the other attributes of the vehicle. If standards force the manufacturer to deviate from this set of decisions, by sacrificing improvements in other attributes for improvements in fuel economy, consumers could then face a cost that is not counted in the light-duty Reference baseline analysis.

Results from the economics literature support that these tradeoffs have existed in the past. For example, Leard et al. (2023) finds that consumers value performance improvements at three times the rate at which they value improvements in fuel economy, and that foregone improvements in performance from recent changes in CAFE standards have essentially offset consumer welfare improvements from the fully valued savings in fuel costs.[272] However, the authors acknowledge that their conclusions do not account for a variety of potential market failures around the under provision of fuel economy and insufficient incentives for innovation, and do not account for how the rate of technology adoption may change over time in response to regulatory standards. Klier and Linn (2016) find that if performance tradeoffs resulted from a hypothetical 10% increase in regulatory stringency, U.S. consumers would value the resulting fuel economy gains at levels approximately 65-85% greater than their willingness to pay for any associated forgone horsepower, assuming a discount rate applied to future fuel savings of 10%, assuming consumers value absolute rather than relative horsepower, and assuming that future technological progress will follow historical patterns. Klier and Linn (2012) find that costs to consumers are larger when manufacturers respond over the medium term rather than the short term. Whitefoot et al. (2017) finds using a simulation-based approach that observed changes in vehicle attributes are consistent with a model in which manufacturers have an incentive to trade off acceleration performance for fuel economy to lower their costs of compliance (relative to other strategies) with CAFE and GHG standards. While this research suggests that manufacturers may tradeoff attributes like horsepower and weight for improvements in fuel economy to more cost effectively comply with standards, it is important to note that these attributes are only relevant to the opportunity cost to the degree which they are valued by the consumer.

Other research casts doubt on the assumption that consumers have faced considerable attribute-efficiency tradeoffs that have led to net losses in consumer welfare or would likely face such tradeoffs in the future. (See Huang, Helfand, et al. 2018; Watten, Helfand, and Anderson 2021; Helfand and Dorsey-Palmateer 2015). That research, for example, suggests that the presence of fuel-saving technologies has not led to adverse effects on other vehicle attributes, such as performance and noise. Instead, research shows that there are technologies that exist that provide improved fuel economy without hindering performance, and in some cases, while also improving performance (such as high-strength aluminum alloy bodies, turbocharging, and increasing the number of gear ratios in new transmissions). Such research also demonstrates that, in response to regulatory standards, automakers have improved fuel economy without adversely affecting other vehicle attributes. Even as the availability of more fuel-efficient vehicles has increased steadily over time, research has shown that the attitudes of drivers towards those vehicles with improved fuel economy has not been affected negatively. To the extent some performance-efficiency tradeoffs may have occurred in the past, such tradeoffs may decline over time, with technological advancements and manufacturer learning over longer vehicle design periods (Bento 2018; Helfand & Wolverton 2011).

As discussed above, NHTSA analysis showing private benefits in excess of private costs suggests that market failures explain buyer’s perceived reluctance to purchase more fuel-efficient vehicles. NHTSA tests the sensitivity of its central analysis to the potential for opportunity costs of foregone vehicle attributes by assuming instead that this is a result of manufacturers trading off fuel efficiency with other desirable features that consumers also value. Here we include an approximation of potential consumer effects that could result

[272] Leard et al. (2023) find that their baseline results for the degree to which consumers undervalue fuel economy differ from Busse et al. (2013). After re-estimating their results using the same dataset as Busse et. al (2013), they find results that are closer to full valuation as in Busse et al. (2013). Conversely, they do not find significant changes when re-estimating results using the methodology in Busse et al. (2013) and their own dataset. Thus, as the authors conclude, results appear to be sensitive to the underlying data used to estimate them.

from potential forgone vehicle attribute improvements that exceed the Reference baseline 30-month payback period. As discussed below, these estimates may be overstated due to some potential countervailing effects.

The reference baseline 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 vehicle. The light duty 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 (e.g., roughly how long new cars are held by their initial owner) less the undiscounted value of fuel savings over the first 30 months. The agency recognizes that this is a rough, indirect, and uncertain approximation, and the magnitude of the opportunity cost is likely to vary among individual vehicle buyers. The logic underlying this sensitivity is that in a world without market failures, if consumers do not value fuel savings beyond 30 months but standards require manufacturers to make improvements in fuel economy or fuel efficiency 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 to 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 vehicle buyers thus represents an additional cost of adopting fuel economy or fuel efficiency 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 2031, the implicit opportunity cost for light duty vehicles is approximately $127 per vehicle at a 3 percent discount rate.

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 out-of-pocket cost of the standards to the consumer. 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 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. Further, we believe that the inclusion of fuel savings benefits in the primary analysis is justified due to potential market failures, such as those discussed at the beginning of this section and covered in Chapter 2.1.4 of the FRIA.

9.2.3.10. Implicit Opportunity Costs for HDPUVs and Commercial Operator Share

As in the case of light-duty vehicles, NHTSA does not assume that there are any offsetting opportunity costs to improvements in the fuel economy of HDPUVs in the Reference baseline analysis. During the process of preparing its analysis, NHTSA considered the possibility that there are important differences in the types of buyers who make up the market for HDPUVs, in particular a larger share of commercial operators, and that the assumptions implicit in its analysis of light-duty private costs and benefits might apply differently in the HDPUV market.

Since many light duty commercial vehicles are ultimately used in a manner similar to personal vehicles (e.g., rental vehicles represented about 47 percent of commercial light duty sales in May 2023, up from about 39 percent from a year before according to Cox Automotive), it is possible that the preferences of commercial light-duty buyers mirror their non-commercial counterparts, hence minimizing the total cost of buying and operating a vehicle may not be essential to their profit maximation strategy.[273] Given this, the opportunity cost to commercial light-duty buyers would be the same as non-commercial buyers.

However, in the HDPUV market, vehicles perform a narrower set of functions, and commercial operators in this realm are more likely to seek vehicles with the lowest cost of ownership that can fulfill their business need. It is possible that rather than privately valuing only 30 months of fuel savings from new vehicle purchases, commercial buyers might instead be presumed to be profit-maximizers that choose vehicles offering combinations of attributes that maximize the profits they earn by operating them in commercial service, and if their profits could be improved by selecting a more fuel-efficient model they would do so. In the absence of other market failures, producers would then respond to commercial buyers' demands communicated through the market by supplying more fuel-efficient vehicles.

Under these alternative assumptions, and in the absence of market failures, incremental increases in HDPUV fuel efficiency standards that would generate fuel savings for commercial operators would be accompanied by some sacrifice in other vehicle attributes that imposes costs on commercial operators, or else requiring increases in fuel efficiency would be unnecessary. In our sensitivity analysis, NHTSA presents two cases in which we assume that such costs offset any net private benefit to commercial buyers of HDPUV vehicles, without explicitly modeling them. In the first case, NHTSA assumes that half of HDPUV sales are for commercial use while the remaining half are purchased for personal and other non-commercial use. NHTSA calculates net private benefits as the sum of technology costs, lost consumer surplus from reduced new vehicle sales, and safety costs internalized by drivers minus fuel savings, benefits from additional driving, and savings from less frequent refueling. The aggregate opportunity cost to commercial operators of other vehicle attributes presumed to be sacrificed is then calculated as 50 percent (the share of HDPUV market that are assumed to be commercial operators) of the value of these net private benefits.[274] Since there is uncertainty over this quantity, NHTSA ran an additional, edge-case sensitivity case in which it assumes that all consumers are commercial buyers who would experience opportunity costs that would offset any private fuel saving benefits.

In Table 9-6 we find that after adjusting for this offset for the case in which commercial operators represent half of the HDPUV market, social net-benefits decrease by just under $1.6 billion. When the entire market is commercial, social net-benefits decrease by around $3.1 billion. In both cases, net benefits remain significantly positive. Assuming the entire market is filled with commercial operators is an extreme assumption that is at odds with available evidence from the current composition of the market, and the projected future market share of commercial operators, and is included here solely as a test of model sensitivity to assumptions. Even in this upper-bound case, NHTSA finds that the results are not overly sensitive to this input assumption.

NHTSA's analysis suggests that market failures affect the heavy-duty vehicle market, which plays a role in limiting the adoption of fuel efficiency-improving technologies. Many heavy-duty vehicle purchasers are individual consumers, who may be subject to the same behavioral and market failures mentioned above, such as loss aversion, asymmetrical information, and status quo bias. Some institutional (e.g., government) or commercial actors may also experience those same behavioral biases. Commercial actors in the heavy-duty market may also experience other market failures and uncertainties, including short-termism, principal-agent split incentives, uncertainty about the performance and service needs of new technologies and first-mover disadvantages for consumers, uncertainty about the resale market, and market power and first-mover

[273] See Cox Automotive Inc. 2023. Fleet Sales Continue Hot Streak in May. Published: June, 2023. Available at: https://www.coxautoinc.com/market-insights/may-2023-fleet-sales/. (Accessed; Feb. 23, 2024).

[274] To approximate the commercial share of the HDPUV market we reviewed data submitted to the State of California by Truck and Engine Manufacturers Association on HDPUV sales in that state. We determined that roughly half of vehicles sold were pickup trucks intended for personal use. See https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fww2.arb.ca.gov%2Fsites%2Fdefault%2Ffiles%2F2018-11%2F181204emaanalysis_0.xlsx&wdOrigin=BROWSELINK. (Accessed: May 31, 2023). Data was submitted in advance of the California Air Resources Board's Dec. 4, 2018 Public Workshop Meeting to Provide an Update on Light- and Heavy-Duty Fleet Requirements and Public Workgroup to discuss Advanced Clean Trucks Regulation. More info: https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks/act-meetings-workshops. (Accessed: Feb. 23, 2024).

disadvantages among manufacturers.[275] Consistent with NHTSA's approach for light-duty vehicles, full fuel savings benefits are included in the reference baseline.

9.2.4. Effect of Social and Environmental Parameters

9.2.4.1. Electricity Grid Assumptions

Consistent with feedback and additional consultation with DOE, the analysis supporting this final rule uses a grid mix from the Electrification Futures Study (EFS),[276] specifically the 2022 Standard Scenarios forecast ("mid-case, nascent tech, current policies"), developed by the National Renewable Energy Laboratory (NREL). This grid mix forecast is mapped into GREET 2023 to develop the CAFE Model's electricity emission factors used in the Reference baseline. To better follow how deviations from this forecast assumption could affect costs and benefits as well as total emissions from the light duty and HDPUV fleets, we model two additional forecasts: 1) the AEO 2023 reference baseline grid forecast, that serves as the default electricity grid mix forecast for R&D GREET 2023, and 2) the EPA Post-IRA 2022 reference baseline with the Integrated Planning Model.[277]

The most prominent difference among the three modeled upstream emissions scenarios is the differing rates of renewable energy capacity in the US electricity grid mix, and hence the upstream electricity emission factors used as inputs in the CAFE Model. The time between NPRM and final rule was one of evolving understanding of numerous renewable electricity incentive programs; each of the three cases examined here assumes different trajectories for incentive availability, uptake, and resulting capacity buildout. In general terms, the AEO 2023 reference baseline is more conservative in its treatment of these programs, while the EPA Post-IRA forecast projects a more pronounced effect, especially in the later years of analysis. For further discussion on the upstream emissions sensitivity analysis inputs and underlying assumptions, please refer to the accompanying docket memo.[278]

Our findings show that differences in upstream emissions resulting from alternative electricity grid mix forecasts could alter overall emissions levels and net benefits in the LD and HDPUV fleets. Across cases, the AEO 2023 case generates a lower level of emissions reductions in the No-Action Alternative than the Reference baseline or EPA's Post-IRA forecast. Figure 9-20 shows a steady decline in emissions in the LD fleet across cases that generally follows the Reference baseline. The most significant deviation occurs beyond roughly CY 2039, at which point the EPA Post-IRA case declines at a more rapid rate. The AEO 2023 case and the Reference baseline converge to similar values by CY 2050. A similar trend is present in the HDPUV results Figure 9-21, however the difference across sensitivity cases is less pronounced, especially beyond CY 2040. In both fleets, the EPA Post-IRA forecast projects higher levels of reference baseline emissions than the Reference baseline before CY 2040.

[275] E.g., Birky et. al (2017) note that small manufacturerers are hesitent to enter the market due to fear of competition from the large OEMs. Also, Lowell and Culkin (2021) notes that the classes in this group remain dominated by the "big 3" US car companies. See Lowell, D., Culkin, J. 2021. Medium- and Heavy-Duty Vehicles: Market Structure, Environmental Impact, and EV Readiness. Available at: https://www.erm.com/globalassets/documents/mjba-archive/reports/2021/edfmhdvevfeasibilityreport22jul21.pdf. (Accessed: Feb. 23, 2024).
[276] National Renewable Energy Laboratory. 2022. Electrification Futures Study: 2022 Standard Scenarios. Available at: https://scenarioviewer.nrel.gov/?project=fc00a185-f280-47d5-a610-2f892c296e51&layout=Default. (Accessed: Jan. 2024),
[277] EPA. 2023. Post-IRA 2022 Reference Case: EPA's Power Sector Modeling Platform v6 Using Integrated Planning Model (IPM). Apr. 5, 2023. Available at:https://www.epa.gov/power-sector-modeling/post-ira-2022-reference-case.
[278] See the Electricity Grid Forecast Docket Memo.

Figure 9-20: Total LD Fleet NO_X and CO2 Emissions in the No-Action Alternative by Sensitivity Case

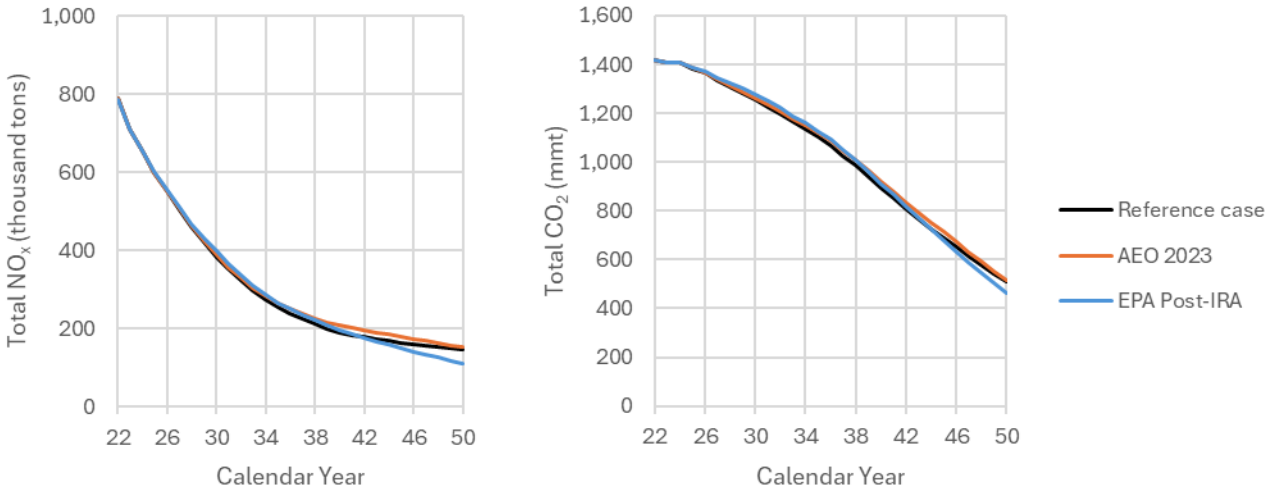
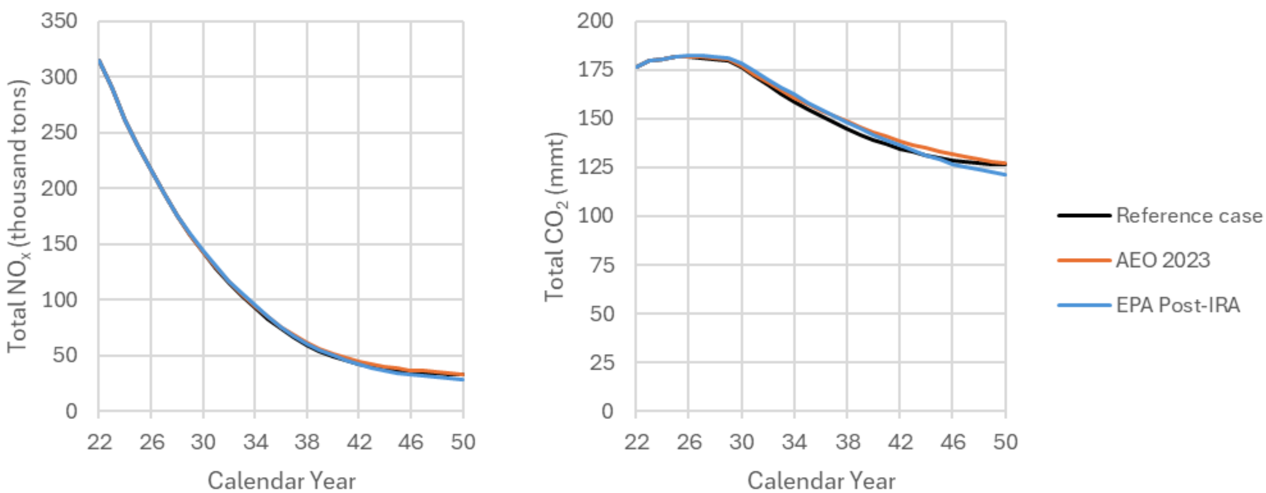


Figure 9-21: Total HDPUV Fleet NO_X and CO_2 Emissions in the No-Action Alternative by Sensitivity Case



The deviation in reference baseline emissions between cases is clearer when parsing out total upstream electricity emissions, as shown in Figure 9-22 (LD) and Figure 9-23 (HDPUV).[279] These plots show higher reference baseline emissions levels in the AEO 2023 scenario across all calendar years through 2050 and for the EPA Post-IRA scenario through 2040. However, in the context of total emissions effects, the changes are small. For example, in the LD fleet, alternative PC2LT002 reduces CO_2 emissions by about 2.22 percent relative to levels in the No-Action Alternative. In the AEO 2023 sensitivity case, the reduction is 2.12 percent and under the EPA Post-IRA case, it is 2.21 percent. Table 9-11 summarizes these emissions effects across sensitivity cases. Results for other pollutants show similar magnitude reductions and changes across sensitivities.

[279] These figures report total fleet-wide emissions, so they capture both total fuel use and emissions rates. For a detailed discussion of differences in emission rates and their sources for the sensitivity cases discussed in this section, see the aforementioned Electricity Grid Forecast Docket Memo.

Figure 9-22: LD Fleet Upstream Electricity NO_X and CO_2 Emissions in the No-Action Alternative by Sensitivity Case

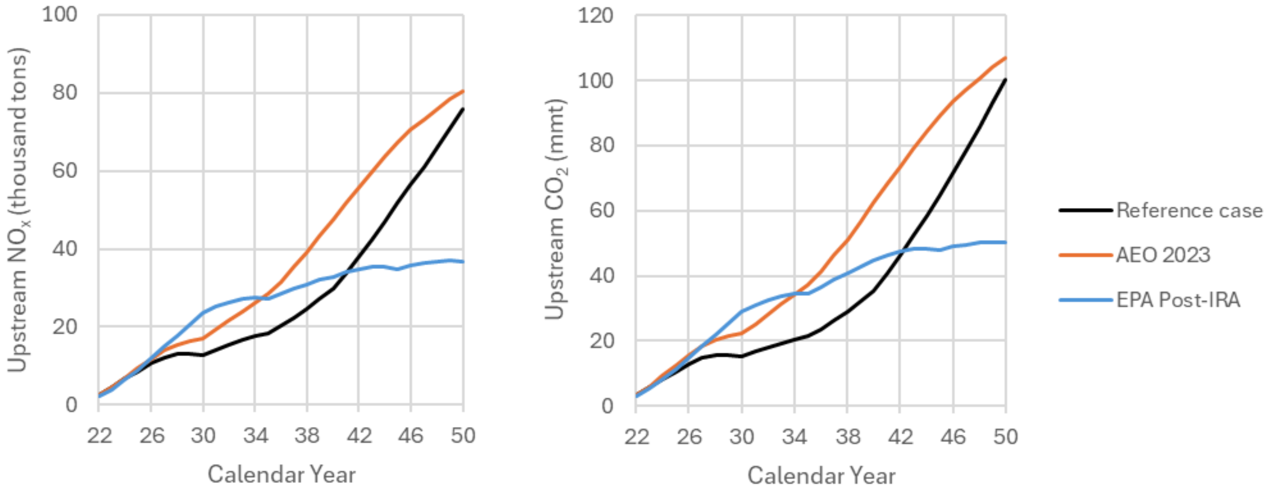


Figure 9-23: HDPUV Fleet Upstream Electricity NO_X and CO_2 Emissions in the No-Action Alternative by Sensitivity Case

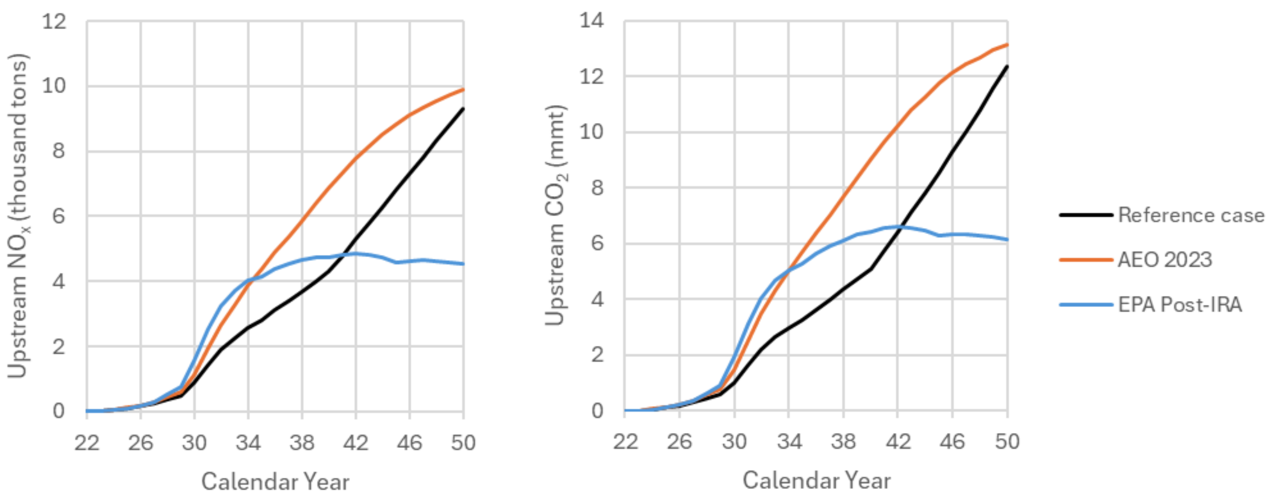


Table 9-11: Emissions Summary, LD Fleet, CY 2022-2050, by Sensitivity Case[280]

	Reference baseline			AEO 2023			EPA Post-IRA		
	No Action	PC2LT002 Change	% Change	No Action	PC2LT002 Change	% Change	No Action	PC2LT002 Change	% Change
GHGs									
CO_2 (mmt)	29,628	-659	-2.22%	30,059	-638	-2.12%	29,800	-660	-2.21%
CH_4	40,354	-825	-2.04%	41,156	-782	-1.90%	41,926	-834	-1.99%
N_2O	1,189	-23	-1.97%	1,197	-23	-1.93%	1,202	-24	-2.00%
Criteria Pollutants									

280 Values in thousands of tons unless otherwise noted.

	Reference baseline			AEO 2023			EPA Post-IRA		
	No Action	PC2LT002 Change	% Change	No Action	PC2LT002 Change	% Change	No Action	PC2LT002 Change	% Change
CO	173,453	-1,025	-0.59%	173,602	-1,016	-0.59%	173,458	-1,022	-0.59%
VOC	20,150	-237	-1.18%	20,193	-235	-1.16%	20,155	-236	-1.17%
NO_X	9,276	-57	-0.62%	9,533	-44	-0.46%	9,257	-57	-0.62%
SO_2	1,315	1	0.06%	1,584	14	0.91%	1,232	-6	-0.49%
$PM_{2.5}$	924	-5	-0.49%	947	-3	-0.35%	921	-5	-0.51%

When interpreting these results, it is important to emphasize that sensitivity cases examining the effect of alternative grid mix assumptions test a model parameter that is subject to a high degree of uncertainty. This is especially true given recent developments in energy market technology, policy, and economics. Therefore, the energy use projections of the Reference baseline may be conservative to the extent that either the AEO 2023 or NREL 2022 projections do not incorporate other components that influence energy markets. Additionally, as these two alternative grid mix sensitivity cases only modify upstream CAFE emission factors for GHGs and criteria pollutants, the only monetized changes from the Reference baseline are a result of avoided health damage costs of criteria pollutants and avoided SC-GHG values. No other incremental costs, such as changes in the levelized costs of electricity due to capacity investment, have been considered in the CAFE modeling.

At a 3 percent social discount rate, both grid forecast sensitivity cases reduce net benefits relative to the Reference baseline. Assuming a 2.0 percent SC-GHG discount rate, the AEO 2023 forecast reduces net benefits by $1.1 billion, and the EPA Post-IRA forecast reduces net benefits by $0.4 billion, both computed over the lifetime of light duty vehicles through MY 2031. Because the AEO 2023 case assumes higher emissions levels for electricity use, any additional electricity consumption in the action alternatives results in a smaller reduction in emissions relative to levels in the No-Action Alternative. This in turn reduces net benefits. The behavior in the EPA Post-IRA forecast is more complex, as emissions rates are initially higher than the Reference baseline but are lower – in some cases significantly lower – beyond 2040. This produces lower net benefits through CY 2040 than in the Reference baseline, but higher net benefits than the Reference baseline in the remaining years. In total, the net benefits reductions prior to CY 2040 slightly outweigh the increases in later years, producing fewer net benefits overall for PC2LT002 in the EPA Post-IRA case relative to the Reference baseline.

When assessing HDPUV standards, NHTSA relies on calendar year accounting for its benefit-cost analysis. This, combined with the lack of statutory restrictions on considering electrification, leads the effect of the two alternative upstream electricity mix scenarios to differ from that in the light duty fleet. The AEO 2023 forecast reduces benefits by approximately $0.6 billion at a 3 percent social discount rate and 2.0 percent SC-GHG discount rate. The EPA Post-IRA forecast increases net benefits by $0.4 billion. Calendar year accounting examines the entire on-road fleet beyond the years for which proposed standards are set through CY 2050. In the case of the EPA Post-IRA forecast, this results in additional benefits where the sensitivity forecast shows lower electricity upstream emissions relative to the Reference baseline. To the extent that the proposed alternative leads to increased electrification, a grid with more renewables in the out years will generate more net benefits than a grid with higher emission factors.

9.2.4.2. Tailpipe Emissions Assumptions

The analysis in this final rule incorporates downstream emission factors from MOVES4, as discussed in TSD 5.3. We analyzed the effect of this change by running a version of the model using the tailpipe emission factors from the NPRM, which were derived from MOVES3. Effects reported in Chapter 9.2.1 are marginal, in most cases within the bounds of rounding for both the LD and HDPUV fleets. Overall tailpipe emissions reductions from the action alternative were slightly smaller using MOVES3 input values in the LD fleet but increased by less than 0.2 percentage points across all modeled emissions. Results for the HDPUV analysis were of similar magnitude except total tailpipe emissions of N_2O and VOC, which decreased under MOVES3 assumptions by 0.8 percent and 0.3 percent, respectively.

9.2.4.3. Mass-Size Safety and Crash Avoidance

Estimates regarding the future safety impacts of CAFE requirements reflect our best judgment regarding the evolution of factors that affect vehicle safety. Nevertheless, there is some uncertainty regarding the values applied to the CAFE safety analysis. These uncertainties include (1) the joint effects of the mass effects model across vehicle classes; (2) estimates of driver behavior; and (3) the effectiveness of crash avoidance technologies. To address these uncertainties, we perform five sensitivity analyses that adjust underlying safety parameters for both the light duty and HDPUV fleets. Table 9-12 provides values for the number of fatalities, social costs, and social benefits for Alternatives PC2LT002 and HDPUV108. Below those values, the table provides the difference in these outcomes when different safety assumptions are applied to Alternatives PC2LT002 and HDPUV108 respectively.[281] In each of the following sensitivity checks, all inputs are held constant other than the noted safety parameter. The models use a 3% discount rate for dollar valuations. Fatalities are not discounted.

(1) Adjustments to the mass parameters influence the assumed average mass disparity between vehicles in crashes. A lower mass disparity between vehicles reduces fatalities and a higher mass disparity increases fatalities. For the light duty fleet, lowering the mass disparity parameter reduces the number of fatalities attributable to alternative PC2LT002 by 645. Increasing the mass disparity parameter results in an additional 644 fatalities. For HDPUV fleet, there is one less fatality for lower mass disparity and one greater fatality for higher mass disparity in HDPUV108 under these sensitivity cases.

For the light duty fleet, the gain in net social benefits from assuming a low mass safety parameter is $2.5 billion. Conversely, the loss from assuming a high mass safety parameter is a $2.5 billion reduction relative to PC2LT002. The relative difference in net social benefits for the HDPUV fleet is a gain of approximately $20 million dollars from the low mass parameter, and a $20 million loss from assuming a high mass parameter.

(2) Since the 2019 COVID pandemic, traffic and vehicle fatalities have increased across U.S. roadways. This increase is a deviation from previous trends, and we do not yet know whether or how fast fatalities will decline to pre-pandemic levels (or even lower), though they have leveled off and declined slightly from 2021 to 2022. As a sensitivity analysis we apply 2022 fatality rates as a reference baseline from which to estimate future fatalities occurring under PC2LT002. This results in an additional 58 deaths. For the HDPUV fleet, there are two additional fatalities for HDPUV108 under this sensitivity case.

For the light duty fleet, the additional loss in net social benefits from using 2022 fatalities rates as a reference baseline is $500 million. For the HDPUV fleet, the additional loss in net social benefits from using 2022 fatalities rates as a reference baseline is approximately $40 million.

(3) Many crash avoidance technologies are nascent, and the future effectiveness of these technologies is uncertain. Higher technology effectiveness rates tend to increase the social costs of delaying new vehicles from entering the fleet. Lower technology effectiveness rates tend to reduce the social costs of slowing vehicle turnover, since the relative safety difference between new vehicles and old vehicles on the road decreases. Under the sensitivity analysis assuming low effectiveness of these technologies there would be an additional 18 fatalities. Under a scenario with high technological effectiveness there would be 26 fewer deaths. There is no discernable effect on the HDPUV fleet under alternative HDPUV108 under either sensitivity case.

For the light duty fleet, the gain in net social benefits from assuming a low technological effectiveness is less than $100 million. Conversely the loss from assuming a high technological effectiveness is less than a $100 million relative to PC2LT002. The relative gain in net social benefits for the HDPUV fleet is approximately $10 million from assuming a low technological effectiveness and the loss from assuming high technological effectiveness less than $10 million.

[281] While changes in the safety parameters affect fatalities, non-fatal injuries and property damage crashes, Table 9-10 provides only differences in fatalities. Changes in net social benefit of each scenario includes the social value of non-fatal injuries, and property damage crashes attributable to changes in the sensitivity paratmeter.

Table 9-12: Relative Differences Between RB and Sensitivity Cases, Light Duty and HDPUV Fleets, 3% Social Discount Rate, 2.0% SC-GHG Discount Rate

	Light Duty				HDPUV			
Scenario	Fatalities	Total social costs ($b)	Total social benefits ($b)	Net social benefits ($b)	Fatalities	Total social costs ($)	Total social benefits ($b)	Net social benefits ($b)
Reference	442	24.5	47.1	22.7	-6	1.58	8.99	7.41
Sensitivity Cases	**Difference From Reference PC2LT002**				**Difference From Reference HDPUV108**			
Mass-size-safety (low)	645	2.70	0.10	-2.50	1.00	0.01	-0.01	-0.02
Mass-size-safety (high)	-644	-2.60	-0.20	2.50	-1.00	-0.01	0.00	0.02
Crash avoidance (low)	-18	-0.10	-0.20	0.00	0.00	0.00	-0.01	-0.01
Crash avoidance (high)	26	0.10	0.10	0.00	0.00	0.00	0.00	0.00
2022 FR fatality rates	-58	0.40	0.70	0.50	-2.00	-0.03	0.01	0.04

9.2.4.4. Social Cost of Greenhouse Gases (SC-GHGs)

The social costs of three greenhouse gases (SC-GHGs) are quantified in our analysis: CO2, CH4, and N2O. NHTSA's analysis quantifies resulting changes in emissions of three important greenhouse gases (SC-GHGs): CO_2, CH_4, and nitrous oxide (N_2O). These costs are monetized to represent the value to society of reducing a GHG by one ton. TSD Chapter 5 details how NHTSA estimates changes in GHG emissions expected to result from the different rulemaking alternatives and TSD Chapter 6 includes a discussion of how these costs are derived. The agency calculates the monetized climate benefits resulting from anticipated reductions in emissions of each of these three GHGs using estimates of the social costs of greenhouse gases (SC-GHG) values reported in a recent report from EPA (hereinafter referred to as the "2023 EPA SC-GHG Report").[282] In the proposed rule and numerous prior analyses, NHTSA used values reported by the federal Interagency Working Group (IWG) on the SC-GHG.[283] NHTSA has elected to use the updated values in the 2023 EPA SC-GHG Report to reflect the most recent scientific evidence on the cost of climate damages resulting from emission of GHGs.

We include the interim IWG values from 2021 in a sensitivity case as they are those used in the NPRM prior to updating to the values used in the central analysis. Since the SC-GHG affects only the monetization of GHGs and does not factor into the technology choices in the CAFE Model pathways, or any of the other dynamic models, only benefits and net benefits are impacted in our results. The direction of the changes between the reference baseline and the preferred alternative (PC2LT002) remains the same in the reference baseline and the alternative SC-GHG values case, but the magnitude of benefits is smaller in the alternative SC-GHG values case. In the preferred alternative, social benefits are $36.1 billion in the 3% IWG SC-GHG

[282] EPA. 2023. EPA Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances. National Center for Environmental Economics, Office of Policy, Climate Change Division, Office of Air and Radiation. Washington, D.C. Available at: https://www.epa.gov/environmental-economics/scghg. (Accessed: March 22, 2024) (hereinafter, "2023 EPA SC-GHG Report").

[283] Interagency Working Group on Social Cost of Greenhouse Gases, United States Government. 2021. Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990. White House. 1-48. Available at: https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf. (Accessed: Feb. 14, 2024).

case and $59.7 billion in the reference baseline. Net social benefits are 11.6 billion in the 3% IWG SC-GHG case and 35.2 billion in the reference baseline. Costs and all other metrics are unaffected.

9.2.5. Effect of Policy-Related Parameters

9.2.5.1. EPCA Standard-Setting Year Conditions

EPCA places a set of conditions on the consideration of the fuel economy of AFVs and the application of compliance credits when determining maximum feasible fuel economy standards for PCs and LT. Specifically, 49 U.S.C. 32902(h) states that when determining maximum feasible CAFE standards, NHTSA:

1. may not consider the fuel economy of dedicated automobiles,
2. shall consider dual fueled automobiles to be operated only on gasoline or diesel fuel, and
3. may not consider, when prescribing a fuel economy standard, the trading, transferring, or availability of credits under 49 U.S.C. 32903.[284]

Section VI.A.5.a.5 (titled "Factors that NHTSA is Prohibited from Considering") of the preamble discusses these provisions in greater detail.

As discussed in that section, NHTSA interprets 32902(h) as applying to the agency's consideration of MYs that are the subject of the rulemaking at hand, but not to MYs beyond the rulemaking time frame. To evaluate the effects of extending these conditions beyond the rulemaking time frame (in this instance, prior to MY 2027 and/or beyond MY 2031), NHTSA conducted three additional sensitivity cases:

1. applying standard-setting conditions to MYs 2027-2035,
2. applying standard-setting conditions to MYs 2027-2050, and
3. applying standard-setting conditions to MYs 2023-2050.

In general, the impact of extending the EPCA standard-setting condition years reduces the estimated net social benefits of the Preferred Alternative. However, it is important to note that net social benefits remain positive for each sensitivity case. Compared to the reference baseline, applying standard-setting conditions to:

- MYs 2027-2035 result in a 1.1 billion dollar increase in social costs, a 0.5 billion dollar decrease in social benefits, and a 1.6 billion dollar decrease in net social benefits;
- MYs 2027-2050 result in a 2.2 billion dollar increase in social costs, a 1.4 billion dollar decrease in social benefits, and a 3.6 billion dollar decrease in net social benefits;
- MYs 2023-2050 result in a 16.6 billion dollar decrease in social costs, a 39.9 billion dollar decrease in social benefits, and a 23.3 billion dollar decrease in net social benefits.

When compared to the reference baseline, gasoline consumption and CO_2 emissions decrease under sensitivity cases 1 and 2. Conversely, when compared to the reference baseline, gasoline consumption and CO_2 emissions increase under sensitivity case 3; however, there continues to be an overall reduction in those metrics when compared to the No-Action Alternative. When compared to the reference baseline, electricity consumption increases under sensitivity case 1 before decreasing under sensitivity cases 2 and 3. While electricity consumption increases and decreases relative to the reference baseline, it stays positive relative to the No-Action Alternative for each sensitivity case.

In MY 2031, the technology penetration simulations resulted in an increase in the adoption of SHEVs and PHEVs for all these sensitivity cases. Compared to the reference baseline, applying standard-setting conditions to:

- MYs 2027-2035 result in a 1.2 percent increase in the number of SHEVs and PHEVs in MY 2031,
- MYs 2027-2050 result in a 1.2 percent increase in the number of SHEVs and PHEVs in MY 2031,
- MYs 2023-2050 result in a 22.9 percent increase in the number of SHEVs and PHEVs in MY 2031.

[284] 49 U.S.C. 32902.

On average, when compared to the reference baseline, MY 2031 vehicle costs are:

- $3 per vehicle higher when standard-setting conditions are applied to MYs 2027-2035,
- $3 per vehicle higher when standard-setting conditions are applied to MYs 2027-2050,
- $285 per vehicle lower when standard-setting conditions are applied to MYs 2023-2050.

These trends occur because the model's technology solution to comply with both NHTSA and EPA's MYs 2023-2026 standards changes costs in the reference baseline. Additional information about the reference baseline is discussed in preamble Section IV.

9.2.5.2. Tax Credit

In the reference baseline, NHTSA includes the impact of three tax credit provisions of the IRA: two of the CVCs, and the AMPC. The former are paid to purchasers of qualifying clean vehicles, while the latter is paid to the manufacturers of qualifying battery cells and modules. NHTSA recognizes that there is uncertainty over both the value of each credit that vehicles employing these technologies will qualify for, and the degree to which these credits are captured by consumers and manufacturers. For example, the § 30D credit has requirements related to mineral sourcing, the price of new vehicles, and the income of purchasers that may limit the ability of some vehicles and batteries to qualify for the incentive, while § 45W is only available to commercial entities including lease programs. After NHTSA completed its proposal, DOE completed a report projecting the combined average nominal value of the CVCs that are expected to paid out to qualifying vehicle purchasers during the period in which the credits remain in effect.[285] For the final rule, NHTSA relied on these projections in its central analysis. The incidence of these credits is also uncertain and will in practice be split between consumers and producers, and the overall shares captured by each will depend on the elasticities of supply and demand, as well as the pricing and manufacturing strategies of producers.

NHTSA tested the sensitivity of both the average expected value of the credits and their incidence for its analysis. First, we set the values of the CVCs and the AMPC to $0 in the "No EV Tax Credits" case. This simulates the impact of assuming that no vehicles or batteries qualify for the IRA credits. In a separate case we simulate the effect of removing the AMPC and retain the CVCs at their Reference baseline level. In Table 9-2, we show that compared to the Reference baseline, removing the AMPC increases net social benefits by $3.9 billion under 3 percent discounting, and removing both AMPC and CVCs increases net benefits by a little over $1 billion above levels seen in the Reference baseline. While removing the credits will affect the level of electrification in the pre-standard setting years, it will only influence adoption of PHEVs during the standard setting years. PHEV adoption in the No-Action Alternative is somewhat lower in each case relative to the Reference baseline, while incremental adoption in the preferred alternative is higher in the "No AMPC" case and lower in the "No EV tax credits" case. Incremental SHEV adoption is also higher in the "No AMPC" case than in the Reference baseline. We find larger impacts in the HDPUV fleet. In Table 9-6 each adjustment increases the social net benefits of the Preferred Alternative by more than $30 billion for the HDPUV fleet. We next evaluated increasing the average value of the CVCs to its maximum nominal possible value of $7,500 for each qualifying vehicle. This scenario assumes that every vehicle with qualifying technology would either meet the mineral sourcing requirements in the IRA, as well as the pricing and income requirements, or be sold as a commercial vehicle (including leases to consumers). We find that this has a significant impact on net benefits for HDPUV, as they drop below $0. For light duty the impact is a decrease of about $4.4 billion in net benefits. Since producers receive a larger benefit in this case relative to the Reference baseline, they apply more costly, but also more fuel-efficient technology in the No-Action Alternative. As a result, increasing the standards does not force as much additional technology adoption (fewer vehicles are transitioned to BEVs in the HDPUV fleet for example). This causes the final standards to have a less beneficial impact. We ran two additional cases, one in which we allowed CVC credit values to follow a linear path rather than using DOE's schedule, and one in which we used the schedule of CVC values from the NPRM as the nominal basis for modeling the credit. The linear schedule of credits has little impact on either light duty or HDPUV net benefits. However, using the NPRM credit values causes HDPUV net benefits to fall below zero. This is once again due to the large shifts in reference baseline electrification that take place when inputs are changed in

[285] DOE. 2024. Estimating Federal Tax Incentives for Heavy Duty Electric Vehicle Infrastructure and for Acquiring Electric Vehicles Weighing Less Than 14,000 Pounds. Memorandum. Mar. 11, 2024. See TSD Chapter 2.5.2, and Preamble III.C.5 for details on how NHTSA modeled the IRA tax credits in its central analysis.

the HDPUV analysis. The findings suggest that the PC and LT fleet's results are somewhat sensitive to the average value of the realized credits. HDPUV results show greater sensitivity to these assumptions, especially when the credits pass a certain threshold and cause significantly higher electrification in the reference baseline.

We next evaluate the effect of adjusting our central assumption that the incidence of the credits is split evenly between producers and consumers. In our Reference baseline, any credit captured by producers effectively decreases the cost of production for the vehicle, while any share captured by consumers decreases the price paid. In our sensitivity analysis we tested the impact of allowing consumers to capture 75 percent of the credits ("Consumer tax credit share 75%"), and 25 percent of the credits ("Consumer tax credit share 25%"). In the first case we would expect technology adoption to be lower in the No-Action Alternative, since producers must pay a higher price in the compliance simulation for technology eligible for the tax credit. In the second case we would expect technology adoption to be higher (the tax credit reduces compliance technology costs more than it does in the central analysis), but for overall sales to decline relative to the Reference baseline (the prices consumers that face are higher than in the central analysis). For the light-duty analysis we found that PHEV adoption rates in the No-Action Alternative are indeed lower by about 1.4 percent when consumers take home a larger share of the credit. This leads to slightly higher incremental PHEV adoption under the final standards. As shown in Table 9-2, under 3 percent discounting of benefits, we find in the "Consumer tax credit share 75%" scenario that net social benefits associated with the final standards are somewhat higher than in the Reference baseline for light duty. In the HDPUV fleet, net benefits are much more sensitive, as they rise by more than $30 billion. In this case, there are significant incremental adoptions of BEV technology in the preferred alternative, which does not happen in the Reference baseline. In the "Consumer tax credit share 25%" scenario, when we allow producers to capture more of the credits, we find that PHEV adoption in both the No-Action Alternative and under the final standards are both significantly higher than in the Reference baseline. This primarily comes at the expense of SHEV adoption in the No-Action Alternative. Net benefits from the Preferred Alternative shrink significantly, to less than $0 for HDPUV, but are not significantly affected for light duty. Together these results indicate first that the sensitivity of our results for the preferred alternative, in terms of its ability to produce positive net benefits, comes in the more optimistic cases for tax credit uptake. When credit uptake is low or non-existent, perhaps due to future difficulties manufacturers face in setting up supply chains that allow their vehicles to qualify for the credits, the preferred alternative spurs more incremental technology adoption and is more beneficial to society. The ability for manufacturers to capture more of the credit in our model is also important in determining their technology adoption decisions, as they over-comply significantly in the No-Action Alternative for HDPUV when they receive 75 percent of the credits. When manufacturers receive less of the credit, the HDPUV side again sees a larger impact, where the Preferred Alternative's higher standards bind for more of the manufacturers and generate significantly more incremental BEV adoption than in the Reference baseline. This is less true of the LD fleet, where making this assumption only causes the Preferred Alternative's impact on fuel cost savings to increase by about $13 per vehicle as shown in Table 9-3.

9.2.5.3. Petroleum Equivalency Factor

In the CAFE program for compliance, as required by law,[286] LD EVs receive a fuel economy adjustment called the petroleum equivalency factor (PEF), which adjusts fuel economy based on the portion of electricity used to power the vehicle. By statute, the DOE calculates and sets the PEF for use in CAFE compliance.[287]

The PEF value for EVs had remained unchanged since the year 2000 – set at a value of 82,049 Wh/gal; however recently, the DOE had proposed an update to the PEF value, completely removing the (1.0/0.15) fuel content factor (FCF) and updating electric grid assumptions, ultimately adjusting the PEF to 23,160 Wh/gal – roughly 28% of the PEF's original value – for BEVs starting in MY 2027.[288] NHTSA incorporated the proposed PEF into its reference baseline (RB) analysis for the NPRM. Since then, the DOE has modified the PEF value for its final rule – namely phasing out the FCF over time. The finalized set of PEF values for the duration of this rulemaking are now used in the reference baseline.

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[286] 49 U.S.C. 32904(a)(2)(B); 10 CFR part 474. Note that the PEF is not applicable to the HDPUV fleet.
[287] 49 U.S.C. 32904(a)(2)(B).
[288] 88 FR 21525 (Apr. 11. 2023).

The effects of the original PEF value (82,049 Wh/gal – used in previous CAFE rulemakings) as well as the originally proposed (notice of proposed rulemaking (NOPR)) PEF value (23,160 Wh/gal – used in the CAFE NPRM) were analyzed as sensitivity cases; we refer to these cases as the FCF case (as the circa-2000 PEF value includes this un-phased FCF within its calculation) and NOPR case, respectively. The FCF and NOPR sensitivity cases are discussed below, alongside the RB in relation to No Action and regulatory action under the Preferred Alternative.

Existing BEVs in manufacturers fleets, or BEVs built to comply with state ZEV programs, and BEVs voluntarily deployed consistent with ACC II levels change the technology compliance pathway to meet CAFE standards. For the FCF sensitivity, in the absence of CAFE standards (i.e., the No Action case), manufacturers that build BEVs have relatively high compliance CAFE values with relatively few BEVs in their fleets.[289] In response to CAFE standards, they add traditional ICE technology like HCR and TURBO technology, but do not need to add as much SHEV or PHEV technology (that is somewhat more expensive than ICE technology) because their BEVs carry most of the weight in improving their fleet fuel economy compliance values. In the reference baseline, manufacturers must add more of *both* traditional ICE and SHEV/PHEV technology to improve their fleet fuel economy compliance values. The following paragraphs discuss the technology penetration rates between the RB (with the finalized set of PEF values) and the FCF sensitivity case (with the original PEF value).

PHEV penetration was similar among both PEF sensitivities and the RB – resulting in 1.8% penetration for both the RB and FCF case and 2.0% for the NOPR case under No Action. Under the preferred alternative, the RB yielded a PHEV penetration of 5.7%; the FCF case resulted in 5.1% PHEV penetration, and the NOPR case yielded 5.0% PHEV penetration – both less penetration compared to the RB but within a similar range.

The RB resulted in SHEV penetration of 23.3% and 28.3% for the No Action and Preferred Alternative, respectively. The NOPR case yielded the highest SHEV penetration for both the No Action and the Preferred Alternative – 29.3% and 35.6% of the LD fleet, respectively. Conversely, lower SHEV values resulted from the FCF PEF sensitivity case – 21.4% SHEV penetration under No Action and 23.3% under the Preferred Alternative.

The NOPR PEF case resulted in relatively higher penetration rates of more conventional technologies like HCR technology under both No Action and under the preferred alternative – 20.6% and 17.9% of the fleet, respectively. The RB and FCF case yielded similar results under No Action – 22.2% and 22.1% HCR penetration, respectively. The FCF case yielded the greatest penetration of HCR technologies under the Preferred Alternative at 21.1% fleet penetration; the RB yielded 19.7% under the Preferred Alternative. Note that for HCR technology, the No Action values yield higher tech penetration compared to the preferred alternative.

Comparing the PEF sensitivities with the RB, net social benefits (the difference between total SCs and total social benefits) vary. The RB, under the 3% discount rate, yields net social benefits of $35.2B, under the Preferred Alternative over No Action; in contrast, the NOPR case yields the lowest social benefits – $26.9B. The FCF case yielded $29.7B in net social benefits. We note that net social benefits values are still positive under all PEF cases.

Under the 7% discount rate, the RB yields net social benefits of $30.8B, under the Preferred Alternative over No Action. The FCF PEF case, still in proximity to the other case values, yields lower net social benefits at 25.3$B. The NOPR PEF case results in the lowest net social benefits – $24.0B under the Preferred Alternative over No Action. As is the case under the 3% discount rate, net social benefits values are still positive under all PEF cases.

The consumer-specific benefits (the difference between regulatory cost and retail fuel expenditure) for each PEF case value show a cost savings for consumers under the Preferred Alternative over No Action. The RB, which uses the finalized set of PEF values, yields the greatest per-vehicle cost savings, valued at $247 savings per-vehicle. The NOPR case, which uses the proposed PEF value of 23,160 Wh/gal, yields the

[289] See also 88 FR 21530 (April 11, 2023) ("This approach demonstrates how the current PEF value leads to overvaluation of EVs in determining fleetwide CAFE compliance, which allows manufacturers to maintain less efficient ICE vehicles in their fleet by utilizing a few EV models to comply with the CAFE standards.").

lowest per-vehicle cost savings of $189; the original FCF PEF value of 82,049 Wh/gal yields a somewhat-higher per-vehicle cost savings of $224.

As with other sensitivity cases in this analysis, there are differences in additional metrics, such as gasoline and electricity consumption as well as CO_2 emissions. The largest difference in gasoline consumption between PEF cases was observed under the RB – resulting in 64 billion gallons of gasoline less under the Preferred Alternative compared to No Action. The NOPR PEF case yielded a smaller difference – 61 billion gallons less under the Preferred Alternative compared to No Action. The FCF PEF case yielded the smallest gasoline savings at 49 billion gallons.

All PEF cases yielded similar differences in electricity consumption between the Preferred Alternative and No Action. The greatest electricity consumption was also observed under the RB – 333 TWh more electricity was consumed under the Preferred Alternative compared to No Action. The NOPR PEF yielded a slightly smaller difference – 328 TWh between the Preferred Alternative and No Action. The FCF PEF case resulted in the lowest electricity consumption at 311 TWh over No Action.

The RB resulted in the greatest difference in CO_2 emissions between the Preferred Alternative and No Action – 659 MMT CO_2 less under regulatory action; the NOPR PEF case yielded similar savings of 636 MMT CO_2. The FCF PEF case resulted in a smaller difference – 501 MMT CO_2 less under the Preferred Alternative compared to No Action.

See Table 9-4 for additional metrics for all sensitivity cases and further discussion of the results in Chapter 9.2.1.

9.2.5.4. Zero-Emission Vehicles

NHTSA includes two sensitivity cases related to OEM plans to deploy zero-emission vehicles: No ZEV (also called the alternative baseline) and Reduced ZEV.

The No ZEV alternative baseline cancels out the process by which we assign ZEV candidates to the analysis fleet, wherein some sales volumes turn into ZEVs in the correct amount to align with our understanding of OEM deployment plans based on their comments, which is consistent with the amounts that would be required if the relevant Section 177 states had adopted the full extent of the ZEV programs developed by California. There are still BEVs and PHEVs present in the results of this case, but they are those that were already observed in the baseline fleet, as well as any made by the model outside of standard setting years in response to the assumption that manufacturers will apply technology that pays for itself within 30 months for LD BEVs (or in all years, in the case of PHEVs and HDPUV BEVs). In the reference baseline (Alternative 0), BEVs make up approximately 28 percent of the total light-duty fleet by MY 2031; they make up only 19 percent of the total light-duty fleet by 2031 in the No ZEV alternative baseline. Under the Preferred Alternative, PC2LT002, the tech penetration of BEVs by 2031 does not change compared to either baseline (reference and No ZEV alternative baseline, remaining at 28 percent and 19 percent respectively). This is as expected because we do not adopt BEVs in the standard setting years and the penetration of this technology in Alternative 0 is the penetration in the Preferred Standard.

PHEVs have virtually the same tech penetration in the reference baseline as in the no ZEV alternative baseline, as our focus in the ZEV modelling is not PHEVs, increasing only from 2 percent in the reference case to 3 percent in the No ZEV alternative baseline by MY 2031. Strong hybrids have a slightly higher tech penetration rate under reference baseline than in the No ZEV alternative baseline in model years between 2027 and 2031 at 27 percent compared to 23 percent in the reference baseline in MY 2031. This difference increases in magnitude under the preferred alternative PC2LT002 (28 percent in MY 2031 when compared to the reference baseline versus 45 percent when PC2LT002 is compared to the No ZEV alternative baseline).

The No ZEV alternative baseline also differs from reference baseline in terms of fuel consumption and electricity consumption, mainly because of how ZEV changes technology rates in the reference baseline. When the preferred alternative (PC2LT002) is assessed relative to the reference baseline, it results in a 64 billion gallon reduction in gasoline consumption; when assessed relative to the No ZEV alternative baseline, it results in a 115 billion gallon reduction in gasoline consumption. In the No ZEV alternative baseline analysis, this gasoline consumption is being measured relative to a baseline that has fewer BEVs and therefore has more room for gasoline consumption reductions when other technologies are applied. The increase in electricity consumption is also higher when the preferred alternative is compared to the No ZEV alternative baseline (493 TWh) relative to the reference baseline (333 TWh).

When Alternative PC2LT002 is assessed against the No ZEV alternative baseline, net benefits are higher than when it is assessed against the reference baseline. Using the 2% SC-GHG discount rate under the lifetime costs and benefits perspective (MY), net benefits change from $24.5 billion when using the reference baseline to $35.4 when using the No ZEV alternative baseline. Total benefits change from $59.7 billion when PC2LT002 is assessed relative to the reference baseline to $80.3 billion when assessed relative to the No ZEV alternative baseline and total costs increase from $24.5 billion when assessed relative to the reference baseline to $35.4 when assessed against the No ZEV alternative baseline. These changes in costs and benefits are driven partly by changes in technology application and the corresponding technology costs.

The reduced ZEV sensitivity case allows for increased use of banked credits in our modeling of the ACC I program, which is in place in our modeling in MYs 2022-2025, before the ACC II program could hypothetically take effect in MY 2026. In the reference baseline, we assume some use of banked credits towards ZEV deployment consistent with ACC II, but not ACC I (see TSD 2.5 for further discussion), We add expand this assumption for the reduced ZEV compliance case, anticipating that manufacturers will produce fewer ZEVs to comply with ACC I if they can also use banked credits in those earlier model years. In effect, this change in assumptions slightly decreases the percentage ZEV sales requirement in MYs 2022-2025 (from 14.5% to 11.6% in 2022, 17% to 13.6% in 2023, 19.5% to 15.6% in 2024, and 22% to 17.6% in 2025).

In terms of total technology penetration rates for BEVs, PHEVs, and strong hybrids, virtually no difference exists when the Preferred Alternative is assessed against the reduced ZEV alternative baseline versus the reference baseline, likely because our ZEV compliance approach focuses on model years in 2025 and beyond. In both cases (reference and reduced ZEV) under the preferred alternative, the BEV tech penetration rate grows to approximately 28 percent in MY 2031, while strong hybrids reach 28 percent and PHEVs reach 6 percent in MY 2031. Thus, PC2LT002 has very similar net benefits when assessed relative to the reference case ($35.2 billion) versus the reduced ZEV compliance case ($34.4 billion), using the model year benefit-cost accounting perspective).

9.2.5.5. Circular A-4

While NHTSA was conducting the analysis for this rule, OMB finalized an update to Circular A-4 in 2023, giving additional guidance for conducting regulatory analyses. The effective date of the updated Circular is March 1, 2024, for regulatory analyses received by OMB in support of proposed rules, interim final rules, and direct final rules, and January 1, 2025, for regulatory analyses received by OMB in support of other final rules.[290] Though NHTSA submitted the final rule to OMB before the effective date, NHTSA has started to implement the changes in the updated circular. Specifically, NHTSA has included both a qualitative discussion of uncertainty and distributional effects, which are provided below as well as included updated and varying discount rates included in the sensitivity analysis.

There are likely to be sources of uncertainty in any analysis using estimated parameters and inputs from numerous models, including the CAFE Model. NHTSA currently addresses this uncertainty by varying key parameters and presenting the resulting net benefits, as is shown in this chapter. This type of sensitivity analysis varies one or two key parameters at a time and re-runs the model to produce an updated result. An alternative approach to addressing parameter uncertainty is by incorporating a Monte Carlo analysis. To conduct a Monte Carlo analysis in the CAFE Model context, NHTSA would identify a subset of pivotal parameters and specify underlying distributions for each parameter. The underlying distributions and their sufficient statistics may be sourced from literature and theory, the data and analysis used to estimate the parameter, or expert knowledge and feedback. A Monte Carlo simulation then takes a randomly generated draw from each of the underlying distributions for each of the pivotal parameters, runs the CAFE Model, outputs the final social benefits and costs, and then repeats the process with a new set of random draws from the distributions of each pivotal parameter. This simulation may be repeated several thousand times, with the result being a distribution of net social benefits. This final distribution of net social benefits represents an overall view of parameter uncertainty and may provide a more complex view of the effects of the regulation

[290] OMB Circular A-4 (2023), pp. 93.

compared to a partial sensitivity analysis. The choice of the pivotal parameters within the CAFE analysis may be informed by those variables which are highly influential in the analysis, those that contain natural uncertainty, and/or those that have been included in the sensitivity analysis in past rulemakings. Examples of such parameters may include SC-GHG values, social discount rates, sales elasticity values, future projected fuel prices, the length of the payback period, or electricity grid sensitivities. NHTSA is currently exploring approaches to selecting these key parameters, characterizing their underlying distributions, and incorporating Monte Carlo into the CAFE Model analysis.

NHTSA is also considering how to incorporate and analyze distributional impacts of the CAFE regulation. Although the CAFE Model reports results on a national basis, we recognize that costs, benefits, and other effects reported in our modeling framework could be distributed differently on a regional basis. One path is to consider certain effects from a regional standpoint using FHWA's definition of urbanized and nonurbanized areas.[291] Estimating net social benefits from a specific regional standpoint is currently not feasible due to a lack of availability of regional variation in certain datasets. However, some components of our BCA framework, such as criteria pollutant health damages accounting, already have some location variability built in on the input side and NHTSA is exploring regional variability in VMT and sales, noise and congestion, fuel prices, and labor effects. These results may be presented as an intermediary analysis before aggregating up to total net social benefits. In addition, any presentation of overall effects has variation in the precision of the estimates due to the types of uncertainty discussed above. As such, any intermediary distributional analyses would be presented and interpreted alongside overall social benefits and costs that include this uncertainty through Monte Carlo simulation.

The distribution of regulatory effects by income is highly correlated with the regional distribution, and any additional study of the effects by income group would likely occur after a regional analysis has been conducted. This is due to the data that informs the CAFE analysis containing higher degrees of regional variation and information than income information. Such an analysis may speak to the issue of vehicle affordability for differing consumer groups and resulting changes in consumer surplus that may result from the regulation. The updated Circular A-4 allows agencies to better tailor their BCA approaches in light of their particular statutory mandates, which will be under consideration as NHTSA works on refining its distributional analysis of CAFE.

In its quantitative analysis, NHTSA considers the use of alternative discount rates for both the social discount rate as well as long-term discounting for costs and benefits related to GHGs. The 2023 update to Circular A-4 offers several reasons for discounting the benefits and costs that accrue to future generations at a lower rate than the social discount rate. These reasons include the uncertainty in the changes of the social rate of time preference over multiple generations, which are correlated over time and result in the certainty-equivalent discount rate having a declining schedule.[292] OMB offers a stepped schedule of discount rates over a 150-year horizon, including a discount rate of 2 percent for 2023-2079, 1.9 percent for 2080-2094, and 1.8 percent for 2095 to 2105.[293] NHTSA has considered the application of this stepped schedule for estimating the present value of GHG-related benefits and costs (as these may be included under the definition of long-term impacts), and the net present value of social benefits under this schedule are functionally the same as those presented in our central analysis under the 2 percent SC-GHG case. In addition to this, NHTSA has included the updated Circular A-4's recommendation regarding the social discount rate. The sensitivity analysis includes the incorporation of a social discount rate of 2 percent, which is a change from the discount rate recommended in the 2003 version of Circular A-4. This lower discount rate results directly from changing long-term market rates and the OMB using updated data to measure how the market values tradeoffs of consumption over time. The real rate of return on long-term U.S. government debt provides an approximation of the social rate of time preference, and over the last thirty years this rate has averaged around 2 percent in real terms.[294] This rate accounts for a real rate of 1.7 percent per year, to which OMB adds a 0.3 percent per-year rate to reflect inflation as measured by the personal consumption expenditure inflation index. In the corresponding sensitivity case, this updated social discount rate is applied to all non-GHG related benefits and costs. Compared to a social discount rate of 3 percent, a discount rate of 2 percent represents a slightly greater societal willingness to trade off current consumption for future consumption; that is, both costs and

[291] https://highways.dot.gov/safety/hsip/spm/urbanized-and-nonurbanized-safety-target-setting-final-report/30-geography.
[292] OMB Circular A-4 (2023), p.80.
[293] OMB Circular A-4 Appendix (2023), p.2.
[294] OMB Circular A-4 (2023), p.76.

benefits that occur in the future are not discounted as much as they were under a 3 percent rate and thus their present values increase. Since the stream of costs and benefits of the regulation are such that costs tend to occur sooner while the benefits accrue in later years, this change of discount rate leads to a larger present value of net social benefits compared to the Reference baseline. In the Preferred Alternative, this represents an increase of net social benefits of about $2 billion in the light-duty fleet – from $22.7 in the Reference baseline to $24.7 billion under the 2.5 percent SC-GHG case, from $35.2 in the Reference baseline to $37.2 billion under the 2 percent SC-GHG case, and from $58.7 billion in the Reference baseline to $60.8 billion under the 1.5 percent SC-GHG case.