U.S. Department Of Transportation

National Highway Traffic Safety Administration

Preliminary Regulatory Impact Analysis:

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

August 2021

1. Introduction

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

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

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

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

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[1] *See* 49 U.S.C. Section 32902 and Section VI of the preamble that this PRIA accompanies for more information.

[2] Throughout this PRIA, cost and benefit analyses are presented for individual model years as well as the cumulative total for all model years through MY 2029, although some physical effects are presented on a calendar year basis instead, as appropriate.

[3] This analysis does not contain NHTSA's assessment of the potential environmental impacts of the proposed rule for purposes of the National Environmental Policy Act (NEPA), 42 U.S.C. 4321-4347, which is contained in the agency's Supplemental Environmental Impact Statement (SEIS) accompanying the proposal.

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

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

Although NHTSA and EPA took separate actions in this round of rulemaking for a variety of reasons, NHTSA sought to coordinate its action with EPA's to the greatest extent possible given our statutory and programmatic differences. To NHTSA's knowledge, the proposed CAFE and GHG standards for MY 2026 represent roughly equivalent levels of stringency and may serve as a coordinated starting point for subsequent standards. While the proposed CAFE and GHG standards for MYs 2024-2026 are different, this is largely due to the difference in the "start year" for the revised regulations – EPA is proposing to revise standards for MY 2023, while EPCA's lead time requirements prevent NHTSA from proposing revised standards until MY 2024. The differences in what the two agencies' standards require become smaller each year, until alignment is achieved.

While NHTSA's and EPA's programs differ in certain other respects, like programmatic flexibilities, those differences are not new in this proposal. Some parts of the programs are harmonized, and others differ, often as a result of statute. Since NHTSA and EPA began regulating together under President Obama, differences in programmatic flexibilities have meant that manufacturers have had (and will have) to plan their compliance strategies considering both the NHTSA standards and the EPA standards and assure that they are in compliance with both, but they can still build a single fleet of vehicles to accomplish that goal. NHTSA is proposing CAFE standards that increase at 8 percent per year over MYs 2024-2026 because that is what

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

NHTSA has tentatively concluded is maximum feasible in those model years, under the EPCA factors, and is confident that industry would still be able to build a single fleet of vehicles to meet both the NHTSA and EPA standards. For purposes of this PRIA, we have only attempted to report costs and benefits for the proposed NHTSA CAFE standards, and not also EPA's proposed standards. We refer readers to EPA's documents for more information about their proposal and its effects, and note that costs and benefits of the two programs will largely overlap, since manufacturers will take many actions that respond to both programs simultaneously.

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

As stated above, NHTSA is proposing standards for passenger cars and light trucks that the agency tentatively concludes represent maximum feasible CAFE standards for MYs 2024-2026, pursuant to its statutory authority. While the actual standards being proposed are footprint-based target curves, NHTSA estimates that the proposed standards would require, on an average industry fleet-wide basis, roughly 48 miles per gallon (mpg) in Model Year 2029.

NHTSA projects that under these proposed standards, required technology costs would increase by $79.6 billion over the lifetimes of vehicles through MY 2029. 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 vehicles would increase by roughly $1,000, on average, as compared to if the baseline standards were retained; but concurrently, fuel savings for those vehicles would increase significantly, by roughly $1,200, undiscounted, on average. Overall total discounted benefits attributable to the proposal vary from $121 billion at a 3 percent discount rate (2.5 percent discount rate for social cost of greenhouse gas) to $76 billion at a 7 percent discount rate (3 percent discount rate for social cost of greenhouse gas)[8]. Total discounted benefits are $110.5

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[5] 49 U.S.C. 32902(b)(1).

[6] 49 U.S.C. 32902(a).

[7] 49 U.S.C. 32902(f).

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

billion at a 3 percent discount rate (3 percent discount rate for the social cost of greenhouse). It is important to stress that these estimates could change – sometimes dramatically – with different assumptions. For example, if estimates of future fuel prices or the social cost of greenhouse gas are too low, corresponding input revisions could significantly increase net benefits. Similarly, if NHTSA's assumption about a rebound effect of 0.15 is too high, net benefits will increase, whereas if it is too low, net benefits would decrease. And NHTSA's assumption that vehicle sales will decline because consumers may only value 30 months of fuel savings produces slight increases in costs associated with safety. If that assumption is incorrect, net benefits outweigh costs by a somewhat larger margin. It is also worth stressing that, while net benefits are estimated to be higher under less stringent alternatives, NHTSA believes for purposes of this proposal that the maximum feasible standards are not likely to be ones that leave benefits on the table, as discussed in more detail in Section VI of the accompanying NPRM preamble.

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

Table 1-1 – Estimated Present Value of Benefits and Costs of Preferred Alternative for Model Years 2023 through 2026, 3% Discount Rate for All Costs and Benefits Besides GHGs (2.5% discount rate for Climate Benefits) (billions in 2018$)[9]

MY	Cost	Benefit	Net Benefits
2023	$5.6	$3.5	-$2.1
2024	$8.9	$13.6	$4.7
2025	$10.7	$21.2	$10.5
2026	$12.2	$27.5	$15.3
Sum	$37.4	$65.8	$28.4

NHTSA and EPA estimate benefits, costs, and net benefits using similar methodologies and achieve similar results, however different accounting approaches may give the false appearance of significant divergences. Table 1-1 presents NHTSA's results using comparable accounting to EPA's preamble Table 5. EPA also presents cost and benefit information in its RIA over calendar years 2021 through 2050. The numbers most comparable to those presented in EPA's RIA are those NHTSA developed to complete its Environmental Impact Statement (EIS) using

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

an identical accounting approach. This is because the EIS analysis is not constrained by NHTSA's statutory limitations, such as those in 49 U.S.C. 32902(h) prohibiting consideration of full vehicle electrification during the rulemaking timeframe, or consideration of the trading or transferring of overcompliance credits.[10] NHTSA's EIS analysis estimates $312 billion in costs, $443 billion in benefits, and $132 billion in net benefits using a 3% discount rate over calendar years 2021 through 2050 (2.5% discount rate for climate benefits).[11,12] NHTSA describes its cost and benefit accounting approach in Section V of the NPRM.

2. Baseline and Alternatives Considered

Agencies typically consider regulatory alternatives in proposals as a way of evaluating the comparative effects of different potential ways of accomplishing their desired goal. Executive Orders 12866 and 13563, as well as OMB Circular A-4, encourage agencies to evaluate regulatory alternatives in their rulemaking analyses.[13] This does not amount to a requirement that agencies evaluate the widest conceivable spectrum of alternatives. Rather, the range of alternatives must be reasonable and consistent with the purpose and need of the action.

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

- evolution of the market,
- changes in external factors affecting expected benefits and costs,
- changes in regulations promulgated by the agency or other government entities, and
- the degree of compliance by regulated entities with other regulations.[14]

The No-Action Alternative for this proposal differs in a variety of ways from the No-Action Alternative for the 2020 final rule. First, in the 2020 final rule, the No-Action Alternative

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[10] As the EIS analysis contains information that NHTSA is statutorily prevented from considering, the agency does not rely on this analysis in regulatory decision-making.

[11] *See* Chapter PRIA 6.5 for more information regarding NHTSA's estimates of annual benefits and costs using NHTSA's standard setting analysis. *See* Tables B-7-25 through B-7-30 in Appendix II of the PRIA for a more detailed breakdown of NHTSA EIS analysis.

[12] *See* Draft Supplemental Environmental Impact Statement Docket No. NHTSA-2021-0054.

[13] NEPA also requires agencies to compare the potential environmental impacts of their proposed actions to those of a reasonable range of alternatives. Regulations regarding implementation of NEPA require agencies to "rigorously explore and objectively evaluate all reasonable alternatives, and for alternatives which were eliminated from detailed study, briefly discuss the reasons for their having been eliminated." 40 CFR 1502.14.

[14] OMB Circular A-4, "General Issues, 2. Developing a Baseline." *Available at* https://obamawhitehouse.archives.gov/omb/circulars_a004_a-4/.

represented the most stringent CAFE standards under consideration; in this proposal, the No-Action Alternative represents the *least* stringent CAFE standards under consideration. This means that for readers seeking to compare results between this PRIA and the 2020 Final Regulatory Impact Analysis (FRIA), most of the incremental effects shown in this PRIA are in a direction that is opposite those in the 2020 FRIA.

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

- NHTSA has included California's ZEV mandate as part of the No-Action Alternative. NHTSA has already proposed to rescind the 2019 "SAFE I" rule,[15] and EPA has reopened consideration of whether to grant California a waiver to consider its ZEV mandate.[16] Additionally, California reports that overcompliance with the ZEV mandate has been widespread even under circumstances where California was not legally enforcing the mandate, suggesting that vehicle manufacturers are seeking to meet it whether or not a waiver of preemption is in place. It is therefore reasonably foreseeable that manufacturers selling vehicles in California and in the Section 177 states will be producing sufficient advanced technology vehicles at levels that would comply with the ZEV mandate during the timeframe of this rulemaking.

- NHTSA has included the agreements made between California and BMW, Ford, Honda, VWA, and Volvo, because these agreements by their terms are legally binding contracts, even though they were entered into voluntarily.[17] NHTSA did so by including EPA's baseline GHG standards in its analysis, and introducing more stringent GHG target functions during MYs 2022-2026, but treating only these five manufacturers as subject to these more stringent target functions. Because a significant portion of the market voluntarily adopted the California framework, presumably because the manufacturers who joined believed it could be met, and because that adoption is legally binding once entered into, it is reasonable to assume that it will occur as expected during the rulemaking timeframe, and thus, reasonable to include in the No-Action Alternative.

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

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

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[15] 86 Fed. Reg. 25980 (May 12, 2021).

[16] 86 Fed. Reg. 22421 (Apr. 28, 2021).

[17] *See* https://ww2.arb.ca.gov/news/framework-agreements-clean-cars.

Model documentation, the updated version of the model simulates all the following simultaneously:

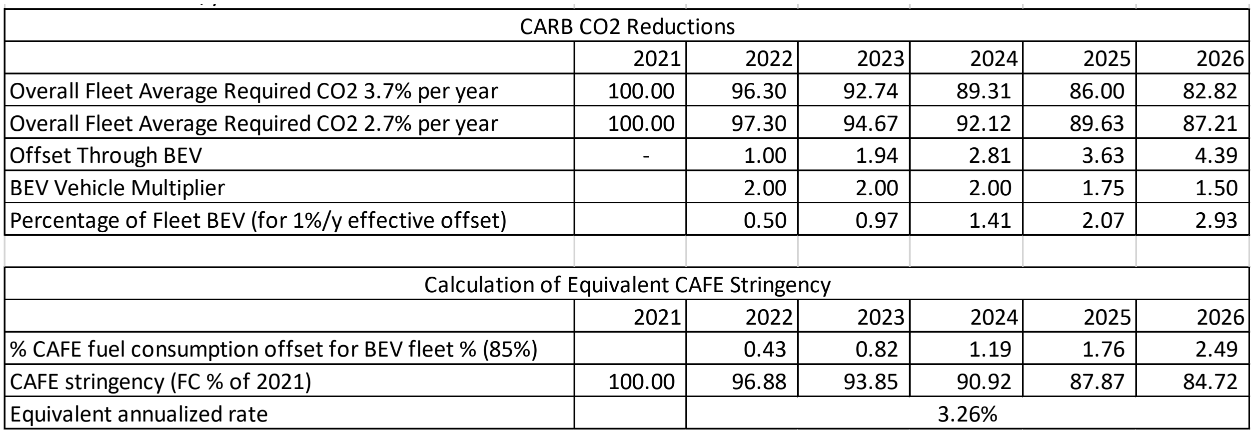
1. Compliance with CAFE standards
2. Compliance with GHG standards applicable to all manufacturers
3. Compliance with alternative GHG standards applicable to a subset of manufacturers
4. Compliance with ZEV mandates
5. Further fuel economy improvements applied if sufficiently cost-effective for buyers

Inclusion of these actions in the No-Action Alternative means that they are necessarily included in each of the Action Alternatives. That is, the impacts of all the alternatives evaluated in this proposal are against the backdrop of these State actions and actions to which automakers have formally committed voluntary. This is important to remember, because it means that automakers will be taking actions to improve fuel economy even in the absence of new CAFE standards, and that costs and benefits attributable to those actions are therefore *not* attributable to possible future CAFE standards.

Besides the No-Action Alternative, the proposal also includes three "Action Alternatives." The proposed standards may, in places, be referred to as the "preferred alternative," which is NEPA parlance, but NHTSA intends "proposal" and "preferred alternative" to be used interchangeably for purposes of this rulemaking. Each of the Action Alternatives is more stringent than the No-Action Alternative during MYs 2024-2026, as mentioned above. These alternatives are specified below, with Alternative 1 being the least stringent in MY 2026, Alternative 3 being the most stringent, and Alternative 2 falling between Alternatives 1 and 3 in terms of MY 2026 stringency.

2.1 Alternative 1

Alternative 1 would increase CAFE stringency for MY 2024 by 9.14% for passenger cars and 11.02% for light trucks and increase stringency in MYs 2025 and 2026 by 3.26% per year for both passenger cars and light trucks. NHTSA calculates that the stringency of Alternative 1 in each of MYs 2024-2026 is equivalent to fuel economy standards harmonized with the average stringency of the California framework agreement applied to all manufacturers in those model years. NHTSA calculated the stringency values using the spreadsheet shown in Figure 2-1, assuming manufacturers would achieve a one percent reduction in stringency each model year under the California framework through the application of ZEV vehicle multipliers. The spreadsheet applies a normalized stringency value of 100 percent in MY 2021 for both CO_2 standards and CAFE standards.



CARB CO2 Reductions						
	2021	2022	2023	2024	2025	2026
Overall Fleet Average Required CO2 3.7% per year	100.00	96.30	92.74	89.31	86.00	82.82
Overall Fleet Average Required CO2 2.7% per year	100.00	97.30	94.67	92.12	89.63	87.21
Offset Through BEV	-	1.00	1.94	2.81	3.63	4.39
BEV Vehicle Multiplier		2.00	2.00	2.00	1.75	1.50
Percentage of Fleet BEV (for 1%/y effective offset)		0.50	0.97	1.41	2.07	2.93

Calculation of Equivalent CAFE Stringency						
	2021	2022	2023	2024	2025	2026
% CAFE fuel consumption offset for BEV fleet % (85%)		0.43	0.82	1.19	1.76	2.49
CAFE stringency (FC % of 2021)	100.00	96.88	93.85	90.92	87.87	84.72
Equivalent annualized rate		3.26%				

Figure 2-1 – Stringency Value Calculations

Informed by these calculations, NHTSA defined Alternative 1 by applying the CAFE harmonized stringency increases in MYs 2024-2026, resulting in the coefficients listed in Table 2-1 and Table 2-2.

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

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

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

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

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

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

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

2024	2025	2026
44.9 mpg	46.5 mpg	48.0 mpg

NHTSA considered this alternative as a way to evaluate the effects of industry-wide CAFE standards approximately equivalent to the fuel savings that would result from standards harmonized with the California framework agreement as applied to signatory OEMs' production for the U.S. market.[18]

2.2 Alternative 2 – Preferred Alternative

Alternative 2 would increase CAFE stringency at 8 percent per year, which NHTSA calculates would result in total lifetime fuel savings from vehicles produced during MYs 2021-2029 similar to total lifetime fuel savings that would occur if the fuel economy standards harmonized with the California framework agreement had applied to all manufacturers during MYs 2021-2026.

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

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

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

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

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

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[18] CAFE standards defining this alternative reflect the fact that EPCA does not provide a basis for CAFE standards to include "multipliers" applicable to PHEV and/or BEV production volumes, as well as the fact that EPCA's treatment of BEV energy consumption is different from the "0 grams/mile" treatment for purposes of determining compliance with GHG emissions standards.

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

2024	2025	2026
44.4 mpg	48.2 mpg	52.4 mpg

NHTSA considered this alternative as a way to evaluate the effects of CAFE standards harmonized with the California framework agreement has been applied to all vehicle manufacturers when the framework began.

2.3 Alternative 3

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

Table 2-7 – Characteristics of Alternative 3 – Passenger Cars

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

Table 2-8 – Characteristics of Alternative 3 – Light Trucks

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

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

Table 2-9 – Alternative 3 – Minimum Domestic Passenger Car Standard

2024	2025	2026
45.4 mpg	50.4 mpg	56.0 mpg

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

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

3. Simulating Alternatives with the CAFE Model

3.1 Overall Purpose and Structure of the CAFE Model

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

The purpose of this overview is not to provide a comprehensive technical description of the model, but rather to give an overview of the model's functions, and to describe how it simulates the impacts of changes to fuel efficiency standards. The model documentation accompanying today's notice[19] provides a comprehensive and detailed description of the model's functions, design, inputs, and outputs.

The basic design of the CAFE Model is as follows: the system first estimates how vehicle manufacturers might respond to a given regulatory scenario, and from that potential compliance solution, the system estimates what impact that response will have on fuel consumption, emissions, and economic externalities. A regulatory scenario involves specification of the form, or shape, of the standards (e.g., flat standards, or linear or logistic attribute-based standards), scope of regulatory classes,[20] and stringency of the CAFE standards for each model year to be analyzed.

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[19] The CAFE Model is available at https://www.nhtsa.gov/corporate-average-fuel-economy/compliance-and-effects-modeling-system with documentation and all inputs and outputs supporting today's notice.

[20] While the set of regulatory classes is typically consistent across the set of CAFE alternatives, it may occasionally be necessary, as it is in the Baseline (Alternative 0) in this NPRM, to capture the regulatory classification of the GHG program which uses a similar, but not identical, scheme of classification.

Manufacturer compliance simulation begins with a detailed, user-provided initial representation of the vehicle models offered for sale in a recent model year (MY 2020, in this analysis). The compliance simulation then attempts to bring each manufacturer into compliance with the standards defined by the regulatory scenario. For example, a regulatory scenario may define CAFE standards that increase in stringency by 4 percent per year for 5 consecutive years.

The model applies various technologies to different vehicle models in each manufacturer's product line to simulate how each manufacturer might make progress toward compliance with the specified standard. Subject to a variety of user-controlled constraints, the model applies technologies based on their relative cost-effectiveness, as determined by several input assumptions regarding the cost and effectiveness of each technology, the cost of compliance (determined by the change in CAFE or CO_2 credits, CAFE-related civil penalties, or value of CO_2 credits, depending on the compliance program being evaluated), and the value of avoided fuel expenses. For a given manufacturer, the compliance simulation algorithm applies technologies either until the manufacturer runs out of cost-effective technologies,[21] until the manufacturer exhausts all available technologies, or, if the manufacturer is assumed to be willing to pay civil penalties or acquire credits from another manufacturer, until paying civil penalties or purchasing credits becomes more cost-effective than increasing vehicle fuel economy. At this stage, the system assigns an incurred technology cost and updated fuel economy to each vehicle model, as well as any civil penalties incurred/credits purchased by each manufacturer. This compliance simulation process is repeated for each model year included in the study period (through model year 2050 in this analysis).[22]

This point marks the system's transition between compliance simulation and effects calculations. At the conclusion of the compliance simulation for a given regulatory scenario, the system produces a full representation of the registered light-duty vehicle population in the United States. The CAFE Model then uses this fleet to generate estimates of the following (for each model year and calendar year included in the analysis): lifetime travel, fuel consumption, carbon dioxide 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).

3.2 Simulating Manufacturers' Potential Responses to the Alternatives

3.2.1 Starting Point – the 2020 Fleet

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[21] Generally, the model considers a technology cost-effective if it pays for itself in fuel savings within 30 months, a duration that reflects buyers' significant undervaluation of fuel savings relative to a simple actuarial projection of lifetime fuel savings. Depending on the settings applied, the model can continue to apply technologies that are *not* cost-effective rather than choosing other compliance options; if it does so, it will apply those additional technologies in order of cost-effectiveness.

[22] The extension through calendar year 2050 reflects a balance between completeness and uncertainty, as well as the need to capture the interactions of the new and used vehicle markets as the vehicles produced in MYs 2024-2026 are used, age, and retire. The Energy Information Administration's 2021 Annual Energy Outlook also uses a modeling horizon that extend through 2050.

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

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

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

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

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

3.2.2 Representing Manufacturers' Production Constraints

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

3.2.2.1 Product Cadence

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

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

While these characterizations of product cadence are important to any evaluation of the impacts of CAFE or GHG standards, they are not known with certainty – even by the manufacturers themselves over time horizons as long as those covered by this analysis, which goes out to 2050 because it is necessary to continue to capture the interactions of the new and used vehicle markets as the vehicles produced in MYs 2024-2026 are used, age, and retire. However, lack of certainty about redesign schedules is not license to ignore them.[23] Indeed, when meeting with DOT to discuss plans vis-à-vis CAFE requirements, manufacturers typically present specific and detailed year-by-year information that explicitly accounts for anticipated redesigns. Such year-by-year analysis is also essential to manufacturers' plans to make use of statutory provisions allowing CAFE credits to be carried forward to future model years, carried back from future model years, transferred between regulated fleets, and traded with other manufacturers. Manufacturers are never certain about future plans, but they spend considerable effort developing them.

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

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

In practice, manufacturers are limited in the number of engines and transmissions that they produce. Typically, a manufacturer produces a relatively small number of engines and tunes them for slight variants in output for a variety of car and truck applications. Manufacturers limit complexity in their engine portfolio for much the same reason as they limit complexity in vehicle variants: they face engineering human resource limitations, and supplier, production, and service costs that scale with the number of unique parts produced.

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

Prior to the 2016 Draft Technical Assessment Report, the CAFE Model simulated the application of engine and transmission technologies to individual vehicle models in a manner potentially leading to solutions that would, if followed, create many more unique engines and transmissions than exist in the current portfolio for a given manufacturer (perhaps five to ten times as many). This multiplicity did not account for costs associated with such increased complexity in the product portfolio, and represented a likely unrealistic diffusion of products, as manufacturers have been consolidating global production to increasingly smaller numbers of shared engines and platforms.[24] The lack of a constraint in this area allowed the model to apply different levels of technology to the engine in each vehicle in which it was present at the time that vehicle was redesigned or refreshed, independent of what was done to other vehicles using an identical engine.

One previous CAFE Model peer reviewer commented, "The integration of inheritance and sharing of engines, transmissions, and platforms across a manufacturer's light duty fleet and separately across its light duty truck fleet is standard practice within the industry."[25] Recognizing this previous shortcoming, the current version of the CAFE Model, engines (and transmissions) that are shared between vehicles are treated as applying the same levels of technology over time, consistent with engine (or transmission) inheritance. This shared adoption is referred to as "engine inheritance" in the model documentation. In practice, the CAFE Model first chooses an "engine leader" among vehicles sharing the same engine[26] – the vehicle with the highest nameplate sales in MY 2020. If there is a tie, the vehicle with the highest (sales-weighted) average MSRP is chosen, assuming that manufacturers will choose to pilot the newest technology on premium vehicles if possible. The model applies the same logic with respect to the application of transmission changes. After the CAFE Model modifies the engine on the "engine leader" (or transmission on the "transmission leader") when that vehicle model is expected to be redesigned, the changes to that engine propagate through to the other vehicles that share that engine (or transmission) in subsequent years as those vehicles are redesigned. As mentioned above, these modeling procedures reflect standard industry practices and, therefore, increase the model's ability to arrive at technology pathways that, if not predictive of manufacturers' actual decisions, could nevertheless be realistic and practicable (given the focus on the U.S. market). DOT has modified the CAFE Model to provide additional flexibility vis-à-vis product cadence. While engine redesigns are only applied to the engine leader when it is redesigned in the model, followers may now inherit upgraded engines (that they share with the leader) at either refresh or redesign. All transmission changes, whether upgrades to the "leader" or inheritance to "followers" can occur at refresh as well as redesign. This provides additional opportunities for technology diffusion within manufacturers' product portfolios.

While "follower" vehicles are awaiting redesign, they carry a legacy version of the shared engine or transmission. As one peer reviewer previously stated, "Most of the time a manufacturer will convert only a single plant within a model year. Thus both the "old" and "new" variant of the engine (or transmission) will be produced for a finite number of years." The CAFE Model

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[24] National Research Council. 2015. *Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-Duty Vehicles*. Washington, DC: The National Academies Press. https://doi.org/10.17226/21744, pp. 258-59.
[25] https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/812590-cafe-peer-review.pdf, p. 8.
[26] The model will not consider a vehicle designated as a ZEV candidate to be an engine or transmission leader (though it may, and likely will, choose a different model variant of the same nameplate when appropriate).

currently carries no additional cost associated with producing both earlier revisions of an engine and the updated version simultaneously. Further research would be needed to determine whether sufficient data exist to specify explicitly and apply additional costs involved with continuing to produce an existing engine or transmission for some vehicles that have not yet progressed to a newer version.

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

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

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

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

3.2.2.3 Phase-In Caps

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

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

3.2.2.4 Interactions between Regulatory Classes

The current CAFE Model simulates integrated compliance strategies spanning different regulatory classes, accounting both for standards that apply separately to different classes and for interactions between regulatory classes. Light vehicle CAFE (and GHG) standards are specified separately for passenger cars and light trucks.[27] However, there is considerable sharing between these two regulatory classes – where a single engine, transmission, or platform can appear in

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[27] 49 U.S.C. 32902.

both the passenger car and light truck regulatory class. For example, some sport-utility vehicles are offered in 2WD versions classified as passenger cars and 4WD or AWD versions classified as light trucks (but have identical powertrains). As crossover vehicles have grown in popularity, a growing share of new vehicle sales accrue to nameplates that have model variants in each of the regulatory classes. Integrated analysis of manufacturers' passenger car and light truck fleets provides the ability to account for such sharing and reduces the likelihood of finding solutions that could involve introducing potentially impractical levels of complexity in manufacturers' product lines. Additionally, integrated fleet analysis provides the ability to simulate the potential that manufacturers could earn CAFE (or GHG) credits by over-complying with the standard in one fleet and use those credits toward compliance with the standard in another fleet (i.e., to simulate credit transfers between regulatory classes).

While both EPA's GHG standards and California's voluntary GHG standards distinguish between passenger cars and light trucks, the CAFE Model includes a further distinction that is necessary to capture the compliance requirements of the CAFE program, which requires that manufacturers meet a separate minimum standard for domestically manufactured passenger cars: capturing the difference between passenger cars classified as domestic passenger cars and those classified as imports. The CAFE program regulates those passenger cars separately,[28] and the CAFE Model simulates all three CAFE regulatory classes separately: Domestic Passenger Cars (DC), Imported Passenger Cars (IC), and Light Trucks (LT) – as well as the combined "passenger car" and "light truck" classes of the GHG programs.

CAFE regulations state that standards, fuel economy levels, and compliance are all calculated separately for each class. This level of accounting imposes two additional constraints on manufacturers that sell vehicles in the U.S.: (1) the domestic minimum floor; and (2) limited transfers between cars classified as "domestic" and those classified as "imported". The domestic minimum floor creates a threshold that every manufacturer's domestic car fleet must exceed without the application of CAFE credits other than those earned in that specific fleet.[29] If a manufacturer's calculated standard is below the domestic minimum floor, then the domestic floor is the binding constraint (even for manufacturers that are assumed to be willing to pay civil penalties for non-compliance). The second constraint poses challenges for manufacturers that sell cars from both the domestic and imported passenger car categories. While the earliest versions of the CAFE Model considered those fleets as a single fleet (i.e., passenger cars), the model currently requires them to comply separately and limits the volume of credits that can be shifted between them for compliance, per the statutory prohibition mentioned above.

3.2.3 Representing Credits and Civil Penalties

EPCA requires that if a fleet does not achieve the CAFE levels required by standard applicable in a given model year, and the manufacturer does not apply compliance credits sufficient to cover the shortfall, the manufacture must pay a civil penalty to the federal government. Some manufacturers have, in effect, treated this as a compliance flexibility for some fleets in some model years. When considering technology applications to improve fleet fuel economy, the

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[28] 49 U.S.C. 32902, 32904.

[29] 49 U.S.C. 32903(f)(2), (g)(4).

model will add technology up to the point at which compliance is achieved or, depending on inputs regarding the manufacturer's willingness to pay civil penalties and/or apply technology beyond that needed for compliance, the effective cost of the technology (which includes technology cost, consumer fuel savings, and the reduced cost of civil penalties for non-compliance with the standard) is greater than zero. The current implementation further acknowledges that some manufacturers experience transitions between product lines where they rely heavily on credits (either carried forward from earlier model years or acquired from other manufacturers), or simply pay penalties in one or more fleets for some number of years. The model allows the user to specify, on a year-by-year basis, whether each manufacturer should be treated as willing to pay civil penalties for non-compliance. This assumption can be considered as a method to allow a manufacturer to not comply with its standard in some model years, thus treating the civil penalty rate and payment option as a proxy for other actions it may take that are not represented in the CAFE Model, including purchasing credits from another manufacturer or carrying-back credits from future model years.[30]

The first year simulated in this analysis is MY 2020, and each manufacturer begins the simulation with an existing credit position. In the context of CAFE compliance, each manufacturer may have surplus credits – either earned through over-compliance with its own standard or purchased from a competitor – that are specific to both the fleet and model year in which they were earned. CAFE credits may be carried forward for up to five model years, after which they expire.[31] In this analysis, manufacturers with credits earned in MY 2015 may carry them forward into MY 2020 to offset a compliance deficit. The initial banks of credits may include credits that were purchased from other manufacturers, but that have not yet been applied to resolve deficits. In these cases, the credit values have been adjusted[32] to reflect the manufacturer, fleet, and model year banks in which they reside (in the inputs). As this analysis also includes the simultaneous simulation of compliance with GHG standards, starting GHG banks are also relevant to the analysis.[33] Regardless of which program is being simulated (or which compliance metrics are being calculated), the CAFE Model always attempts to apply expiring credits before adding additional technology that is not cost-effective.

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

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[30] DOT staff expect to continue investigating the potential to expand the CAFE Model's representation of provisions regarding compliance credit transfers and trades.

[31] 49 U.S.C. 32903(a).

[32] Credits acquired from other manufacturers are adjusted in the CAFE program to account for differences in standard, fuel economy, fleet, and model year between the company that originally earned the credits and the company that applies them to resolve a compliance deficit. The adjustment works the same for credit transfers between fleets within a single manufacturer's portfolio, and the CAFE Model computes and applies these adjustments dynamically for credits earned and transferred during the simulation.

[33] For manufacturers who have agreed to comply with California's standards, the CAFE Model treats the existing EPA credit banks as if that program applies nationally and existing credit banks are used consistently with that approach.

continue to do so in subsequent analysis years. As in past analyses, this assumption for these manufacturers is based, again, on these manufacturers' past compliance behavior. Of those six manufacturers, half (BMW, Volvo, and VW) have agreed to comply with California's more stringent voluntary standards. This means that they are likely to exceed their CAFE standard throughout the analysis, even in the early years, in the process of complying with the California agreement. While the flexibility exists within the model inputs, the CAFE Model will enforce the relevant (and binding) standard in each year. A full discussion of manufacturers' starting credit positions and behavior with respect to civil penalties is presented in TSD Chapters 2.2.2.3 and 2.2.2.4, respectively.

3.2.4 Representing Fuel-Saving Technology

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

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

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

Table 3-1 – Engine Technologies in the CAFE Model

Technology	Application Level	Application Schedule	Description
SOHC	Engine	Baseline Only	Single Overhead Camshaft Engine
DOHC	Engine	Baseline Only	Double Overhead Camshaft Engine
EFR	Engine	Redesign Only	Improved Engine Friction Reduction
VVT	Engine	Redesign Only	Variable Valve Timing
VVL	Engine	Redesign Only	Variable Valve Lift
SGDI	Engine	Redesign Only	Stoichiometric Gasoline Direct Injection
DEAC	Engine	Redesign Only	Cylinder Deactivation
TURBO1	Engine	Redesign Only	Turbocharging and Downsizing, Level 1 (1.5271 bar)
TURBO2	Engine	Redesign Only	Turbocharging and Downsizing, Level 2 (2.0409 bar)
CEGR1	Engine	Redesign Only	Cooled Exhaust Gas Recirculation, Level 1 (2.0409 bar)
ADEAC	Engine	Redesign Only	Advanced Cylinder Deactivation
HCR0	Engine	Redesign Only	High Compression Ratio Engine, Level 0
HCR1	Engine	Redesign Only	High Compression Ratio Engine, Level 1
HCR1D	Engine	Redesign Only	High Compression Ratio Engine, Level 1 with DEAC
HCR2	Engine	Redesign Only	High Compression Ratio Engine, Level 2
VCR	Engine	Redesign Only	Variable Compression Ratio Engine
VTG	Engine	Redesign Only	Variable Turbo Geometry
VTGE	Engine	Redesign Only	Variable Turbo Geometry (Electric)
TURBOD	Engine	Redesign Only	Turbocharging and Downsizing with DEAC
TURBOAD	Engine	Redesign Only	Turbocharging and Downsizing with ADEAC
ADSL	Engine	Redesign Only	Advanced Diesel
DSLI	Engine	Redesign Only	Diesel Engine Improvements
DSLIAD	Engine	Redesign Only	Diesel Engine Improvements with ADEAC
CNG[34]	Engine	Baseline Only	Compressed Natural Gas Engine

Table 3-2 displays the remaining technologies available in the CAFE Model. These cover upgrades to transmissions, electrification, and body-level technologies that reduce road load. Unlike engine technologies, the CAFE Model will build and apply new transmissions at either refresh or redesign. In the case of engines, a vehicle may only inherit a new version during a

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

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

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

Technology	Application Level	Application Schedule	Description
MT5	Transmission	Baseline Only	5-Speed Manual Transmission
MT6	Transmission	Redesign Only	6-Speed Manual Transmission
MT7	Transmission	Redesign Only	7-Speed Manual Transmission
AT5	Transmission	Baseline Only	5-Speed Automatic Transmission
AT6	Transmission	Refresh/Redesign	6-Speed Automatic Transmission
AT6L2	Transmission	Refresh/Redesign	6-Speed Automatic Transmission, Level 2
AT7L2	Transmission	Baseline Only	7-Speed Automatic Transmission, Level 2
AT8	Transmission	Refresh/Redesign	8-Speed Automatic Transmission
AT8L2	Transmission	Refresh/Redesign	8-Speed Automatic Transmission, Level 2
AT8L3	Transmission	Refresh/Redesign	8-Speed Automatic Transmission, Level 3
AT9L2	Transmission	Baseline Only	9-Speed Automatic Transmission, Level 2
AT10L2	Transmission	Refresh/Redesign	10-Speed Automatic Transmission, Level 2
AT10L3	Transmission	Refresh/Redesign	10-Speed Automatic Transmission, Level 3
DCT6	Transmission	Refresh/Redesign	6-Speed Dual Clutch Transmission
DCT8	Transmission	Refresh/Redesign	8-Speed Dual Clutch Transmission
CVT	Transmission	Baseline Only	Continuously Variable Transmission
CVTL2	Transmission	Refresh/Redesign	CVT, Level 2
EPS	Vehicle	Refresh/Redesign	Electric Power Steering
IACC	Vehicle	Refresh/Redesign	Improved Accessories
CONV	Vehicle	Baseline Only	Conventional Powertrain (Non-Electric)
SS12V	Vehicle	Redesign Only	12V Micro-Hybrid (Stop-Start)
BISG	Vehicle	Redesign Only	Belt Mounted Integrated Starter/Generator
SHEVP2	Vehicle	Redesign Only	P2 Strong Hybrid/Electric Vehicle
SHEVPS	Vehicle	Redesign Only	Power Split Strong Hybrid/Electric Vehicle
P2HCR0	Vehicle	Redesign Only	SHEVP2 with HCR0 Engine
P2HCR1	Vehicle	Redesign Only	SHEVP2 with HCR1 Engine
P2HCR2	Vehicle	Redesign Only	SHEVP2 with HCR2 Engine
PHEV20	Vehicle	Redesign Only	20-mile Plug-In Hybrid/Electric Vehicle with HCR Engine
PHEV50	Vehicle	Redesign Only	50-mile Plug-In Hybrid/Electric Vehicle with HCR Engine
PHEV20T	Vehicle	Redesign Only	20-mile Plug-In Hybrid/Electric Vehicle with Turbo Engine
PHEV50T	Vehicle	Redesign Only	50-mile Plug-In Hybrid/Electric Vehicle with Turbo Engine
PHEV20H	Vehicle	Redesign Only	PHEV20 with HCR Engine

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

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

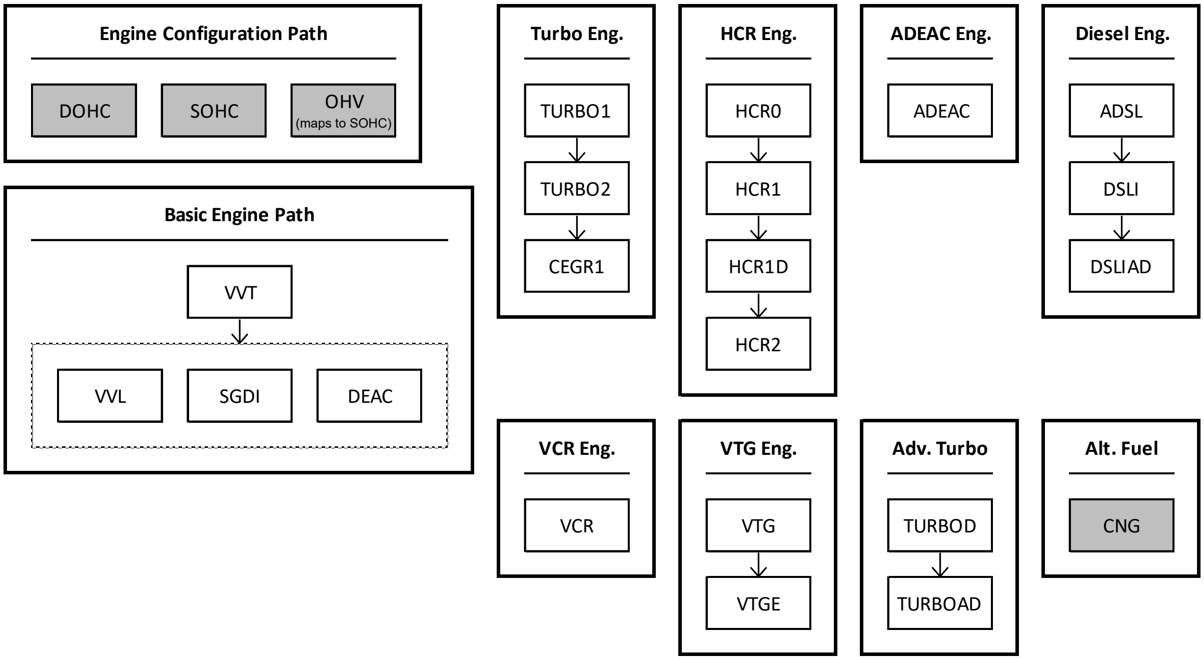

Figure 3-1 – Engine Technology Paths in the CAFE Model

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

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

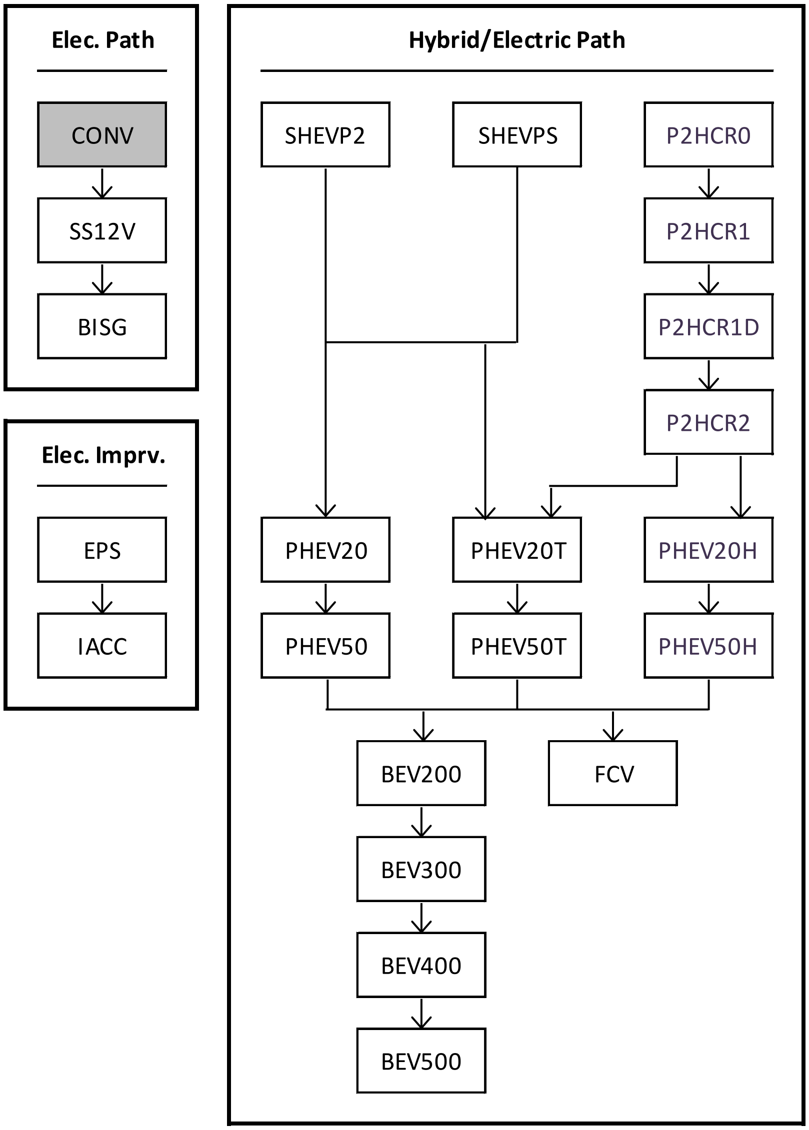

Figure 3-2 – Electrification Technology Paths in the CAFE Model

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

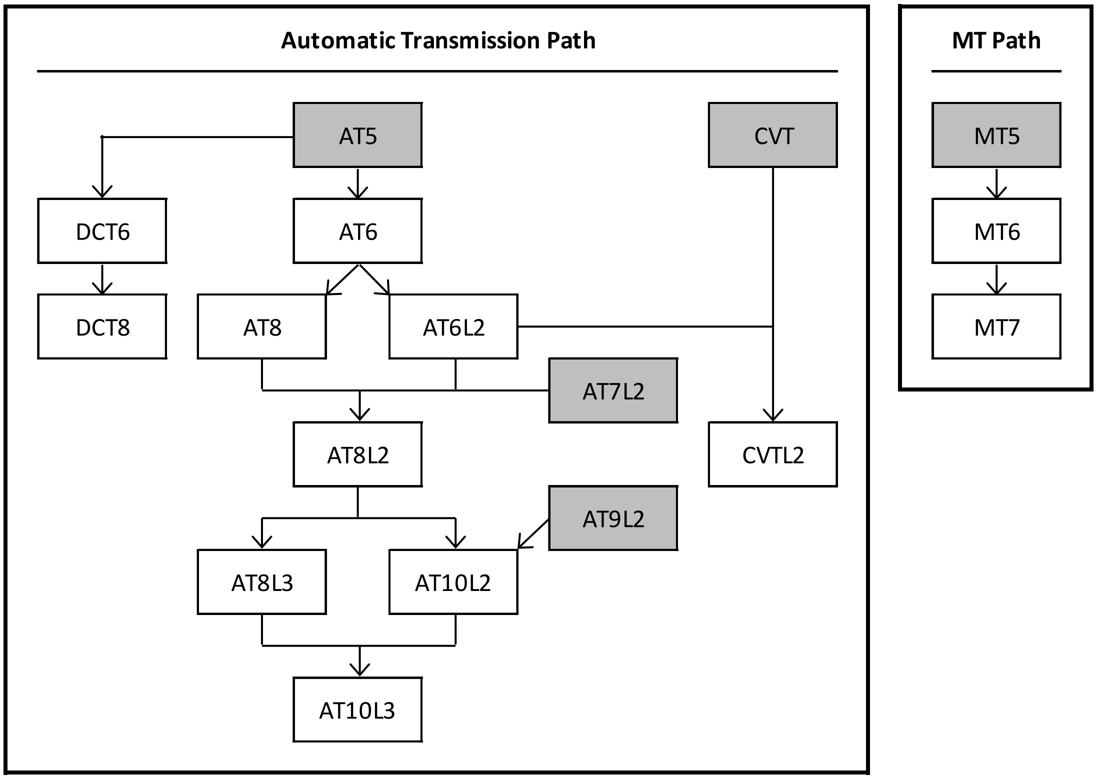

Figure 3-3 – Transmission Paths in the CAFE Model

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

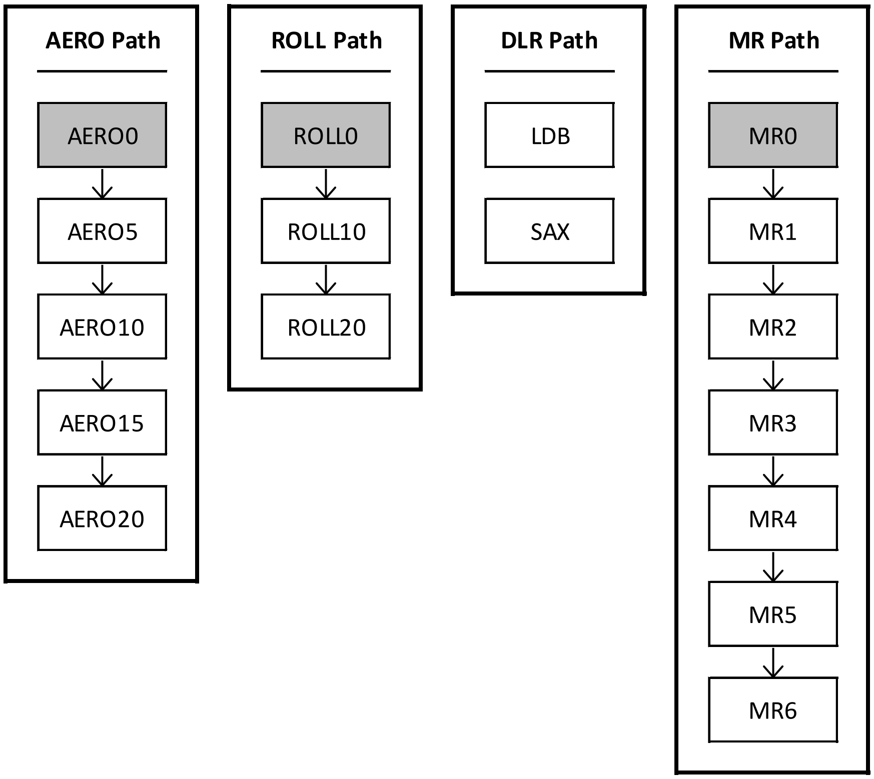

Figure 3-4 – Other Technology Paths in the CAFE

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

Table 3-3 – Technology Classes in the CAFE Model

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

3.2.4.1 Technology Effectiveness

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

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

Figure 3-5 characterizes the technology effectiveness of the engine technologies in the CAFE Model. These parallel boxplots provide information about the distribution of effectiveness across all the combinations to which each technology could be applied, and this figure (like the others that follow it) combines all the technology classes into a single boxplot.[35] The shaded areas of the boxplot represent the middle 50 percent of observations, and the length of the lines extending from that box (the "whiskers") reflect the degree of dispersion in the values beyond

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[35] For more detailed information about technology effectiveness, interested parties can download the full database of effectiveness values, the translated Autonomie outputs, and the report in the docket for this rulemaking, NHTSA-2021-0055.

that central block of observations.[36] Shorter boxes and whiskers reflect more tightly grouped effectiveness values, and longer whiskers indicate effectiveness values farther away from the center of the values.

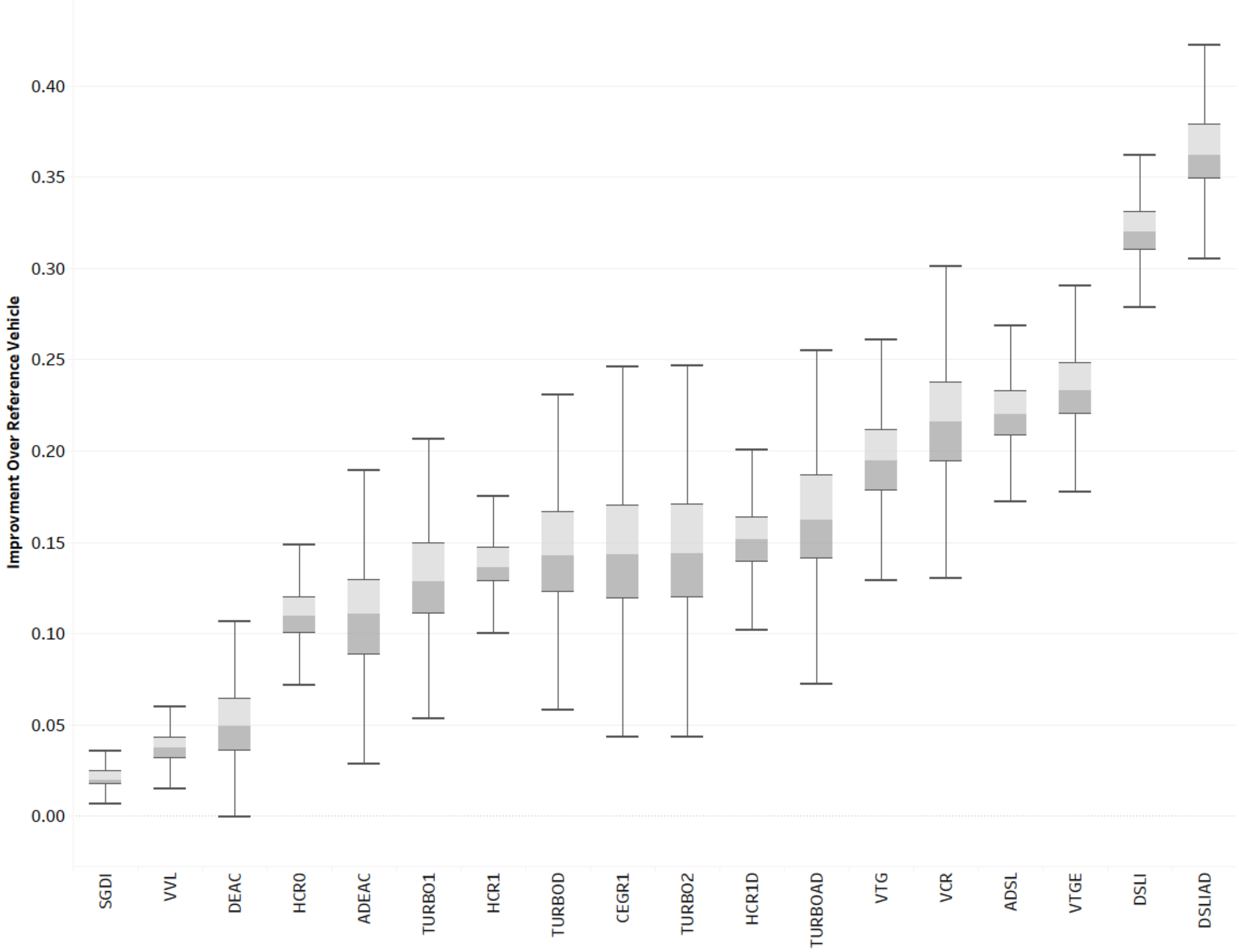

Figure 3-5 – Engine Technology Effectiveness

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

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

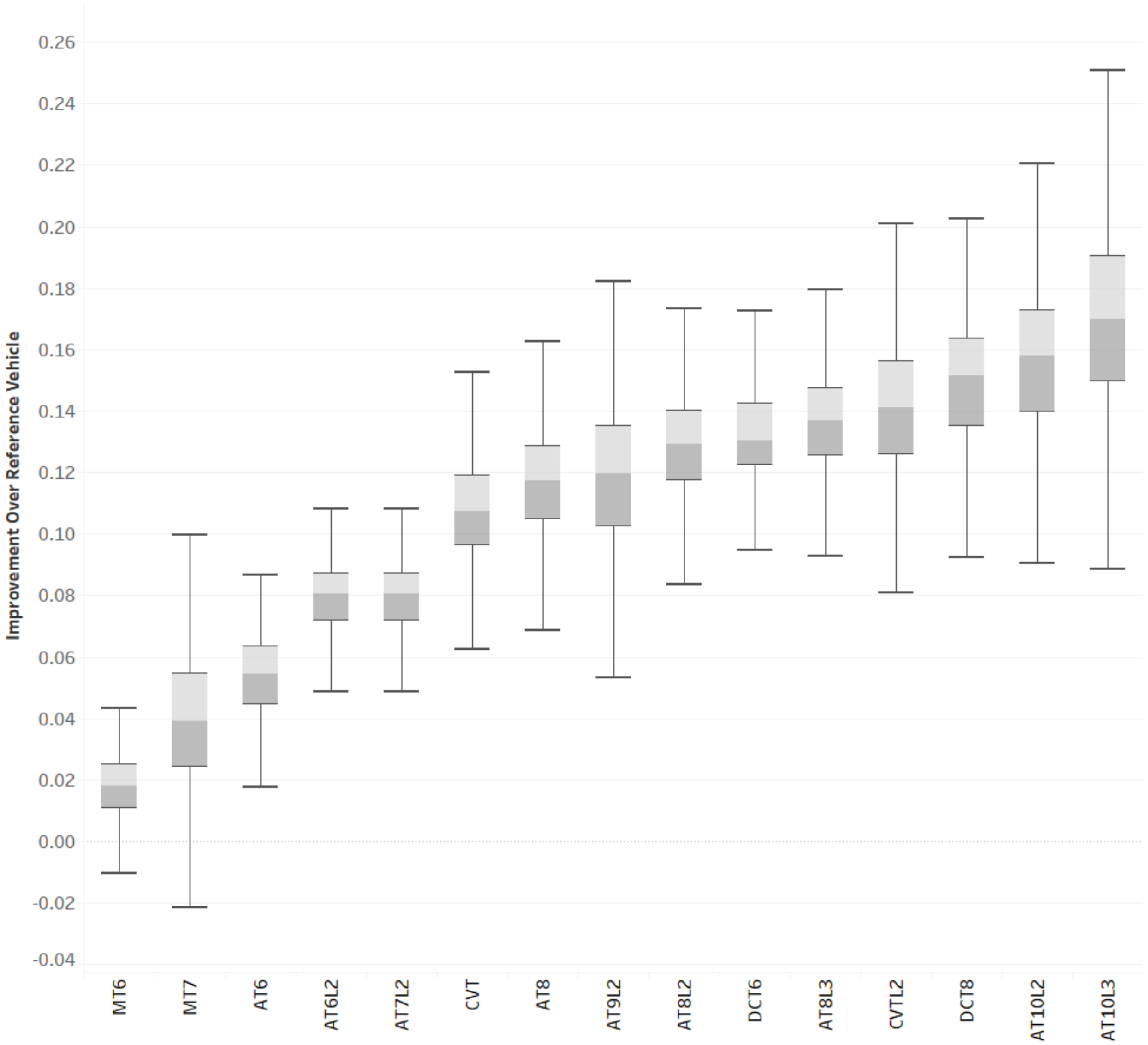

Figure 3-6 – Transmission Technology Effectiveness

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

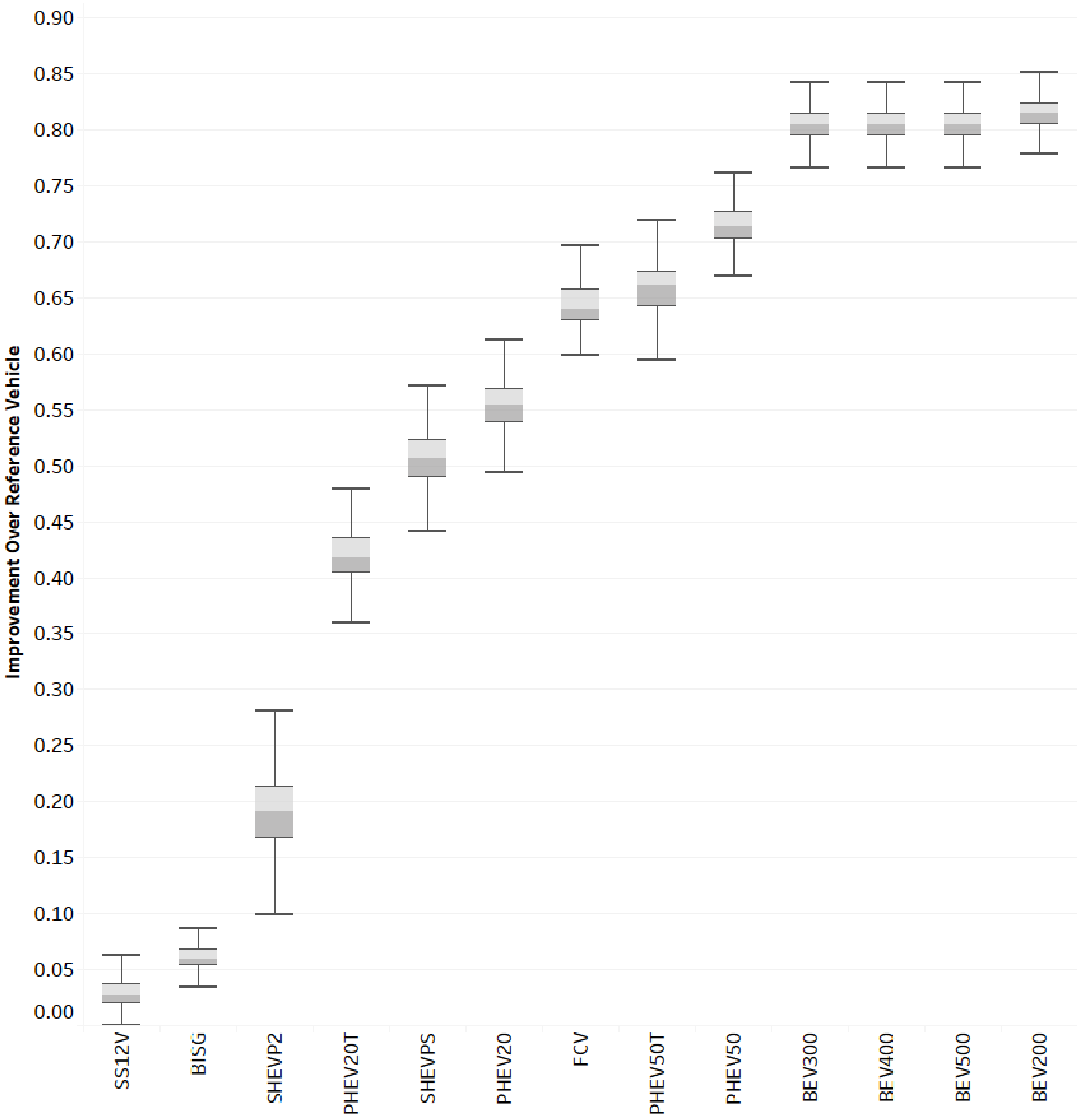

Figure 3-7 – Electrification Technology Effectiveness

The electrification technologies in Figure 3-7 are generally the most effective ways to improve fuel economy and, as Chapter 3.2.4.2 discusses, also among the most expensive. The two least transformative technologies, stop-start (SS12V) and integrated starter generators (BISG), are also the least effective. However, after those two technologies, the model transitions to various degrees of hybridization. The SHEVP2 is paired with the vehicle's existing engine – typically a more advanced engine – and the 15 to 25 percent improvement is on top of the improvement provided by the advanced engine. The plug-in hybrids paired with turbocharged engines are generally less effective than their Atkinson counterparts (for the same range), but may be more appropriate in higher power applications. The most effective technologies are full battery electric vehicles, of varying ranges, that can reduce the energy consumption of the reference vehicle by 80 percent or more. In the context of CAFE and GHG compliance, each of these technologies that has at least some fully electric range (as well as the fuel cell vehicle, FCV) are heavily credited toward compliance through a variety of fuel economy adjustments, ratings, and multipliers (depending upon the program). For example, in the GHG program, BEVs are treated as emitting no carbon on the test cycle (a rating of 0 grams/mile) through model year 2026. The values in Figure 3-7 represent improvements on the test cycle, but can count for considerably more improvement when considered for compliance purposes.

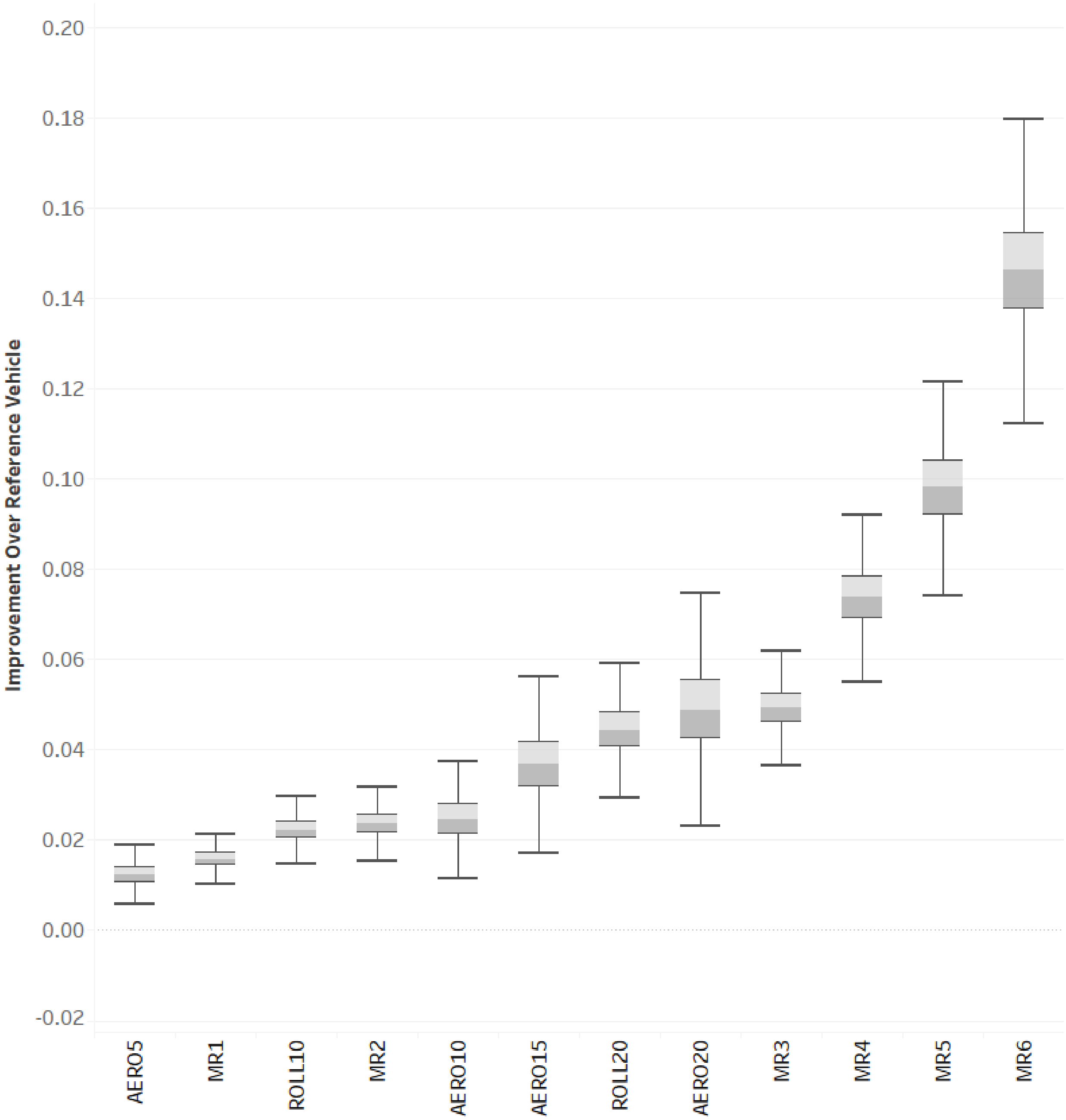

Figure 3-8 – Body-level Technology Effectiveness

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

3.2.4.2 Technology Cost

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

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

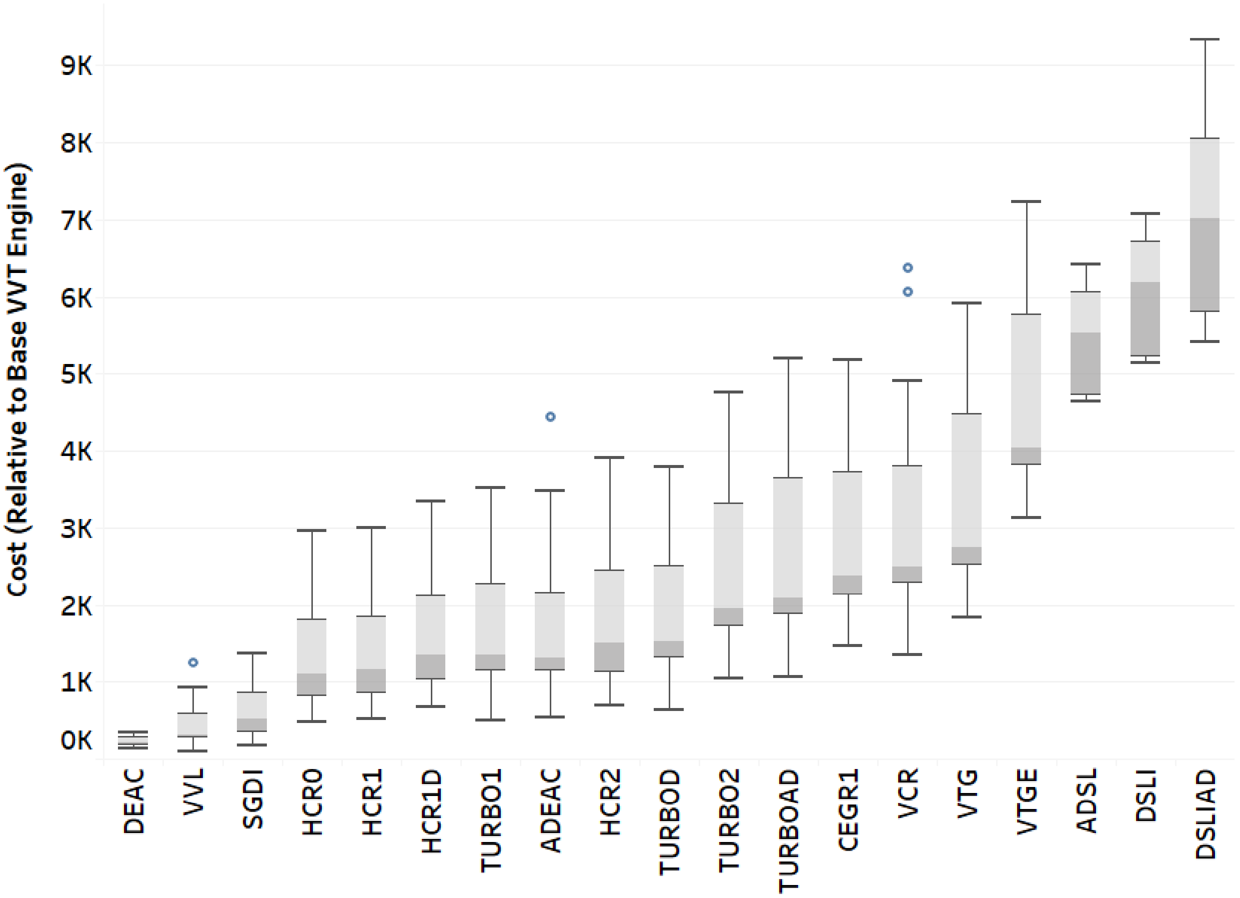

Figure 3-9 – Engine Technology Cost Distributions (Retail Price Equivalent), 2020

Figure 3-9 describes the incremental cost (over the basic VVT engine) of the engine technologies in this analysis in 2020. The cost of each engine technology varies with the size, configuration, and performance level of the engine – so the same technology will likely cost more when applied to a large engine than to a small one. This gives each engine technology a cost distribution, relative to the reference engine, over all of the possible engine sizes and configurations.[37] Consistent with Figure 3-5, describing engine technology effectiveness, the basic engine technologies improve fuel economy at the lowest cost; more common turbocharged and high compression ratio engines have generally higher costs (across configurations); and the most advanced gas and diesel engines also carry the highest costs.

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

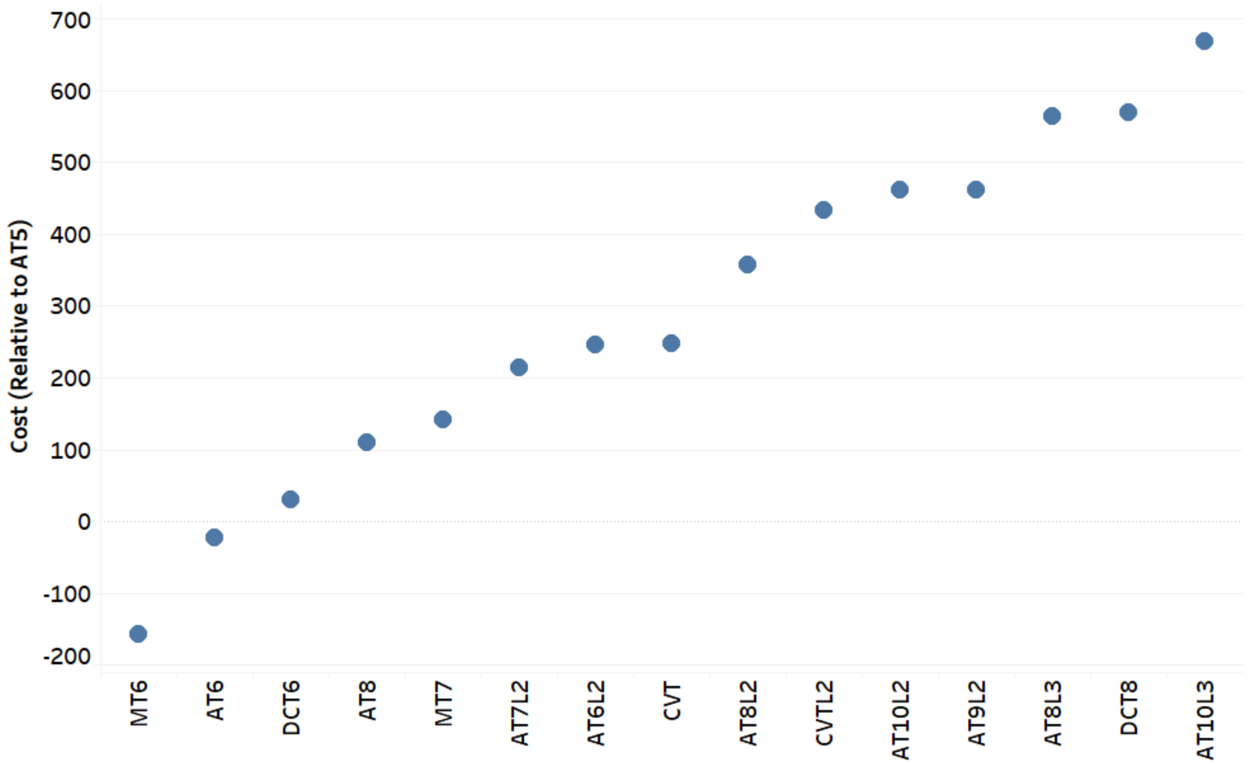

Figure 3-10 – Transmission Cost (Retail Price Equivalent), 2020

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

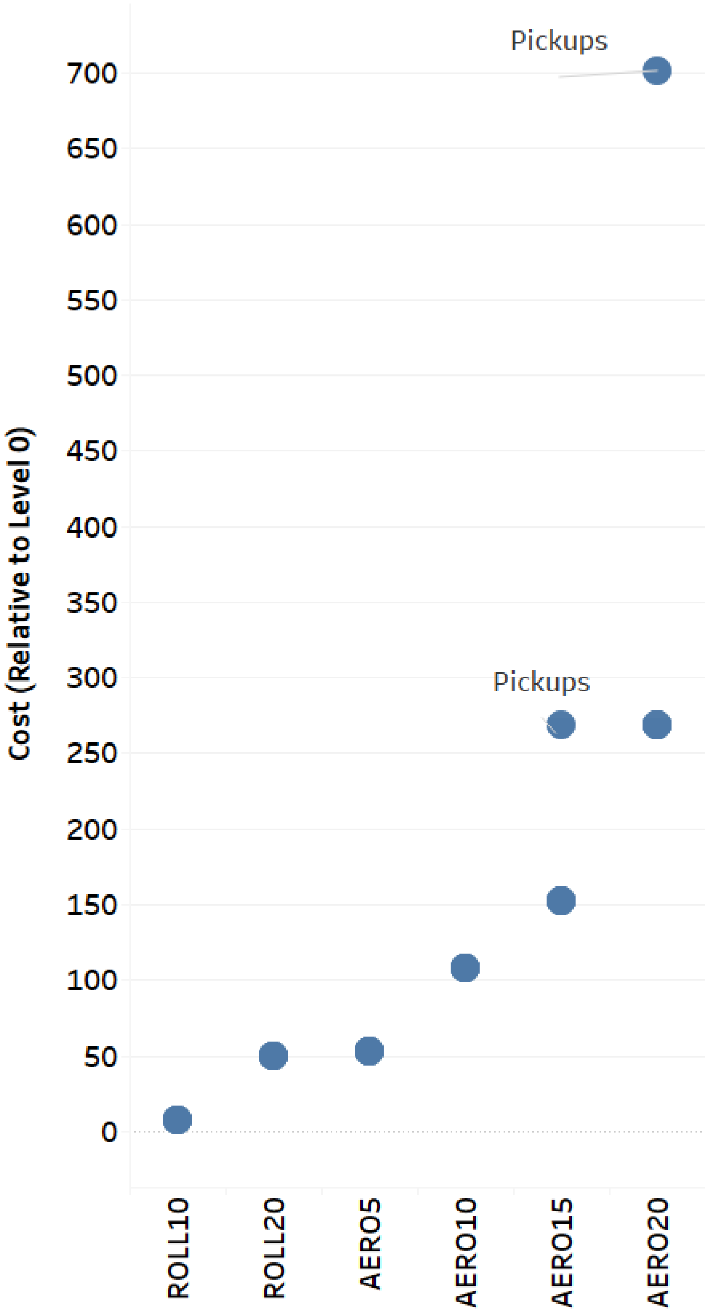

Figure 3-11 – Aerodynamic and Rolling Resistance Improvement Costs (Retail Price Equivalent), 2020

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

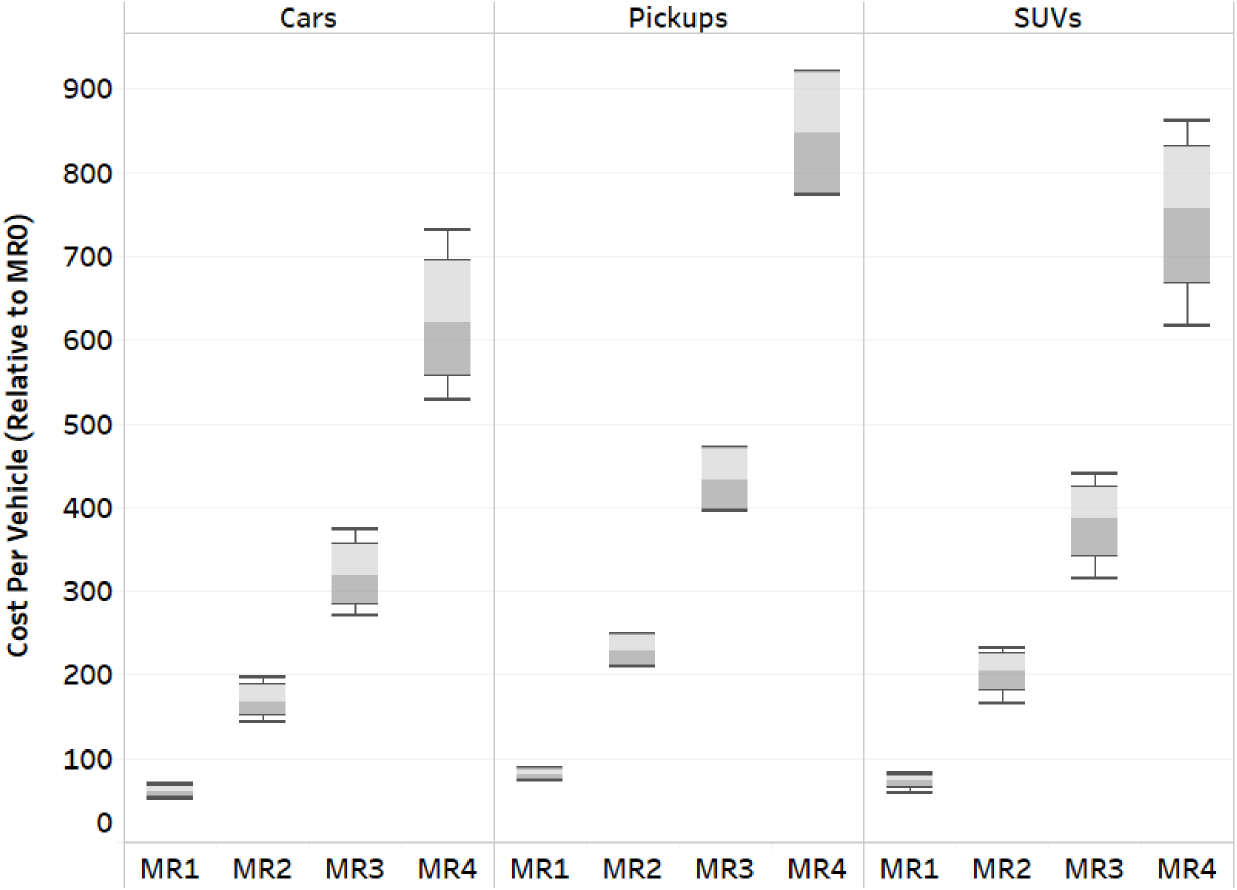

Figure 3-12 – Mass Reduction Costs (Per-Vehicle), Up to 15% Reduction in Glider Weight (Retail Price Equivalent), 2020

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

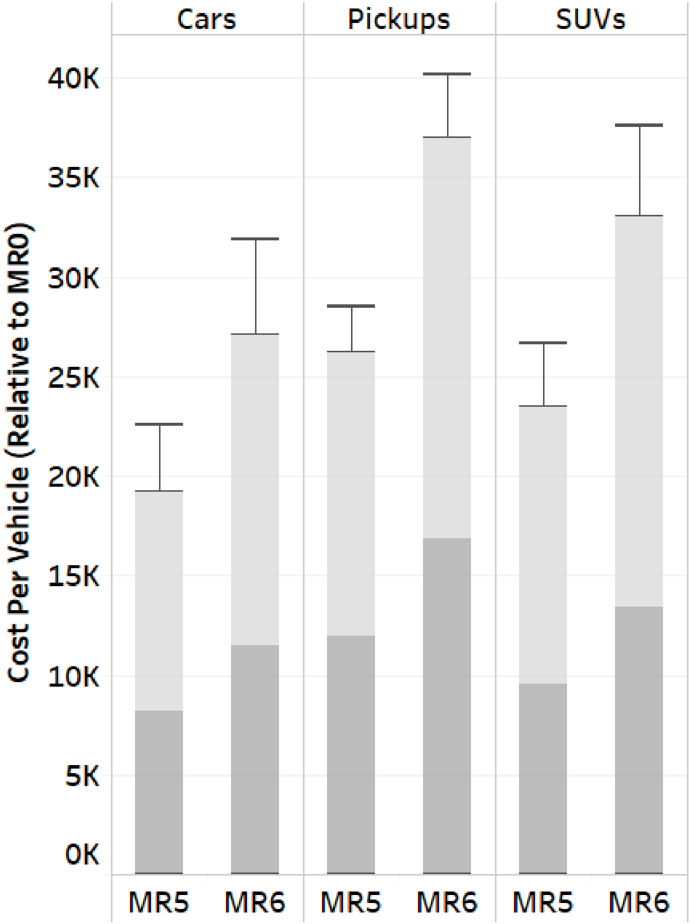

Figure 3-13 – Mass Reduction Costs (Per-Vehicle) for Highest Levels (Retail Price Equivalent), 2020

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

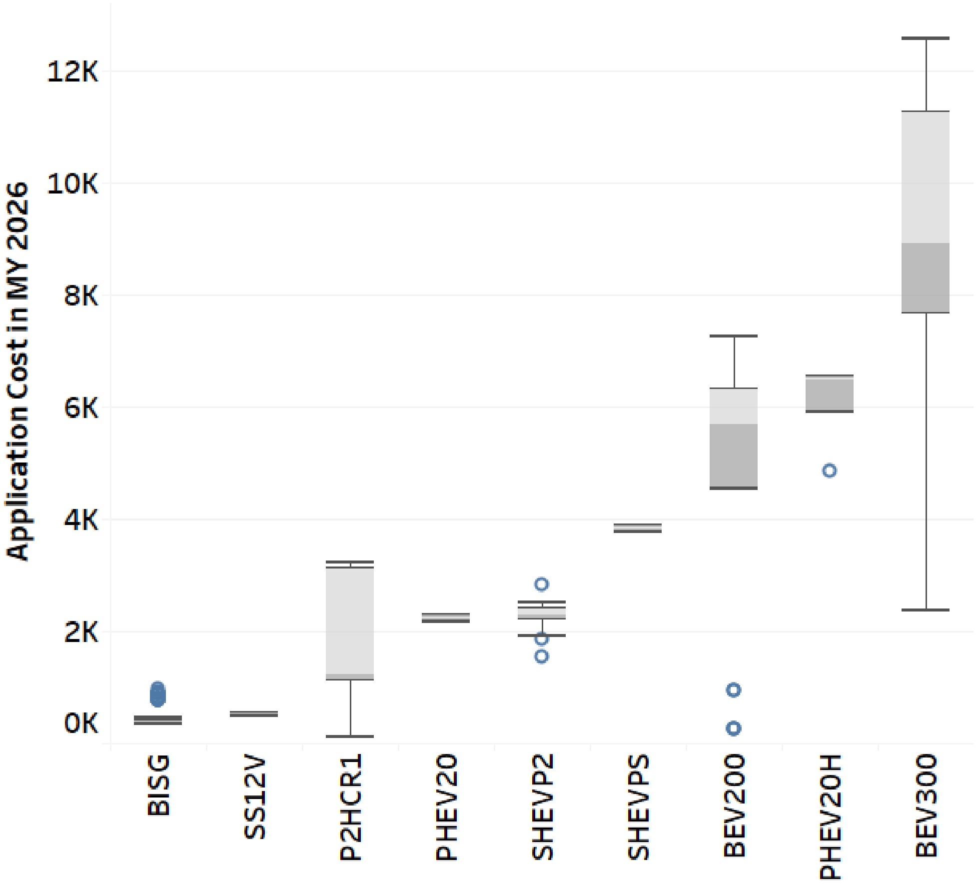

Figure 3-14 – Electrification Cost Distributions (Retail Price Equivalent), 2026

The costs of electrification technologies are not as easily described as technologies on other vehicle systems. In addition to the fixed cost components like power management systems that accompany strong hybrids or plug-in vehicles, there are costs that vary with the power requirements of the powertrain they replace (like electric motor power). In addition to these system costs, the cost of the battery is significant and variable over both vehicle size and time. The size of the batteries required by most of these technologies (except for SS12V and BISG, which have fixed battery sizes) scales with both the technology class (i.e., the body-style and power requirements) of the vehicle, but also by the amount of body-level technology that has been applied to the vehicle *within* a technology class. For example, the same vehicle model would have a larger battery at MR2 than at MR4, where the energy required to move the vehicle would be inherently less due to its lower mass. Given the influence of technology content on both battery size and cost, the direct manufacturing costs for batteries are also a product of the Argonne simulation study, which uses Argonne's BatPaC[38] model to estimate battery cost. Of all the technology costs in this analysis, battery costs decline the fastest over time – so the year in

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

which the technology is applied matters more for electrification technologies than for fuel-saving technologies in other systems.

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

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

3.2.5 Simulating Manufacturers' Compliance Decisions

In general, the model adds technology for several reasons, which it references sequentially. First, the model applies credits associated with a manufacturer's application of off-cycle and AC efficiency technology (and, if simulating compliance with GHG standards, AC leakage) to the relevant year's compliance performance. If California's Zero Emission Vehicle (ZEV) mandate is simulated to be in place, as it is in this analysis, the model will then add advanced technology to vehicles up to the point of compliance with ZEV.[39] The production of vehicles satisfying the

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

ZEV mandate affects a manufacturer's CAFE (and GHG) compliance status – the vehicles are both fuel efficient and benefit from generous alternative fuel credit provisions (both programs credit these vehicles in excess of their fuel savings, but do so to different degrees), both of which impact the amount of additional technology required to achieve compliance with standards. The model then applies any "forced" technologies.[40] Next, the model applies any technologies that were applied to a leader vehicle in an earlier year and must be inherited by follower vehicles (on the shared system) that are freshened or redesigned in the current year (and thus eligible to receive the updated version of the shared component). After applying forced and inherited technologies, the model evaluates the manufacturer's compliance status, applying all cost-effective technologies regardless of compliance status (essentially any technology for which the effective cost is negative). Then the model applies expiring CAFE credits (if allowed to consider credit application, either outside of standard-setting years or under the conditions of the EIS analysis that remove those constraints). At this point, the model checks the manufacturer's compliance status again. If the manufacturer is still not compliant (and is assumed to be unwilling to pay civil penalties), the model will add technologies for which the effective cost is positive (meaning that the cost of the technology is greater than the combination of the first 30 months of fuel savings it produces and the reduction in required civil penalty payment) until the manufacturer reaches compliance. If the manufacturer exhausts opportunities to comply with the standard by improving fuel economy (typically due to a limited percentage of its fleet being redesigned in that year), the model will apply banked CAFE credits to offset the remaining deficit.

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

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

and fleet mix shifts as a consequence of the technology application, the CAFE Model iterates the compliance simulation again (with, possibly, new fleet volumes, standards, and achieved CAFE levels) until the technology solutions stop changing between iterations.[41]

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

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

Unlike previous analyses of CAFE alternatives, the baseline for this analysis includes the simultaneous simulation of multiple programs related to fuel economy. In particular, the baseline includes California's Zero Emissions Vehicles (ZEV) mandate, discussed in detail in TSD Chapter 2.3, as well as California's Framework Agreement GHG requirements to which five manufacturers have agreed. In addition to these programs, there are Federal CAFE and GHG standards in place for model years 2020 – 2026 that were finalized in 2020. While the alternatives considered in this analysis propose new CAFE standards for model years 2024 – 2026, the reference point against which the effects of those standards is measured is a baseline that includes three programs interacting simultaneously to shape vehicle offerings and compliance positions across the industry.

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

In addition, the model must account for the new ZEV vehicles that are scheduled to be produced over time (and in every alternative, regardless of CAFE stringency). These vehicles are

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

simulated as BEVs (of varying ranges) and get the appropriate credit provisions under both the CAFE and GHG programs. For the manufacturers who adopted California's voluntary standards (like Ford, who is used in the compliance example in Chapter 3.2.6), the model must treat the GHG standard as the stringency required under California's voluntary standards. However, for manufacturers that did not sign the agreement with California, their GHG standard in MY 2021 – 2026 still reflects the GHG standards that were finalized in conjunction with CAFE standards in 2020. This means that the CAFE Model is simulating three programs simultaneously for any single manufacturer, but actually simulates four programs simultaneously across the industry (because there are two sets of GHG standards in place at the same time).

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

In addition to identifying which program represents the binding constraint in any given year, and accounting for the relevant credit positions and accounting for each program, the CAFE Model must also faithfully represent a variety of provisions that are unique to each program.[42] For example, beyond the different definitions of the standards themselves (the model uses the functions and coefficients native to each program to define the standards), there are a number of provisions related to the treatment of alternatively fueled vehicles. In the CAFE program, alternative fuel vehicles benefit from a compliance fuel economy adjustment called the petroleum equivalency factor (PEF) that adjusts fuel economy on electricity (or the portion of fuel economy represented by electricity, for PHEVs), E85, CNG, or hydrogen. However, in the GHG program, electricity is treated as generating no GHG emissions (i.e., a rating of 0 grams/mile) until MY 2026, at which point upstream emissions are currently attributed to the electricity consumption. Alternatively fueled vehicles also benefit from the application of sales/production multipliers (which vary by technology and over time) in the GHG programs, and the CAFE Model accounts for those as well.

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

Given information about regulations, and technology cost and effectiveness, the model attempts to apply technology to each manufacturer's fleet in a manner than minimizes "effective costs." The effective cost captures more than the incremental cost of a given technology – it represents

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

the difference between their incremental cost and the value of fuel savings to a potential buyer over the first 30 months of ownership.[43] In addition to the technology cost and fuel savings, the effective cost also includes the change in civil penalties from applying a given technology.[44]

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

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

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[43] 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 Technical Support Document (TSD) discusses the basis for this model input, and the accompanying *Federal Register* notice invites related comment and data.

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

3.2.6 Compliance Example

To better understand how the CAFE Model simulates compliance, it helps to walk through the solution for a single manufacturer, recognizing that no simulation using publicly-available inputs can predict precisely what Ford will actually do. The example that follows examines Ford's simulated compliance actions in the baseline (Alternative 0[45]) and illustrates the features of the model, given the full set of assumptions about technology cost and effectiveness (among others). Ford's voluntary compliance with California's greenhouse gas standards through MY 2026, applied to their national fleet (as was intended by the agreement), makes the example of particular relevance to this analysis. In model years 2021 – 2026, Ford faces requirements under the CAFE program (with standards finalized in 2020 for those model years), California's Zero Emission Vehicle (ZEV) program that requires a particular number of ZEVs produced and sold in both California and the other states who have adopted the ZEV program, and the Framework Agreement between California and five manufacturers (including Ford) regarding the average GHG levels to be achieved by those manufacturers' national new vehicle fleets through model year 2026. These simultaneous programs interact to influence Ford's decisions about how to increase the fuel efficiency of its various fleets, and the pace at which it must do so.

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

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

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

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

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

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

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

In MY 2023, the Fusion is expected to be refreshed (see Table 3-4) and inherits a new transmission from its transmission leader (upgrading from an AT6 to AT8), improves the

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

electronic accessories (IACC), and upgrades the tires (ROLL20). In MY 2024, the Transit Connects are redesigned and upgrade from an AT6 transmission to an AT10L2 (on which it is the designated leader – meaning that vehicles who share that transmission will inherit the new AT10L2 when they are next refreshed or redesigned). However, as a follower on that engine, the Transit Connect models do not initiate a new technology variant. The Transits also improve electronic accessories (IACC), upgrade tires (to ROLL20) and, in all but one case, improve aerodynamic drag from AERO15 to AERO20.

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

Model Year	Tech Key	Target	MPG
Fusion Fwd			
2020	DOHC; VVT; SGDI; AT6; EPS; CONV; LDB; ROLL10; AERO15; MR0	41.6	32
2023	DOHC; VVT; SGDI; AT8; IACC; CONV; LDB; ROLL20; AERO15; MR0	43.5	36.3
2024	DOHC; VVT; SGDI; AT8; IACC; CONV; LDB; ROLL20; AERO15; MR0	44.1	36.3
2026	TURBO1; AT8; IACC; CONV; LDB; ROLL20; AERO15; MR0	45.5	41.2
2027	TURBO1; AT8; IACC; CONV; LDB; ROLL20; AERO15; MR0	45.5	41.2
2030	TURBO1; AT8; IACC; CONV; LDB; ROLL20; AERO15; MR0	45.5	41.2
Transit Connect Lwb Usps (Cargo Van)			
2020	DOHC; VVT; SGDI; AT6; EPS; CONV; LDB; ROLL0; AERO15; MR1	32.1	29.3
2023	DOHC; VVT; SGDI; AT6; EPS; CONV; LDB; ROLL0; AERO15; MR1	33.6	29.3
2024	DOHC; VVT; SGDI; AT10L2; IACC; CONV; LDB; ROLL20; AERO20; MR1	34.1	35.2
2026	DOHC; VVT; SGDI; AT10L2; IACC; CONV; LDB; ROLL20; AERO20; MR1	35.2	35.2
2027	TURBO1; AT10L2; IACC; CONV; LDB; ROLL20; AERO20; MR1	35.2	38.1
2030	TURBO1; AT10L2; IACC; CONV; LDB; ROLL20; AERO20; MR1	35.2	38.1
Transit Connect Swb Cargo Van			
2020	DOHC; VVT; SGDI; AT6; EPS; CONV; LDB; ROLL0; AERO15; MR1	36.1	29.3
2023	DOHC; VVT; SGDI; AT6; EPS; CONV; LDB; ROLL0; AERO15; MR1	37.8	29.3
2024	DOHC; VVT; SGDI; AT10L2; IACC; CONV; LDB; ROLL20; AERO15; MR1	38.4	34.7
2026	DOHC; VVT; SGDI; AT10L2; IACC; CONV; LDB; ROLL20; AERO15; MR1	39.6	34.7
2027	TURBO1; AT10L2; IACC; CONV; LDB; ROLL20; AERO15; MR1	39.6	38.3
2030	TURBO1; AT10L2; IACC; CONV; LDB; ROLL20; AERO15; MR1	39.6	38.3

The 2.5L I4 engine that these models all share is tied to the MY 2020 vintage of the Fusion Fwd and in MY 2026, when the Fusion is redesigned, it upgrades from DOHC; VVT; SGDI (a dual-overhead cam engine with variable valve timing and direct injection) to TURBO1 (a turbocharged engine with VVT, VVL, and SGDI). The Transit Connect models, which are not scheduled for either type of design modification in MY 2026, continue using the legacy version of the shared engine until they are refreshed in MY 2027, at which point they inherit the new TURBO1 engine. As the fleet compliance example will show, Ford did not need to improve the fuel economy of these Transit Connect models in MY 2027 in order to comply with either CAFE standards or California's GHG standards. However, this inheritance occurs in the analysis to minimize the cost of producing a larger number of unique engines, for which we do not estimate additional costs.

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

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

Under CAFE standards, Ford's DC fleet is bound by the minimum domestic passenger car standard (39.8 MPG in MY 2020), which is 3 MPG higher than Ford's estimated compliance value for that fleet. By statute, Ford is not able to use CAFE credits from another fleet (whether earned by Ford in another fleet or another manufacturer) to resolve the deficit with respect to the minimum standard; civil penalties must be paid. The CAFE Model simulates the penalties associated with the deficit (the "Fines" column in Table 3-6). However, after resolving the deficit associated with the minimum standard, a manufacturer may use credits to resolve any *remaining* deficit that occurs as a consequence of its calculated standard (41.9 MPG, in this case). As expected, the CAFE Model transfers credits into the DC fleet in MY 2020 ("Credits In"), in an amount that offsets the remaining compliance deficit. The imported car (IC) fleet is also under its standard, and the model estimates the penalties associated with the deficit. Despite the nearly 10 MPG gap between the standard and compliance value, the sales volumes in the IC fleet are modest, and the size of the penalty payment modest as well. In practice, it is more likely that Ford acquires IC credits from another manufacturer or shuffles credits between fleets in a way that differs from the simulation. Ford's LT fleet exceeds its standard in MY 2020 and generates credits, which the CAFE Model accrues for use in future years.

Under the GHG standards, Ford's PC fleet (the union of its DC and IC fleets in CAFE) is similarly out of compliance with its standard. However, Ford has a sufficient number of compliance credits available and applies a quantity that exactly offsets the PC deficit in MY

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

2020 (2,788,789 credits, the “Credits In” column in Table 3-7). The LT fleet earns 2.2 million credits, and transfers those into the bank for future use. Because credit transfers between fleets are uncapped, earned GHG credits essentially live in a common bank that is not specific to either fleet, only the model year in which they were earned. As such, Ford is able to take expiring credits and push them into the PC fleet in MY 2020, while simultaneously taking earned truck credits in that year and carrying them forward. In this way, a manufacturer is able to renew expiring credits as long as a single fleet performs sufficiently better than its standard. In CAFE compliance, this is not the case. Because the earned credits are tied to both a specific fleet and a specific model year, the credits must be used to offset deficits in the fleet in which they were earned (or be transferred to another fleet, and be subject to adjustments that could significantly erode their value, even before the transfer cap applies). The CAFE Model accounts for both of these credit accounting regimes, simultaneously, while simulating compliance with the two programs simultaneously.

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

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

Model Year	Regulatory Class	Minimum Standard (mpg)	Standard (mpg)	CAFE (mpg)	Fines	Credits Earned	Credits Out	Credits In
2020	Domestic Car	39.8	41.9	36.8	194,524,878	(21,311,574)	-	7,089,840
2020	Imported Car		48	38.8	35,791,989	(2,616,756)	-	-
2020	Light Truck		29.2	30	-	9,918,656	23,121	-
2021	Domestic Car	40.4	42.5	37.2	327,685,228	(24,521,086)	-	-
2021	Imported Car		48.7	38.8	-	(2,982,771)	-	2,982,771
2021	Light Truck		29.7	31.6	-	24,953,156	22,283	-
2022	Domestic Car	41.0	43.2	43.2	-	-	-	-
2022	Imported Car		49.5	39	-	(3,465,420)	-	3,465,420
2022	Light Truck		30.1	32.8	-	38,843,766	-	-
2023	Domestic Car	41.6	43.8	46.5	-	15,313,833	-	-
2023	Imported Car		50.2	53.7	-	1,188,215	-	303,084
2023	Light Truck		30.6	34.1	-	51,794,470	25,082	25,082
2024	Domestic Car	42.2	44.5	46.5	-	11,377,880	-	-
2024	Imported Car		51	53.7	-	895,833	-	66,359
2024	Light Truck		31	35.4	-	63,635,748	24,805	24,805
2025	Domestic Car	42.9	45.2	46.9	-	9,572,173	-	-
2025	Imported Car		51.8	53.7	-	610,470	-	64,260
2025	Light Truck		31.5	35.5	-	56,021,360	23,121	23,121
2026	Domestic Car	43.5	45.8	47.4	-	8,851,344	-	-
2026	Imported Car		52.5	53.7	-	372,000	-	62,000
2026	Light Truck		32	35.6	-	48,647,016	22,283	22,283
2027	Domestic Car	43.5	45.8	47.5	-	9,264,303	-	-
2027	Imported Car		52.5	53.7	-	361,308	-	-
2027	Light Truck		32	35.7	-	48,561,279	-	-
2028	Domestic Car	43.5	45.8	47.5	-	9,207,744	-	-
2028	Imported Car		52.5	53.7	-	352,212	-	-
2028	Light Truck		32	35.7	-	47,337,985	-	-
2029	Domestic Car	43.5	45.8	47.6	-	9,720,486	-	-
2029	Imported Car		52.5	53.7	-	345,876	-	-
2029	Light Truck		32	35.7	-	46,485,505	-	-

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

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

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

Model Year	Regulatory Class	Standard (g/mi)	Rating (g/mi)	Credits Earned	Credits Out	Credits In	ZEV Target	ZEV Credits
2020	Passenger Car	194	226	(2,788,789)	-	2,788,789		
2020	Light Truck	289	281	2,240,277	2,240,277	-		
2020	TOTAL	264	266	(548,512)	2,240,277	2,788,789	36,091	3,801
2021	Passenger Car	189	224	(3,367,852)	-	3,367,852		
2021	Light Truck	282	263	5,636,045	4,800,265	-		
2021	TOTAL	257	252	2,268,193	4,800,265	3,367,852	48,833	30,149
2022	Passenger Car	177	191	(1,548,067)	-	1,548,067		
2022	Light Truck	258	253	1,624,712	1,624,712	-		
2022	TOTAL	235	235	76,645	1,624,712	1,548,067	65,502	119,321
2023	Passenger Car	170	174	(469,515)	-	704,272		
2023	Light Truck	249	242	2,339,712	1,150,242	-		
2023	TOTAL	226	222	1,870,197	1,150,242	704,272	79,707	125,703
2024	Passenger Car	164	174	(1,175,632)	-	1,293,195		
2024	Light Truck	240	233	2,286,628	1,737,499	-		
2024	TOTAL	218	216	1,110,996	1,737,499	1,293,195	89,995	125,181
2025	Passenger Car	158	172	(1,627,093)	-	1,743,314		
2025	Light Truck	231	232	(316,332)	1,743,314	2,240,277		
2025	TOTAL	209	214	(1,943,425)	1,743,314	3,983,591	98,926	123,164
2026	Passenger Car	152	170	(2,053,350)	-	2,053,350		
2026	Light Truck	222	231	(2,746,915)	2,053,350	4,800,265		
2026	TOTAL	201	213	(4,800,265)	2,053,350	6,853,615	95,941	120,413
2027	Passenger Car	174	178	(449,160)	-	449,160		
2027	Light Truck	260	234	7,707,449	566,401	76,645		
2027	TOTAL	234	217	7,258,289	566,401	525,805	93,562	118,172
2028	Passenger Car	174	178	(445,970)	-	445,970		
2028	Light Truck	260	234	7,513,293	564,923	445,970		
2028	TOTAL	233	217	7,067,323	564,923	891,940	91,721	116,852
2029	Passenger Car	174	178	(444,304)	-	444,304		
2029	Light Truck	260	234	7,377,991	564,740	444,304		
2029	TOTAL	233	217	6,933,687	564,740	888,608	90,473	116,048

From MY 2024, the simulation shows Ford generating large CAFE credit surpluses as it attempts to comply with California's voluntary GHG standards. We note here that this NPRM proposes more stringent CAFE standards in MYs 2024-2026 that preclude the opportunity to build such sizable credit surplus against lower standards in those years. Under the GHG standards, the model simulates behavior similar to prior years: Ford's PC fleet still falls short of compliance, the LT fleet exceeds its standard, and the model applies credits to offset the PC deficit while banking credits earned by the LT fleet. In both MY 2025 and MY 2026, the CAFE Model simulates the same behavior: Ford complies with standards in neither fleet, but uses banked credits to offset the deficits in both. The reliance on banked credits for these final two model years is an artifact of the specification for Alternative 0. In the baseline alternative, the California program is assumed to expire after MY 2026, at which point the standards revert to the EPA GHG standards that were finalized in 2020. This is illustrated in Table 3-7, where Ford's PC and LT standards revert from 152 g/mi and 222 g/mi in MY 2026, to 174 g/mi and

260 g/mi, respectively, in MY 2027. The CAFE Model sees this relaxation in stringency looming in future years, and applies only enough technology in earlier years to generate the credits needed to comply with the short series of high stringency years before the standards relax. While this may not be how the real world plays out, it reflects DOT's (and thus, the CAFE Model's) understanding of the regulatory landscape as it is currently expected to exist in that time frame.

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

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

3.3.1 Representing the Economic Effects of CAFE and GHG Standards

The CAFE Model contains all of the relationships needed to estimate the range of economic effects that result from changes in CAFE stringency. The economic framework of the benefit cost analysis is discussed in detail in Chapter 4. In general, changes to standards create streams of benefits and costs that accrue to vehicle producers when they build and sell vehicles, owners when they purchase and use vehicles, and the rest of society as they interact with a population of vehicles that has been changed in some way by the standards.

As manufacturers apply technology to their vehicle offerings in order to comply with more stringent standards, the CAFE Model explicitly simulates the price impacts in the new vehicle market. In particular, based on the assumption that all costs related to compliance (the cost of technology or civil penalties) are passed through to buyers of new vehicles, the model uses a price elasticity to adjust aggregate new vehicle sales, relative to the baseline. The price elasticity acts on an adjusted average price increase, by calculating the average price increase net of some portion of realized fuel savings (the first 30 months in this analysis). While the value of the elasticity is a user-defined input, this analysis assumes a unit elastic response (i.e., an elasticity equal to -1.0). 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.

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

These two models work together to modify the total number of new vehicles, the share of passenger cars and light trucks, and, as a consequence, the number of each given model sold by a given manufacturer. Changes to higher levels of sales (either total sales or passenger car/light-truck body styles) are distributed to individual manufacturers and vehicle models based on their observed shares in the MY 2020 fleet. However, these two factors are insufficient to cause large changes to the composition of any of a manufacturer's (regulatory) fleets. In order to significantly change the mix of models produced within a given fleet, the CAFE Model would require a way to trade off the production of one vehicle against another, both within a manufacturer's fleet and across the industry. While NHTSA has experimented with fully-integrated consumer choice models, their performance has yet to satisfy the requirements of a rulemaking analysis. For more detail on both components of the sales response, please see TSD Chapter 4.2.1.

In addition to capturing the influence of changes to average new vehicle prices on total new vehicle sales, the model also accounts for expected changes to the used vehicle population as a consequence of those price increases (and fuel savings). In particular, the CAFE Model dynamically estimates the probability that used vehicles of a given age remain in service each year. It uses this function to dynamically retire portions of older vehicle cohorts in a manner that is responsive to both macroeconomic conditions and simulated price changes in the new vehicle market that influence used vehicle transaction prices and residual value. As new vehicles enter the registered population their retirement rates are governed by this equation, but so are the vehicles already registered at the start of model year 2019. To the extent that a given set of CAFE standards accelerates or decelerates the retirement of those vehicles, additional fuel consumption and social costs may accrue to those vehicles under that standard. The CAFE Model accounts for those costs and benefits, as well as tracking all of the standard benefits and costs associated with the lifetimes of new vehicles produced under the rule. For more detail about the derivation of the scrappage functions, see TSD Chapter 4.2.2.

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

The implementation in the CAFE Model uses this function to define a constraint on "non-rebound" VMT that is held constant across regulatory alternatives, and implicitly includes any changes to both fuel prices over time and the average efficiency of the on-road fleet (as newer more efficient vehicles replace older ones over time). It is NHTSA's 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, as the daily need for a vehicle will remain the same. That said, it is reasonable to assume that fleets with differing age distributions and inherent cost of operation will have slightly different annual VMT (even without considering VMT associated with rebound miles); however, the difference could conceivably be small. Based on the structure of the CAFE Model, the combined effect of the sales and scrappage responses can create small percentage differences in total VMT across the range of regulatory alternatives if steps are not taken to constrain VMT. Because VMT is related to many of the costs and benefits of the program, even small magnitude differences in VMT across alternatives can have meaningful impacts on the incremental net benefit analysis. To enforce this perspective, to the CAFE Model constrains "non-rebound" VMT (defined more explicitly in TSD Chapter 4.3.2.1) to be identical across regulatory alternatives, using the FHWA VMT demand model to determine the constraint in each simulated calendar year.

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

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

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

Rather than rely on the compliance values of fuel economy for either historical vehicles or vehicles that go through the full compliance simulation, the model applies an "on-road gap" to represent the expected difference between fuel economy on the laboratory test cycle and fuel economy under real-world operation. While the model currently allows the user to specify an on-road gap that varies by fuel type (gasoline, E85, diesel, electricity, hydrogen, and CNG), it does not vary over time, by vehicle age, or by technology combination. As discussed in the accompanying TSD, today's analysis uses input values range that from 24% to 29%, depending on the vehicle type and fuel. 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.

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

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

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

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

3.3.3 Costs and Benefits to Producers, Consumers, and Society

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

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

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

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

Other social costs and benefits emerge as the result of physical phenomena, like tailpipe emissions or highway fatalities, which are the result of changes in the composition and use of the on-road fleet. The social costs (in dollars) associated with those quantities represent an economic estimate of the social damages associated with the changes in each quantity. The model tracks and reports each of these quantities by: model year and vehicle age (the combination of which can be used to produce calendar year totals), regulatory class, fuel type, and social discount rate. The list of social costs and benefits is presented in Table 3-8, as well as the population of vehicles that determines the size of the factor (either new vehicles or all registered vehicles) and the mechanism that determines the size of the effect (whether driven by the number of miles driven, the number of gallons consumed, or the number of vehicles produced).

Table 3-8 – Social Costs and Benefits in the CAFE Model

Cost/Benefit	Population	Mechanism
Technology Cost	New vehicles	Production volume
Maintenance/Repair	New vehicles	Production volume
Consumer Surplus	New vehicles	Production volume
Retail Fuel Savings	All Vehicles	Fuel Consumption
Fuel Tax Revenue	All Vehicles	Gallons
Benefit of Additional Mobility	New vehicles	Miles
Benefit of Less Frequent Refueling	New Vehicles	Gallons
Energy Security Cost	All Vehicles	Gallons
Congestion and Noise costs	All Vehicles	Miles
Non-Fatal Injuries	All Vehicles	Miles
Fatalities	All Vehicles	Miles
Criteria Pollutant Damages (CO, NO_x, SO_2, PM)	All Vehicles	Miles, Fuel Consumption
Greenhouse Gas Emissions Damages (CO_2, CH_4, N_2O)	All Vehicles	Fuel Consumption

3.3.4 Representing the Safety Effects of CAFE Standards

There are three avenues by which raising CAFE standards are assumed to affect fleet-wide safety. First, by raising prices for new vehicles and reducing their sales, and by reducing retirement rates for used vehicles, it redistributes VMT from newer cars and light trucks toward older ones, and between new passenger cars and new light trucks as sales shares change over time.[48] Because the safety of new vehicles has gradually improved over time, and to some extent because older models tend to be owned by riskier drivers[49] and driven in less safe conditions (rural roads, etc.), redistributing VMT from newer to older vehicles increases fatalities and injuries slightly. We measure this effect by projecting differential fatality and injury rates for cars and light trucks of different vintages (i.e., model years) and ages during future calendar years, and applying these rates to estimates of the redistribution of total VMT by model year and age that results from reduced sales of new models and slower retirement of older vehicles.

Second, by increasing VMT of the new cars and light trucks that continue to be sold via the rebound effect, raising CAFE standards exposes their drivers and passengers to increased risks of

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[48] The model finds that price increases from the proposal will depress new vehicle sales, but we note that this is dependent on the input assessment that consumers value 30 months of fuel savings when making their purchase decisions. This assumption reflects previous research and appears to be consistent with the basis used for manufacturers' marketing decisions, but individual consumers' assessments of the value of fuel economy are likely to differ.

[49] Metzger KB, Sartin E, Foss RD, Joyce N, Curry AE. Vehicle safety characteristics in vulnerable driver populations. Traffic Inj Prev. 2020 Oct 12;21(sup1):S54-S59. doi: 10.1080/15389588.2020.1805445. Epub 2020 Aug 27. PMID: 32851883; PMCID: PMC7910315. https://pubmed.ncbi.nlm.nih.gov/32851883/).

being involved in crashes. Despite the fact that new cars and light trucks produced during each successive model year are anticipated to be safer than their predecessors, their increased use thus results in slightly more crashes, and slightly larger numbers of fatalities and injuries. We measure this effect as the product of the increase in driving in new cars and light trucks over their lifetimes, and the per-mile risks that their occupants will suffer fatal and non-fatal injuries in crashes.

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

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

4. Economic Analysis of Regulatory Alternatives

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

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

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

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

4.1 Overview of Effects from Increasing Fuel Economy Standards

Figure 4-1 shows the inputs to the model, the behaviors influenced by fuel economy standards, and the resulting benefits and costs in the markets generated throughout the U.S. economy. Vehicle manufacturers respond to increases in required fuel economy by accelerating the pace at which they apply existing and new technology to improve the fuel efficiency of their fleet. Because additional technology is costly to produce and integrate into a vehicle's design, doing so will increase manufacturers' costs to produce those models they redesign, and they will attempt to recover their additional technology costs and maintain profitability by raising some models' prices. At the same time, producers may delay or forego planned improvements to vehicles' other features – such as seating or carrying capacity, passenger comfort, occupant safety, or performance – and focus their engineering capabilities and other resources on meeting higher fuel economy targets. The resulting sacrifices in attributes other than fuel economy on some models may reduce their utility and value to potential buyers.

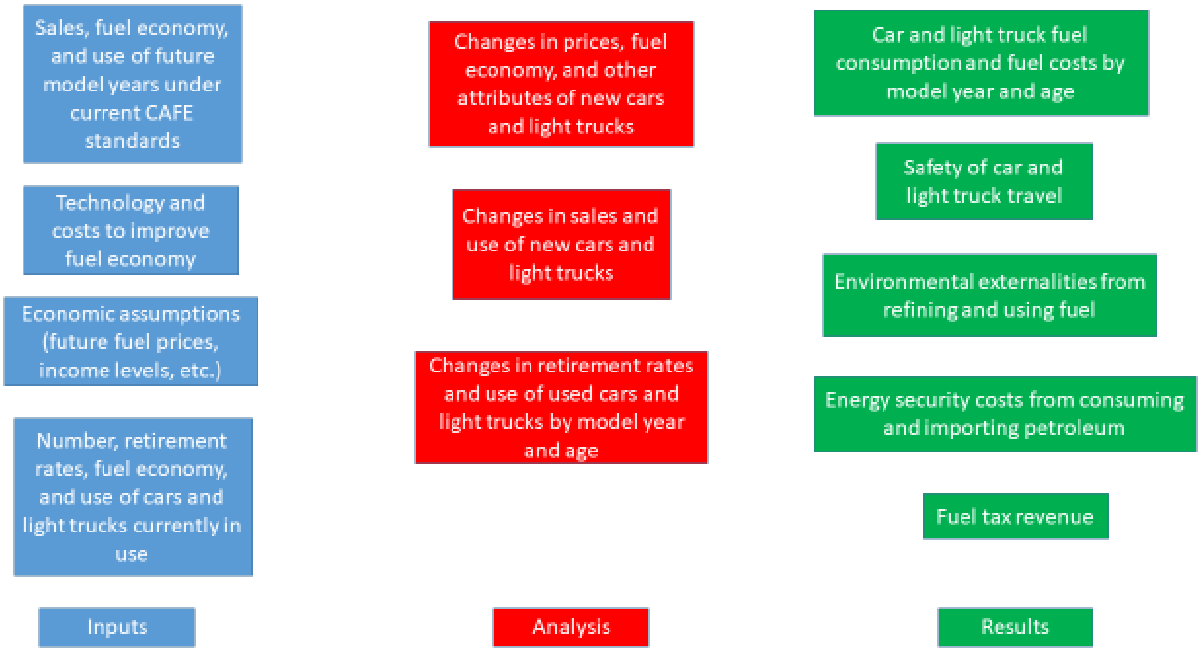

Figure 4-1 – Overview of NHTSA's Analysis of Changes in Fuel Economy Standards

In the absence of demanding CAFE standards, manufacturers design their vehicle models to offer levels of fuel economy, other features, and selling prices they believe will make them most attractive to buyers, and thus maximize their sales and profits.[51] Increasing the stringency of CAFE standards is intended to require manufacturers to raise their vehicles' fuel economy levels from this market-determined baseline to levels beyond those they would otherwise provide, because the agency believes that doing so will provide benefits to new car and light buyers – as well as to the general public – that exceed the costs of increasing fuel economy. As the figure indicates, the resulting combination of improvements in fuel economy, changes in vehicles' other features, and higher prices is likely to affect sales of new cars and light trucks. The size of the market response (and even possibly its direction) depends on how potential buyers value the future savings in fuel costs that result from improving fuel economy, how they value accompanying changes in other attributes, and how they weigh higher purchase prices against these changes. Manufacturers presumably will make improvements in fuel economy (beyond what current standards require) when they believe potential buyers are willing to pay higher prices for models that offer them, but raising CAFE standards is specifically intended to require producers to increase fuel economy beyond its market-determined level. However, doing so could marginally reduce sales of new cars and light trucks if consumers do not recognize the full value of fuel saved, since if manufacturers could increase sales, and, by extension, profits by increasing fuel economy beyond the levels they currently provide, they would presumably do so even in the absence of higher CAFE standards.

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

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

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

crashes, so shifting travel from newer to older vehicles will affect the safety of drivers and their passengers.

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

4.2 Measuring Benefits and Costs from Raising CAFE Standards

In theory, the economic benefits and costs resulting from higher CAFE standards are measured by changes in consumers' and producers' welfare in all markets that are ultimately affected, plus any accompanying changes in externalities generated by production or consumption of the products traded in those markets. NHTSA's evaluation of its proposed action evaluates these benefits and costs arising in four different markets that are likely to be affected either directly or indirectly. These include the market for new cars and light trucks, the market for used cars and light trucks, markets for transportation fuels (including those refined from petroleum and, increasingly, electricity), and the market for crude petroleum. The agency examines benefits and costs in these markets in the order they arise: raising CAFE standards affects the market for new cars and light trucks directly, and its consequences for the fuel economy, prices, and sales of new vehicles in turn generate indirect impacts on new vehicles' use, the number of used cars and light trucks in service and how much they are driven, production and consumption of gasoline and other transportation fuels, and U.S. production, imports, and refining of crude petroleum.[52]

Insofar as possible, the agency's analysis estimates theoretically correct measures of changes in economic welfare in the affected markets, which consist of changes in consumer and producer surplus plus any changes in the value of externalities arising from production or consumption. Throughout its analysis, however, NHTSA makes assumptions that simplify measuring these benefits and costs. The most important of these is that the supply of new cars and light trucks and transportation fuels is "perfectly elastic," so that changes in demand do not lead to changes in their prices. This assumption simplifies the measurement of benefits and costs because it implies that the welfare of producers is generally unaffected, so that changes in consumer welfare and the value of externalities capture most or all benefits and costs from requiring higher fuel economy, or put another way, costs for complying with the standards are passed through to consumers. While acknowledging that this is a simplification of real-world production conditions, the agency believes that this assumption is likely to have little effect on its estimates

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[52] Some gasoline consumed in the U.S. may also be imported in already-refined form, rather than refined domestically.

of benefits and costs from the proposed action.[53] Similarly, the agency's analysis generally assumes that the magnitude of any externalities varies proportionally with changes in production or consumption activity that generates them; in other words, the value of externalities per unit of activity (such as per mile driven or gallon of fuel consumed) is assumed to be unaffected by changes in production or consumption levels. Again, the agency acknowledges that in some cases this assumption simplifies real-world conditions, but believes any effect on its estimates of benefits or costs from changes in the relevant externalities is likely to be modest.

4.2.1 Private versus "External" Benefits and Costs

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

4.2.2 Perspective for Measuring Benefits and Costs

OMB's guidance on regulatory analysis directs agencies to measure the benefits and costs of their proposed actions against a baseline alternative that represents "the best assessment of the way the world would look absent the proposed action."[54] Where that future world includes existing government regulations, OMB's guidance further advises that a baseline should reflect "changes in regulations promulgated by the agency or other government entities, and the degree of compliance by regulated entities with other regulations," and that "[f]or review of an existing regulation, a baseline assuming no change in the regulatory program generally provides an appropriate basis for evaluating regulatory alternatives."[55]

In accordance with OMB's guidance, NHTSA is using the CAFE standards established previously for model year 2022-26 cars and light trucks as the baseline alternative for this regulatory analysis. The baseline the agency uses for this analysis also reflects specific assumptions about the administration of EPA's companion program to reduce GHG emissions from cars and light trucks, as well as California's voluntary agreement with some manufacturers to reduce their vehicles' emissions, and ZEV mandates. Since the agency has yet to issue CAFE

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[53] More specifically, the agency's analysis implicitly assumes that the *sum* of changes in consumer and producer surplus in each affected market is likely to vary relatively little under alternative assumptions about the extent to which supply is inelastic and prices change as a consequence of changes in demand of the magnitude likely to result from imposing higher CAFE standards.

[54] OMB Circular A-4, p. 15.

[55] *Id.*

standards for model years 2026 and beyond, the agency assumes for the baseline that the standards previously established for model year 2026 would be extended to apply to subsequent model years. Proposed alternatives are compared against the baseline.

This analysis relies on many economic assumptions and forecasts, and while these do not vary between the baseline scenario and the various regulatory alternatives, they nevertheless contribute to benefits and costs of each regulatory alternative when those are measured by comparison to the regulatory baseline. Forecasts of overall U.S. economic activity, personal income, and other macroeconomic variables, which affect the projections of new vehicle sales and retirement rates of used vehicles, are taken from the U.S. Energy Information Administration's *Annual Energy Outlook 2021* (AEO 2021).[56] This is also the source for the forecasts of U.S. fuel prices, global petroleum supply and prices, and U.S. imports of crude petroleum and refined fuel that are used in this analysis.[57] Finally, the agency relies on U.S. DOT guidance for valuing travel time when assessing benefits from less frequent refueling and costs of increased congestion delays.[58]

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

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

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[56] U.S. Energy Information Administration, Annual Energy Outlook 2021, Reference Case Table 20 (https://www.eia.gov/outlooks/aeo/tables_ref.php).

[57] U.S. Energy Information Administration, Annual Energy Outlook 2018, Reference Case Tables 11 and 12 (https://www.eia.gov/outlooks/aeo/tables_ref.php).

[58] U.S. Department of Transportation, Office of the Assistant Secretary for Transportation Policy, "Revised Departmental Guidance on Valuation of Travel Time in Economic Analysis" https://www.transportation.gov/office-policy/transportation-policy/revised-departmental-guidance-valuation-travel-time-economic.

4.3 Impacts on the Market for New Cars and Light Trucks

Raising CAFE standards requires manufacturers to improve the fuel economy of some – and perhaps most – car and light truck models, and by doing so will increase manufacturers' costs to produce them. These direct impacts are the initial source of all costs and benefits that ultimately result from imposing higher standards. Of course, potential buyers are also sensitive to new vehicles' purchase prices, and these are likely to rise as manufacturers attempt to recover the costs for improving fuel economy in order to sustain their profitability. Inherent engineering tradeoffs between fuel economy and other features such as performance also mean that imposing higher CAFE standards may cause manufacturers to scale back or even forego planned improvements in these other features, while they focus their engineering expertise and other resources on increasing fuel economy. Finally, gradual technological progress in vehicle design and production methods enables manufacturers to improve vehicles' fuel economy slowly over time, thereby reducing their incremental costs for further increasing fuel economy to meet higher CAFE targets.

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

First, NHTSA assumes that car and light truck manufacturers will be able to recover their full incremental costs for producing vehicles that meet higher CAFE targets in the form of higher selling prices. The agency does not attempt to estimate price increases for specific car and light truck models, and instead simply assumes that their average price will rise sufficiently that increases sales revenue will fully cover manufacturers' increased costs. NHTSA's analysis does not attempt to project improvements in vehicles' other attributes that manufacturers would make if they were not compelled to meet higher fuel economy targets, or to value any sacrifices in those other features producers make in order to meet more demanding CAFE standards. Nor does it account for normal improvements in the fuel economy of future new cars and light trucks that might occur under current CAFE standards, or by how much this might reduce manufacturers' incremental costs to meet higher standards. It does, however, account for fuel economy improvements manufacturers would voluntarily make in response to anticipated increases in future fuel prices and their effect on car and light truck buyers' demands for higher fuel economy.

Manufacturers' use of more advanced technology to improve fuel economy may also increase owners' maintenance or repair expenses.[59] Although some slight deterioration in vehicles' fuel economy as they age and accumulate use appears normal, owners must respond to any unexpected decline by undertaking the maintenance or repairs necessary if they wish to preserve their expected savings in fuel costs. More frequent or costly maintenance and repairs to sustain vehicles' original fuel economy represents an additional cost of requiring new cars and light trucks to meet higher fuel economy targets, and while NHTSA does not attempt to estimate it, doing so would increase the costs of meeting higher CAFE standards.

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

4.3.1 Effects of Changes in Prices, Fuel Economy, and Other Features

This section describes how the CAFE Model currently estimates the effects of higher CAFE standards on new vehicle sales and the used car market. It is followed by a discussion of issues raised by the current approach on which NHTSA requests comment. The changes in selling prices, fuel economy, and any other features of cars and light trucks produced during future model years will affect both sales of individual models and the total number of new vehicles sold. On balance, the changes in prices and fuel economy resulting from manufacturers' efforts to comply with higher CAFE standards are likely to reduce total sales of new cars and light trucks during future model years, because buyers appear to value those improvements at less than manufacturers' costs to make them.

The logic underlying this assertion is simple: if manufacturers believed that potential buyers valued fuel economy sufficiently that improving it while raising 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 observation that manufacturers do not voluntarily

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

provide the levels of fuel economy this proposal would require suggests that they believe being required to do so will reduce their sales and profits.[60] However, the relative importance of prices, fuel economy, and vehicles' other attributes to potential buyers is not fully understood and is also likely to vary widely among consumers, so their combined effect on sales of new car and light truck models – and even on the mix of those two categories – is difficult to anticipate. The following sections detail NHTSA's approach to estimating changes in new car and light truck prices, the response of sales, and their implications for consumer welfare.

Figure 4-2 illustrates the proposed rule's likely effect on total sales of new cars and light trucks. Under the baseline scenario, total demand for new cars and light trucks is shown by the demand curve D_0, which shows the number that will be purchased at each price. The industry-wide supply curve – which depicts the number produced and offered for sale at each price – is shown by S_0 in the figure; in the baseline, demand and supply interact to result in total sales of Q_0 vehicles at a price pf P_0.[61] Increasing the amount of fuel economy-improving technology that manufacturers must employ by raising CAFE standards increases their costs to produce new vehicles, and this effect is shown as an upward shift in the industry-wide supply curve to S_1. To preserve their profitability, manufacturers would charge higher prices that reflected their increased costs (on average across their entire model lineups, if not for each individual model), and if there were no accompanying change in demand, annual sales would decrease to the level corresponding to Q_0*.

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

[61] The industry supply curve for new cars and light trucks is shown in Figure 4-2 as "perfectly elastic," meaning that additional vehicles can be produced at constant incremental costs, and this same assumption of elastic supply is used to analyze most other impacts of raising CAFE standards. NHTSA uses this assumption mainly to simplify the presentation of how benefits are measured, and also partly because the alternative assumption of inelastic supply greatly complicates the analysis of benefits by introducing changes in producer surplus as well as in consumer surplus. Generally, considering the combined changes in consumer and producer surpluses under conditions of inelastic supply would not significantly affect the agency's estimates of total benefits and costs from requiring higher fuel economy, although it would lead to different conclusions about their distribution among vehicle producers, fuel suppliers, and buyers of new cars and light trucks.

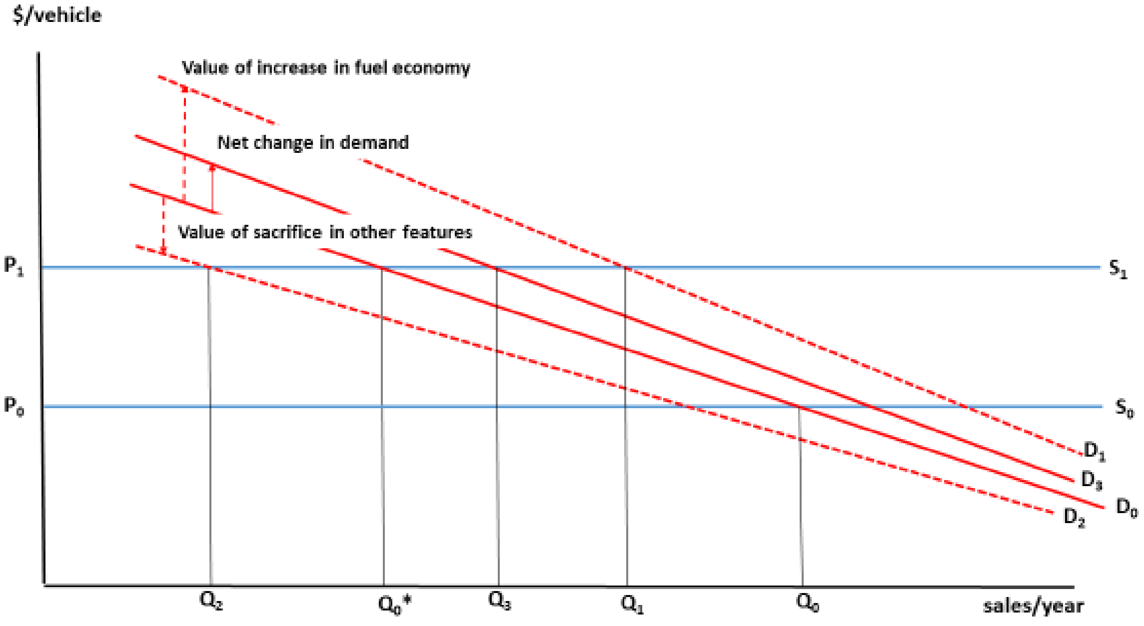

Figure 4-2 – Effect of Changes in Vehicle Prices, Fuel Economy, and Other Attributes on Demand

As indicated in the previous section, however, the combination of fuel economy and other features some new car and light truck models offer will also change, as their manufacturers employ more advanced technology and forego some improvements they would otherwise have made in those models' other desirable features. Both of these changes will affect demand for new vehicles, but 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 example, to the level shown by the demand curve D_1. The upward shift shown in the figure reflects a distribution of buyers' valuations of higher fuel economy, with those toward the upper (or left) end of D_1 willing to pay the most for increased fuel economy, and buyers showing progressively lower values moving down and to the right along D_1.

In conjunction with price increases that reflect manufacturers' higher costs, the increase in demand caused by the improvement in fuel economy would limit the decline in sales to Q_1, if no other changes in vehicles' attributes occurred.[62] At the same time, however, any accompanying reduction in improvements to their other features will reduce new models' desirability to potential buyers; this would reduce demand, as illustrated for example by the downward shift in the demand curve to D_2. In conjunction with higher prices that fully recovered manufacturers'

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

costs, this would reduce their sales to Q_2 if it were not accompanied by improvements in their fuel economy.

The net effect of these two changes on demand for new cars and light trucks is difficult to anticipate, because it depends on the specific changes in fuel economy and vehicles' other features, as well as on the distributions of values that buyers attach to fuel economy and those other attributes. As Figure 4-2 shows, if buyers view the combination of higher fuel economy and smaller improvements in other features as making future models more desirable on balance, demand for new vehicles will ultimately settle at a position such as D_3. As a consequence, sales will decline (to the level Q_3 shown in the figure), because the effect of higher prices will outweigh the increase in new vehicles' overall desirability. Viewed another way, sales of new cars and light trucks will decline as long as potential buyers find that the combination of higher prices and foregone improvements in vehicles' other features outweighs the value of their improved fuel economy, which the agency concludes is the most likely response.[63]

The likely decline in sales of new cars and light trucks during future model years when stricter CAFE standards take effect produces two sources of economic costs. Figure 4-3 illustrates these costs for a simplified case where demand for new cars and light trucks increases (from D_0 to D_1) as their manufacturers improve fuel economy to comply with stricter standards but make no accompanying sacrifices in their 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 to recoup producers' higher costs) suppress sales by more than enough to offset this gain. Thus on balance, sales of new cars and light trucks decline to Q_1. This example provides a conservative estimate of costs, because if manufacturers forego any improvements in vehicles' other features as part of their effort to increase fuel economy, the decline in sales will be larger than Figure 4-3 shows.

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[63] Again, if manufacturers could increase sales and profits by improving fuel economy and raising prices enough to recover their higher costs, they would do so voluntarily.

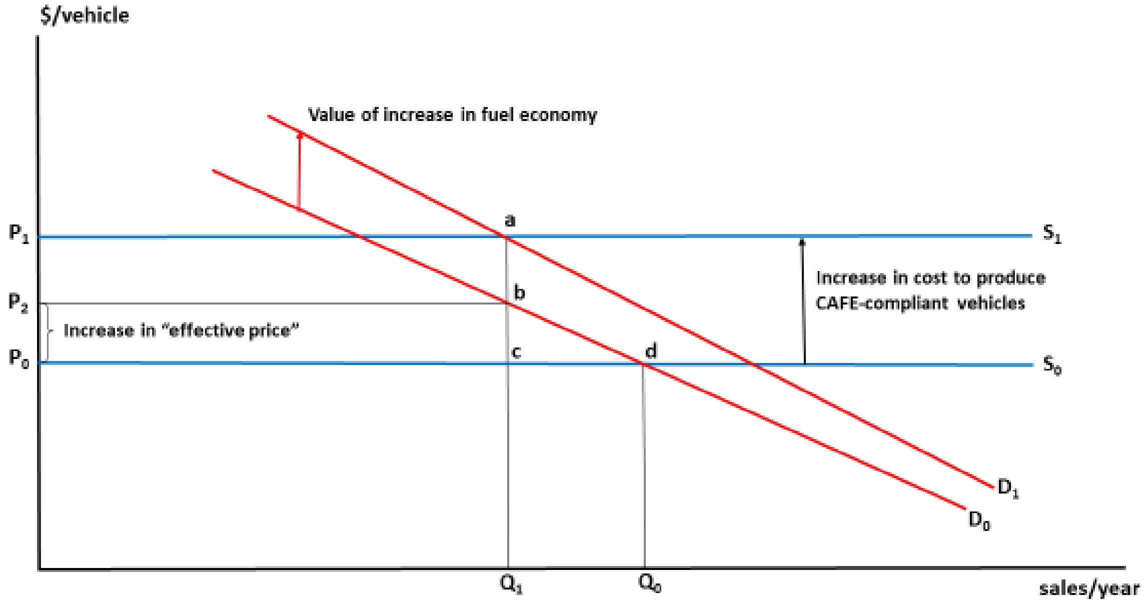

Figure 4-3 – Effects of Requiring Higher Fuel Economy

First, although buyers who purchase new cars and light trucks even at their higher price are those with the highest values of improved fuel economy, they are likely to experience some loss in welfare from the combination of higher prices and improved fuel economy. Their net loss in welfare is measured by their increased outlays for the models they continue to purchase, shown as rectangle P_1acP_0 in Figure 4-3 (its area is the increase in price multiplied by the number that continue to be sold), minus the value they attach to the savings in fuel costs that result from higher fuel economy. This latter value is the smaller rectangle P_1abP_2, since its area equals the value of improved fuel economy (the distance ab, or the upward shift in the demand curve) multiplied by the number of new vehicles that continue to be sold (Q_1). Together, these partly offsetting impacts leave net losses to buyers equal to rectangle P_2bcP_0.[64] 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 buyers is equal to the product of this effective price increase and the number of vehicles that continues to be sold.

Second, some buyers who would have purchased new cars and light trucks under the baseline fuel economy standard will decide not to do so once stricter CAFE standards take effect, and these buyers experience smaller losses in welfare. Their valuation of higher fuel economy is lower than those who continue to purchase new vehicles, and as a consequence the combination of improved fuel economy and higher prices deters their purchases and reduces the number sold

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

from Q_1 to Q_0. The welfare loss to buyers who forego purchases they would otherwise make because of new vehicles' higher "effective price" is represented by triangle bcd.

4.3.2 How Car and Light Truck Buyers Value Increased Fuel Economy

Technologies that can be used to improve fuel economy can also be used to increase other vehicle attributes, especially acceleration performance, weight, and energy-using accessories. While this is most obvious for technologies that improve the efficiency of engines and transmissions, it is also true of technologies that reduce mass, aerodynamic drag, rolling resistance or any road or accessory load. The exact nature of the potential to trade-off attributes for fuel economy varies with the technology, but at a minimum, increasing vehicle efficiency or reducing loads allows a more powerful engine to be used while achieving the same level of fuel economy. How consumers value increased fuel economy and how fuel economy regulations affect manufacturers' decisions about how to use efficiency improving technologies can have important effects on the estimated costs, benefits, and indirect impacts of fuel economy standards.

NHTSA's preliminary regulatory impact analysis assumes that in the absence of fuel economy standards consumers will purchase, and manufacturers will supply, improvements in fuel economy that "pay for themselves" in fuel savings over the first 30 months of use. This assumption is based on statements manufacturers have made to NHTSA and to NASEM CAFE committees, and has been relied upon in NHTSA's prior analyses of fuel economy standards. However, this assumption may be problematic when the baseline standards are binding – meaning that they constrain consumers to purchase vehicles that are more fuel efficient than they would have chosen in the absence of fuel economy standards. To demonstrate this, we introduce a standard economic model of consumer optimization subject to a budgetary constraint.[65]

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[65] Note that the following section examines whether consumers are rational in their fuel economy consumption patterns. This analysis could represent a scenario where consumers are rational, or one in which the underweight future fuel savings in their car purchasing decisions.

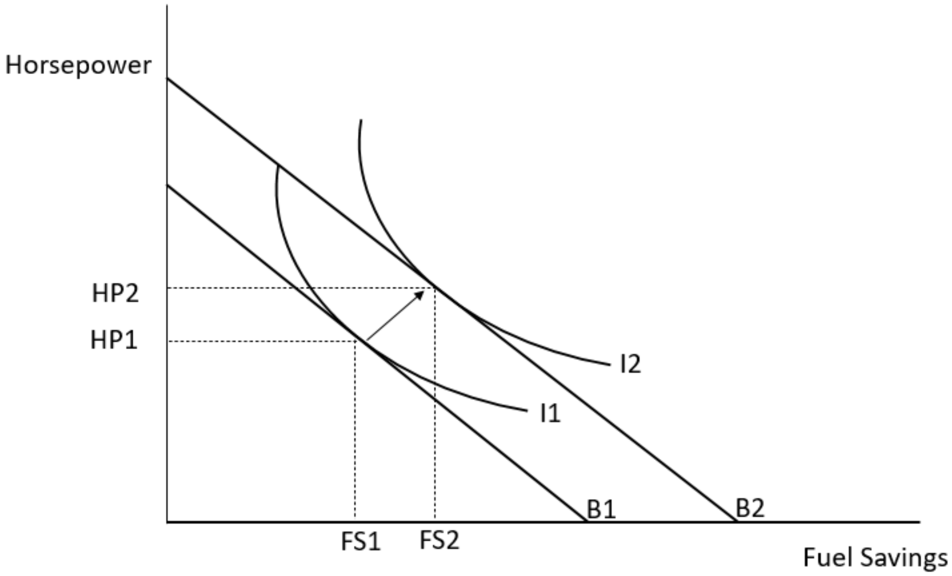

Figure 4-4 – Constrained Optimization Model of Consumer Preferences Between Horsepower and Fuel Economy in the Absence of Fuel Economy Standards

Figure 4-4 models consumer behavior when constrained by a budget. Line B1 represents the consumer's original budget constraint. Curve I1 is called an indifference curve, which shows each combination of horsepower, which we use here to represent a variety of attributes that could be traded-off for increased fuel economy, and fuel savings between which a consumer is indifferent. The curvature of the indifference curve reflects the principle of diminishing marginal utility – the idea that consumers value consumption of the first unit of any product greater than subsequent units. Curve I1 represents the highest utility achievable when subject to budget constraint B1, as the consumer may select the combination of performance and fuel economy represented by point (HP1, FS1) – which is the point of tangency between I1 and B1. When new technology becomes available that makes either fuel economy or performance (or both) more affordable, the consumer's budget constraint shifts from B1 to B2, and the consumer can now achieve the point of tangency between I2 and B2 (HP2, FS2). In this case, both fuel economy and performance are modeled as normal goods – meaning that as they become more affordable, consumers will elect to consume more of each.

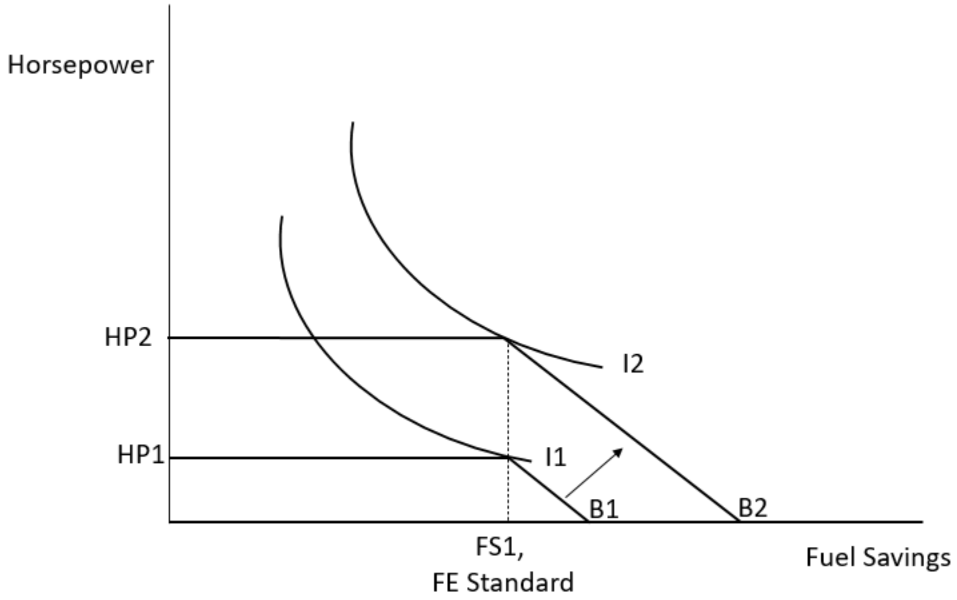

Figure 4-5 – Constrained Optimization Model of Consumer Preferences Between Horsepower and Fuel Economy in the Presence of Binding Fuel Economy Standards.

A different analysis is required when fuel economy standards also bind on consumer decisions. Here, minimum fuel economy standards eliminate some combinations of performance and fuel economy, creating a corner solution in the budget constraint. Figure 4-5 shows this effect, as the consumer will elect the point of tangency with budget constraint B1 at the corner solution at (HP1 and FS1), which is also the minimum fuel economy standard. When new technology is introduced (or becomes cheaper) which makes fuel economy and performance more affordable, the consumer's budget constraint shifts from B1 to B2 again, but the existing fuel economy standard is still binding, so a corner solution remains at FS1. The consumer will choose the corner combination of fuel economy and performance again, where I2 is tangent with B2, at point (FS1, HP2). Note that the consumer has elected to improve performance from HP1 to HP2, but has not elected to improve fuel economy.

This model implies that fuel economy standards prevent consumers from achieving their optimal bundle of fuel economy and performance given their current preferences, creating an opportunity cost to consumers in the form of lost performance. The constrained optimization model can be slightly tweaked to show this loss to consumers. In this example, the y-axis uses the composite good M reflecting all other goods and services, including performance. This makes the interpretation of the y axis simpler, as it can be more easily translated into dollars.

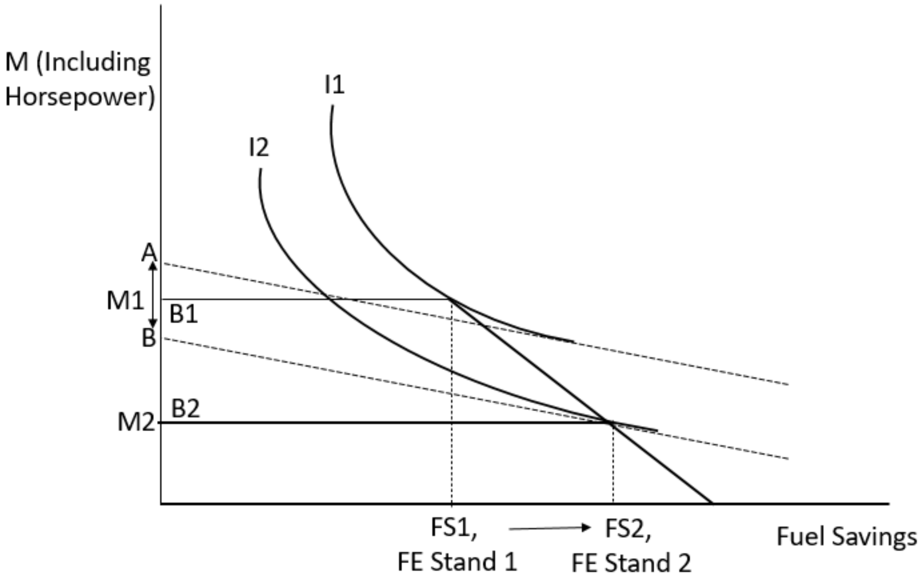

Figure 4-6 – Constrained Optimization Model of Consumer Preferences Between Horsepower and Fuel Economy Showing Opportunity Cost of Fuel Economy Standards

Figure 4-6 shows the effect of new binding fuel economy standards on consumer behavior. The consumer begins at point (M1, FS1) on indifference curve I1. If more stringent fuel economy standards were in place, the consumer would shift to the lower indifference curve I2 – reflecting a lower level of utility – and would consume at point (M2, FS2). One concept from the economics literature for valuing the change in welfare from a change in prices or quality (or in this case fuel economy standards) is to look at the compensating variation between the original and final equilibrium. The compensating variation is the amount of money that a consumer would need to return to their original indifference curve.[66] It is found by finding the point of tangency with the new indifference curve at the new marginal rate of substitution between the two products and finding the equivalent point on the old indifference curve. Figure 4-6 shows this as the distance between points A and B on the Y-axis.[67]

The above logic appears to explain the trends in fuel economy and vehicle performance (measured by horsepower/pound) between 1986 and 2004, when gasoline prices fluctuated between $2.00 and $2.50 per gallon and new light duty vehicle fuel economy standards remained nearly constant (Figure 4-7). Over the same period numerous advanced technologies with the potential to increase fuel economy were adopted. However, the fuel economy of new light duty vehicles did not increase. In fact, increases in the market share of light trucks caused fuel economy to decline somewhat.

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[66] There is a very similar concept for valuing this opportunity cost known as the equivalent variation. NHTSA presents the compensating variation here for simplicity but acknowledges that the equivalent variation is an equally valid approach.

[67] Boardman, Greenberg, Vining, Weimer (2011). *Cost-Benefit Analysis; Concepts and Practice.* p. 69-73.

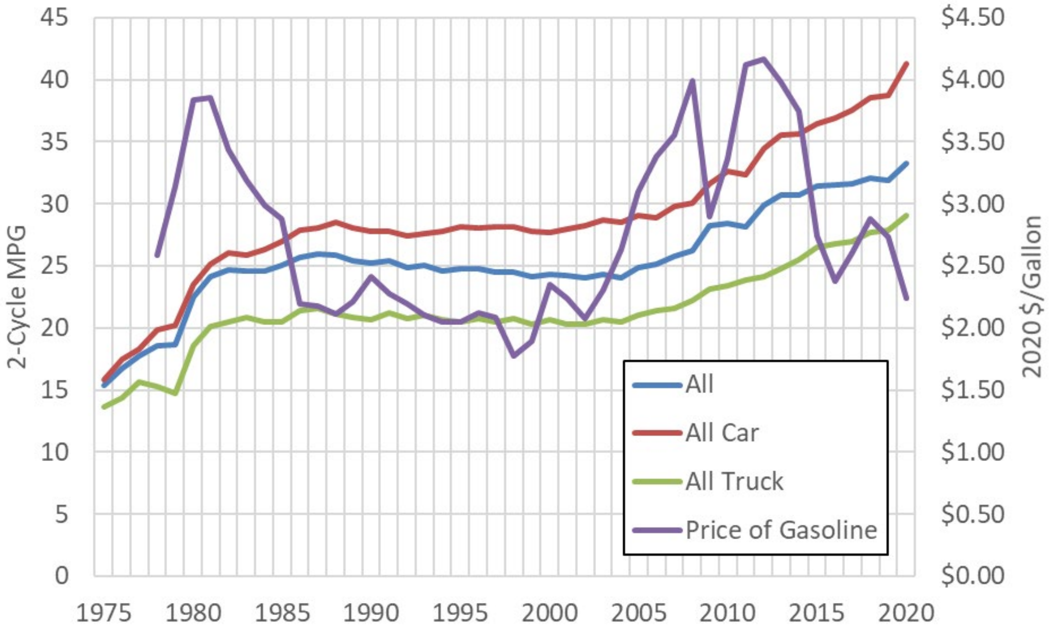
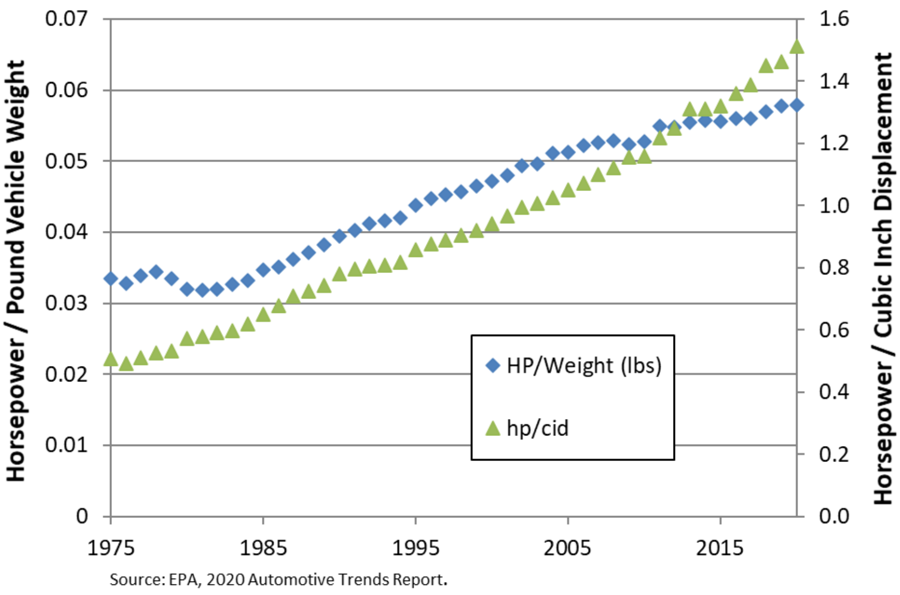


Figure 4-7 – Test Cycle Combined Fuel Economy and Gasoline Price: 1975-2020

On the other hand, from 1986-2004 the acceleration performance of light-duty vehicles increased by 45% (Figure 4-8). Advances in engine technology are reflected in the steadily increasing ratio of power output to engine size, measured by displacement. Without increased fuel economy standards, all the potential of advanced technology appears to have gone into increasing performance and other attributes (for example average weight also increased by 27% from 1986-2004) and none to increasing fuel economy. Fuel economy remained nearly constant at the levels required by the car and light truck standards, consistent with the idea the standards were a binding constraint on the fuel economy of new vehicles. The pattern for periods of price shocks and increasing standards is different, however, as can be seen in Figure 4-7. In the early period up to 1986, there is almost no change in performance and vehicle weight decreased. However, in the more recent period post-2004, performance continued to increase although apparently at a slower rate than during the 1986-2004 period and vehicle weight changed very little. The large and rapid price increases appear to have been an important factor. Even before manufacturers can respond to prices and regulations by adding fuel economy technologies to new vehicles, demand can respond by shifting towards smaller, lighter, and less powerful makes and models. The period of voluntary increase in fuel economy is consistent with the constrained optimization problem presented above if fuel economy standards no longer constrained consumer behavior after the change in fuel prices, though more research is needed to establish whether this consumer choice model explains some of behavior observed over this time period.



Source: EPA, 2020 Automotive Trends Report.

Figure 4-8 – Trends in Performance and Engine Technology: 1975-2020

If this constrained optimization model is a reliable predictor of consumer behavior for some substantive portion of the new vehicle market, it would have important implications for how NHTSA models baseline consumer choices. In this case, it would mean that as technology that could improve fuel economy is added absent standards, it would be primarily geared towards enhancing performance rather than fuel economy. Depending on how consumers value future fuel savings, it might be appropriate for NHTSA to change its methods of analysis to reflect consumer preferences for performance, and to develop methods for valuing the opportunity cost to consumers for constraining them to more fuel efficient options.

4.3.2.1 Potential Implications of Behavioral Theories for Fuel Economy Standards

In this proposed rule, the cost-effectiveness of technology-based fuel economy improvements is used to estimate fuel economy improvements by manufacturers in the baseline case and to estimate components of the benefits and costs of alternative increases in fuel economy standards.

How manufacturers choose to implement technologies that can increase fuel economy depends on consumers' willingness to pay (WTP) for fuel economy and the other attributes the technologies can improve. Consumers' WTP for increasing levels of an attribute defines the consumers' demand function for that attribute. Here, we consider how consumers' WTP for increased fuel economy (WTP_{FE}) and for performance (WTP_{HP}), where FE stands for fuel economy and HP stands for "Horse Power"/performance, and the cost of technology (C) affect manufacturers' decisions about how to implement the technologies with and without fuel economy standards. For the purpose of this discussion, it is convenient to think of fuel economy in terms of its inverse, the rate of fuel consumption per mile. While miles per gallon (mpg) delivers decreasing fuel savings per mpg, decreasing fuel consumption delivers constant fuel savings per gallon per mile (gpm) reduced. Thinking in terms of gpm is appropriate because fuel economy standards are in fact defined in terms of the inverse of fuel economy, i.e., gpm.

In the CAFE Model we typically assume that for a technology that can improve fuel economy, consumers are willing to pay an amount equal to the first thirty months of fuel savings (WTP_{30FE}). This is an important assumption for several reasons. The market will tend to equilibrate the ratio of consumers' WTP for fuel economy divided by its cost to the ratio of consumers' WTP for other attributes divided by their cost. The value of the first thirty months of fuel savings is typically about one-fourth of the value of savings over the expected life of a vehicle, discounted at annual rates between 3% and 7%. Arguably, this represents an important undervaluing of technology-based fuel economy improvement relative to its true economic value. Our use of the 30-month payback assumption is based on statements manufacturers have made to us and to NASEM CAFE committees. It is also based on the fact that repeated assessments of the potential for technology to improve fuel economy have consistently found a substantial potential to cost-effectively increase fuel economy. But it is also partly based on the fact that the substantial literature that has endeavored to infer consumers' WTP for fuel economy is approximately evenly divided between studies that support severe undervaluation and those that support valuation at approximately full lifetime discounted present value (e.g., Greene et al., 2018; Helfand and Wolverton, 2011; Greene, 2010; for a more complete discussion see TSD Chapter 6.1.6). The most recent studies based on detailed data and advanced methods of statistical inference have not resolved the issue.[68]

If consumers value technology-based fuel economy improvements at only a small fraction of their lifetime present value and the market equates WTP_{30FE}/C to WTP_{HP}/C, the market will tend to oversupply performance relative to fuel economy (Allcott et al., 2014; Heutel, 2015). The WTP_{30FE} assumption also has important consequences when fuel economy standards are in effect. Alternative 0 in this proposed rule assumes not only that the SAFE standards are in effect but that the manufacturers who agreed to the California Framework will be bound by that agreement. If those existing regulations are binding, it is likely that $WTP_{HP} > WTP_{30FE}$. (For simplicity we assume that over the range of fuel economy and performance achievable by the technology, both WTP values are constant.[69]) This outcome would be expected in a market where consumers undervalue fuel savings in their normal car buying decisions and standards require levels of fuel economy beyond what they are willing to pay.[70] This is illustrated in Figure 4-9. The initial consumer demand function for vehicles (D_0) is shifted upward by WTP_{30FE} to represent the consumer demand function for the increased fuel economy the technology could produce (D_{30FE}) and by WTP_{HP} to represent the demand function (D_{HP}) for the potential increase in performance. Because the technology has a cost (C), the manufacturers' supply function (S_0) shifts upward to $S_1 = S_0 + C$.[71] If the cost of the technology exceeds

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[68] NASEM, 2021, Ch. 11.3.

[69] Although there are diminishing returns to increased miles per gallon, in terms of fuel savings in gallons or dollars, there are not diminishing returns to reductions in fuel consumption per mile, except due to decreasing marginal utility of income. WTP_{HP} likely decreases with increasing performance, but if the changes are not too large, the assumption of constant WTP is reasonable.

[70] If there are no binding regulatory constraints and fuel economy and other vehicle attributes are normal goods, consumers will elect more of each in the event technological progress makes it possible to afford them. This simplifying assumption is consistent with a scenario where consumers' baseline vehicle choices are constrained by regulatory standards. *See* Chapter 4.3.2 for more discussion.

[71] The supply function for new cars is assumed to be perfectly elastic for the sake of simplicity of exposition. Note that if the cost of the technology exceeds consumers' WTP for both fuel economy and performance, the technology will not be adopted in the absence of regulations requiring it.

consumers' WTP for either the fuel economy or the performance it can deliver, the technology will not be adopted in the absence of regulations requiring it. In Figure 4-9 we show the case where $C < WTP_{30FE} < WTP_{HP}$. In this case, using the technology to increase performance provides the greatest increase in sales and revenues: $Q_{HP} > Q_{30FE} > Q_0$. Since both WTP values are assumed to be approximately constant over the range of improvement the technology can provide, there is no possible combination of fuel economy and performance improvement that would produce a larger increase in sales than using the technology entirely to increase performance.[72] Importantly, as long as $C < WTP_{HP}$, the actual cost of the technology does not affect the manufacturer's decision to use 100% of its potential to increase performance and 0% to increase fuel economy. The technology's payback period for the increase in fuel economy is irrelevant. If we reverse the relative WTP values (i.e., $WTP_{30FE} > WTP_{HP}$), then the manufacturer will choose to use 100% of the technology's potential to increase fuel economy and 0% to increase performance, assuming constant WTP values.[73] This conclusion may contradict our current method, which assumes that even with increasing fuel economy standards in Alternative 0, manufacturers will adopt fuel economy technologies with $WTP_{30FE} < C$ and use them to increase fuel economy rather than performance.

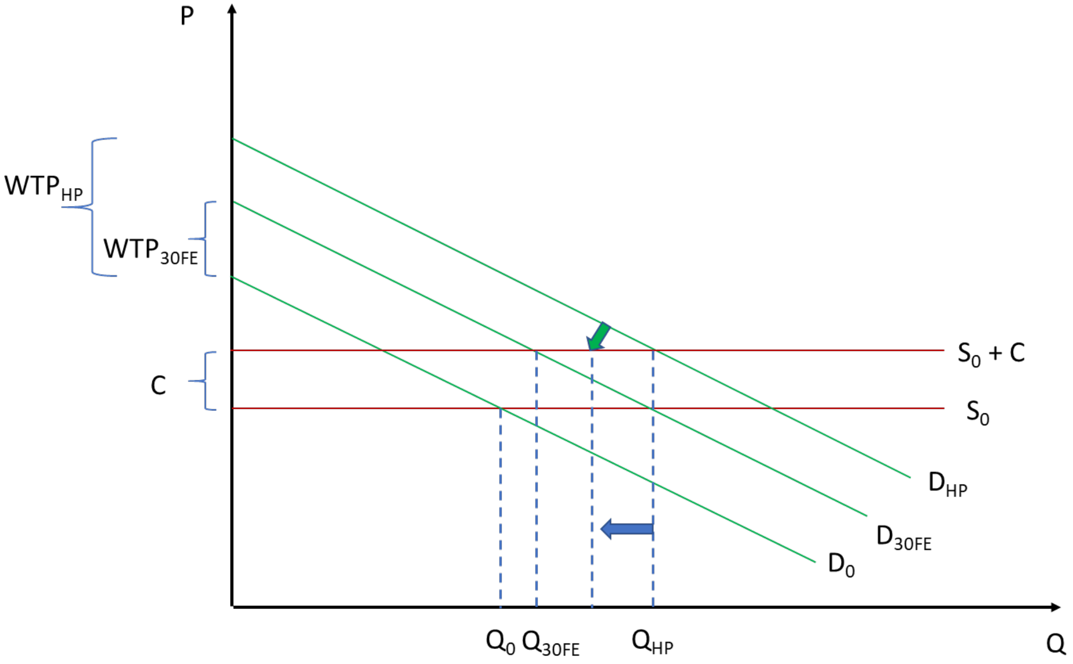

Figure 4-9 – Manufacturers Decision to Adopt a Technology When $WTP_{HP} > WTP_{30FE} > C$

Because the expected present value of fuel savings is several times the 30-month value, it is quite possible that the WTP for performance lies between the lifetime present value of fuel savings and the 30-month value: $WTP_{PVFE} > WTP_{HP} > WTP_{30FE}$. This possibility is illustrated in Figure

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[72] In fact, all that is required is that over the range of increases achievable by the technology, $WTP_{HP} > WTP_{FE}$.

[73] However, as noted above, the market will tend to equate WTP_{HP}/C to WTP_{FE}/C, so if there is sufficient variation in WTP_{HP} over the range of values achievable by the technology, some of each will be provided.

4-10, in which there are three demand functions in addition to the initial demand function, D_0. In Figure 4-10, if the consumer were willing to pay for the full present value of fuel savings, the technology would be applied 100% to increasing fuel economy, provided $C < WTP_{PVFE}$. But if standards were binding and the consumer were willing to pay for only 30 months of fuel savings, the technology would be applied 100% to increasing performance, provided $C < WTP_{HP}$. Suppose that the cost of the technology is not C, but a much smaller value, say $c < C$ and $c < WTP_{30FE}$. Assuming consumers value increased fuel economy at WTP_{30FE}, it remains the case that all the technology's potential will be applied to increasing performance because that gives the greatest increase in sales. The implication is that when there is a binding fuel economy standard, as long as $WTP_{HP} > WTP_{30FE}$, no technologies would be used to increase fuel economy in the absence of a regulatory requirement to do so. If consumers' WTP for fuel economy is WTP_{30FE} and regulatory standards are binding, $WTP_{HP} > WTP_{FE}$ seems likely.

If $WTP_{30FE} < WTP_{HP}$ (recalling that HP can represent attributes in addition to fuel economy), the above analysis of producer behavior contradicts the current operation of the CAFE Model, which assumes that manufacturers will apply technologies whose costs are less than WTP_{30FE} to improving fuel economy in the absence of regulations requiring them to do so. For the Final Rule, NHTSA is considering changing the assumption that in the absence of standards that require it, manufactures will adopt technologies to improve fuel economy that have a payback period of 30 months or less, in favor of the above analysis. We are interested in receiving comments that specifically address the validity of the current and proposed approach.

As discussed in the TSD Chapter 4.2.1.1, there is no consensus in the literature about how consumers value fuel economy improvements when making vehicle purchases. In this and past analyses, we have assumed that consumers value only the first 30 months of fuel savings when making vehicle purchase decisions. This value is a small fraction, approximately one fourth of the expected present value of future fuel savings over the typical life of a light-duty vehicle, assuming discount rates in the range of 3% to 7% per year. On the other hand, when estimating the societal value of fuel economy improvements, we use the full present value of discounted fuel savings over the expected life of the vehicle because it represents a real resource savings. However, the possibility that consumers' perceptions of utility at the time of purchase (decision utility) may differ from the utility consumers experience while consuming a good and that experienced utility may be the preferable metric for policy evaluation has been raised in the economic literature (Kahneman and Sugden, 2005). In our methods, we use WTP_{30FE} to represent consumers' decision utility. Gallons saved over the life of a vehicle, valued at the current price of gasoline, and discounted to present value appears to be an appropriate measure of experienced utility. The large difference between our measure of decision utility and lifetime present value fuel savings as a measure of experienced utility has potentially important implications for how we estimate the impacts of fuel economy standards on new vehicle sales and the used vehicle market. It seems plausible that as consumers experience the fuel savings benefits of increased fuel economy, their valuation of the fuel economy increases required by regulation may adjust over time towards the full lifetime discounted present value. In addition, behavioral economic theory accepts that consumers' willingness to pay for fuel economy may change depending on the context of consumers' car purchase decisions. The implications of such possibilities are analyzed below. We are interested in how they might affect our current methods for estimate the impacts of standards on new vehicle sales and the used vehicle market, and whether any changes to our current methods are appropriate.

The existence of fuel economy standards changes manufacturers' decision making. First, if a standard is set at a level that requires only part of the technological potential to increase fuel economy, if $C < WTP_{HP}$, and $WTP_{HP} > WTP_{30FE}$, the remainder of the technology's potential will be used to provide some increase in performance. This appears to have occurred post 2004 when the rate of improvement in performance slowed while fuel economy improved. Assuming that consumers value fuel economy improvement at time of purchase at WTP_{30FE}, there would be a consumers' surplus cost of foregone performance equal to the cross-hatched trapezoid in Figure 4-10. The foregone performance cost will be less than what it would have been if none of the technology's potential to increase fuel economy were used to increase performance. Even if the cost of the technology is less than WTP_{30FE}, the technology will be applied to improve fuel economy only up to the required level and the remainder of its potential will be used to increase performance. If the cost of applying enough of the technology to achieve the fuel economy standard is greater than WTP_{HP}, there would be no cost of foregone performance since the cost of applying the technology to increasing fuel economy exceeds its opportunity cost when applied to increase performance.[74] In that case, the technology cost represents the full cost of the fuel economy improvement, since that cost exceeds consumers' WTP for the performance it could produce. On the other hand, if under regulatory standards consumers valued fuel economy at WTP_{PVFE} , there would also be no opportunity cost of performance because $WTP_{PVFE} > WTP_{HP}$.

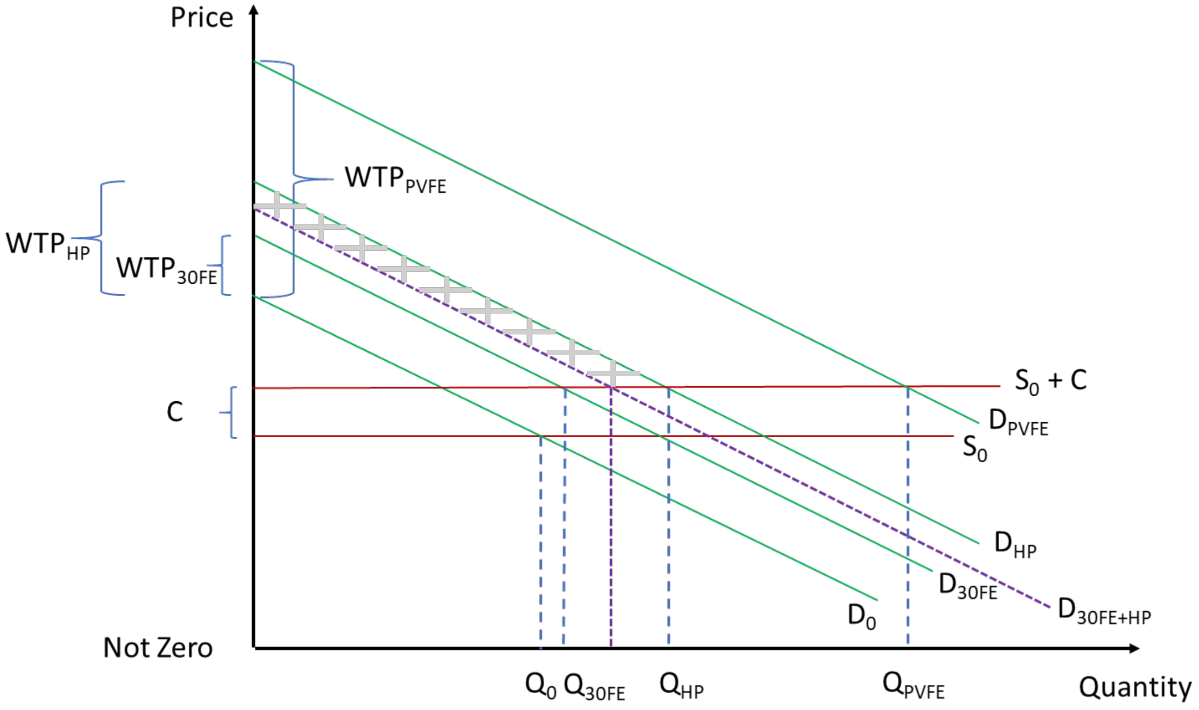

Figure 4-10 – Manufacturers' Decision to Adopt Technology with Fuel Economy Standards

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[74] This is because using the technology to increase performance would not be the second best use of the cost of increasing fuel economy. The second best use would instead be to invest the cost at a market rate of return.

Because the CAFE Model estimates the effects of standards on new vehicle sales and scrappage based on the difference between the cost of technology and the perceived value of fuel savings at the time a new vehicle is purchased, whether consumers perceive the value differently in regulated and unregulated markets is an important question. Traditional utility theory of consumer decision making does not allow that consumers' preference rankings depend on the context of the choices they make. However, in addition to the theory of utility maximizing rational economic behavior, modern economics includes the insights and findings of behavioral economics, which has established many examples of human decision making that differ in important ways from the rational economic model. In particular, the behavioral model allows the possibility that consumers' preferences and decision-making processes often do change depending on the context or framing of choices. The possibility that behavioral theories of decision making may be useful for understanding how consumers value fuel economy and for evaluating the costs and benefits of fuel economy standards was noted in the most recent NASEM (2021) report. An explanation of the different contexts helps to illustrate this point. If a consumer is thinking about buying a new car and is looking at two models, one that includes fuel economy technology and is more expensive and another that does not, she may buy the cheaper, less fuel efficient version even if the more expensive model will save money in the long run. But if, instead, the consumer is faced with whether to buy a new car at all as opposed to keeping an older one, if all new cars contain technology to meet fuel economy standards then she may view the decision differently. Will, for example, an extra $1,000 for a new car -- a $1,000 that the consumer will more than recoup in fuel savings -- deter her from buying the new car, especially when most consumers finance cars over a number of years rather than paying the $1,000 cost up front and will therefore partly or entirely offset any increase in monthly payment with lower fuel costs? In addition, the fact that standards generally increase gradually over a period of years allows time for consumers and other information sources to verify that fuel savings are real and of substantial value.

In addition to loss aversion, there are other contributions from the behavioral economics literature that are important to consider when evaluating the energy paradox. These additional contributions are discussed at length in the 2012 rulemaking and in EPA's draft Technical Assessment Report,[75] and are summarized below:

- Consumers might be ‘‘myopic’’ and hence undervalue future fuel savings in their purchasing decisions.

- Consumers might lack the information necessary to estimate the value of future fuel savings, or not have a full understanding of this information even when it is presented.

- Consumer may be accounting for uncertainty in future fuel savings when comparing upfront cost to future returns.

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[75] For more information, see 77 FR 62913-62917. Also see Section 6.3 of EPA, NHTSA, AND CARB, DRAFT TECHNICAL REPORT: MIDTERM EVALUATION OF LIGHT-DUTY VEHICLES GREENHOUSE GAS EMISSION STANDARDS AND CORPORATE AVERAGE FUEL ECONOMY FOR MODEL YEARS 2022-2025 (2016).

- Consumers may consider fuel economy after other vehicle attributes and, as such, not optimize the level of this attribute (instead ‘‘satisficing’’—that is, selecting a vehicle that is acceptable rather than optimal—or selecting vehicles that have some sufficient amount of fuel economy).

- Consumers might associate higher fuel economy with inexpensive, less well-designed vehicles.

- When buying vehicles, consumers may focus on visible attributes that convey status, such as size, and pay less attention to attributes such as fuel economy that do not visibly convey status.

- Even if consumers have relevant knowledge, selecting a vehicle is a highly complex undertaking, involving many vehicle characteristics. In the face of such a complicated choice, consumers may use simplified decision rules.

- In the case of vehicle fuel efficiency, and perhaps as a result of one or more of the foregoing factors, consumers may have relatively few choices to purchase vehicles with greater fuel economy once other characteristics, such as vehicle class, are chosen.

NHTSA welcomes comment on the insights that the behavioral economics literature can bring to NHTSA’s modeling of light-duty vehicle consumer choice.

The CAFE Model’s representation of consumers’ vehicle choices under regulation reflects the “Gruenspecht Effect,” the theory that regulation will inevitably cause new vehicles to be less desirable than they would have been in the absence of regulation, which will inevitably lead to reduced new vehicle sales, higher prices for used vehicles and slower turnover of the vehicle stock. However, if consumers severely undervalue fuel savings at the time of vehicle purchase, not only is that itself a market failure (a large discrepancy between decision and experienced utility) but it raises important questions about what causes such undervaluation and whether consumers’ perceptions may change as the benefits of increased fuel economy are realized or whether the different framing of new vehicle choices in a regulated market might partially or entirely mitigate that undervaluation. The 2021 NASEM report asserts that if the behavioral model is correct, consumers might value fuel savings at or near their full lifetime discounted present value, potentially reversing the Gruenspecht Effect.

“On the other hand, the Gruenspecht effect is not predicted by the behavioral model, under which it is not only possible but likely that if the fuel savings from increased fuel economy exceed its cost, consumers will find the more fuel-efficient vehicles required by regulation to be preferable to those that would otherwise have been produced.” “It is possible that sales would increase rather than decrease and likewise manufacturers’ profits. In that case, increased new vehicle sales would reduce used vehicle prices, benefiting buyers of used vehicles and accelerating the turnover of the vehicle stock.”[76]

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[76] NASEM, 2021, p. 11-357.

4.3.3 How NHTSA Estimates Changes in Sales

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

4.4 The Effect of Higher CAFE Standards on Vehicle Use

The fuel economy rebound effect – a specific example of the well-documented energy efficiency rebound effect for energy-consuming capital goods – refers to the tendency of motor vehicles' use to increase when their fuel economy is improved and the cost of driving each mile declines as a result. Increasing CAFE standards will lead to higher fuel economy for new cars and light trucks, thus reducing the amount of fuel they consume per mile. The resulting decline in the cost to drive each mile will lead to an increase in the number of miles they are driven each year over their lifetimes. For its analysis of this proposed rule, NHTSA uses a value of 15 percent for the fuel economy rebound effect, which implies that for a 10 percent increase in fuel economy will produce a 1.5 percent increase in average annual driving.[77]

4.4.1 The Fuel Economy Rebound Effect and Vehicle Use

Figure 4-11 illustrates the effect of new vehicles' higher fuel economy on the number of miles they are driven annually. As it shows, vehicles' per-mile operating costs include the cost of fuel they consume, the expected cost associated with potential crashes, maintenance and repair outlays, operating costs other than fuel (oil, tire wear, etc.), and the value of their occupants' travel time.[78] Requiring new cars and light trucks to achieve higher fuel economy will reduce the amount of fuel they consume each mile they are driven, thus reducing their per-mile driving cost; this is shown in the figure as a reduction in the total cost of driving each mile from C_0 to C_1. If the use of new cars and light trucks remained unchanged, their owners' total savings in fuel costs would be the rectangle C_0abC_1, whose area is the product of the reduction in per-mile fuel costs and the number of miles driven.[79] However, the decline in driving costs leads to a

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[77] For a detailed review of empirical evidence on the magnitude of the rebound effect and a discussion of NHTSA's choice of the 15 percent value, see Chapter 4.3.3 of the Technical Support Document accompanying this proposal.

[78] Drivers presumably consider only the fraction of costs they and their passengers expect to bear in the event they are involved in a crash when they decide to make additional trips or drive longer distances; these are shown as the private cost of crash risk in Figure 4-11. The remaining fraction of these costs is borne by occupants of other vehicles (as well as pedestrians and others using the road) and is thus an "external" cost of their decisions. It is included with other external costs drivers impose in Figure 4-12.

[79] Of course, this savings would decline over time as these once-new vehicles are driven progressively less and begin to be retired, but the savings in fuel costs for each successive model year required to meet the higher standards would be equal to this same area during the year it was initially sold.

downward movement along the demand curve for vehicle use, increasing the average number of miles that new cars and light trucks are driven annually from M_0 to M_1.

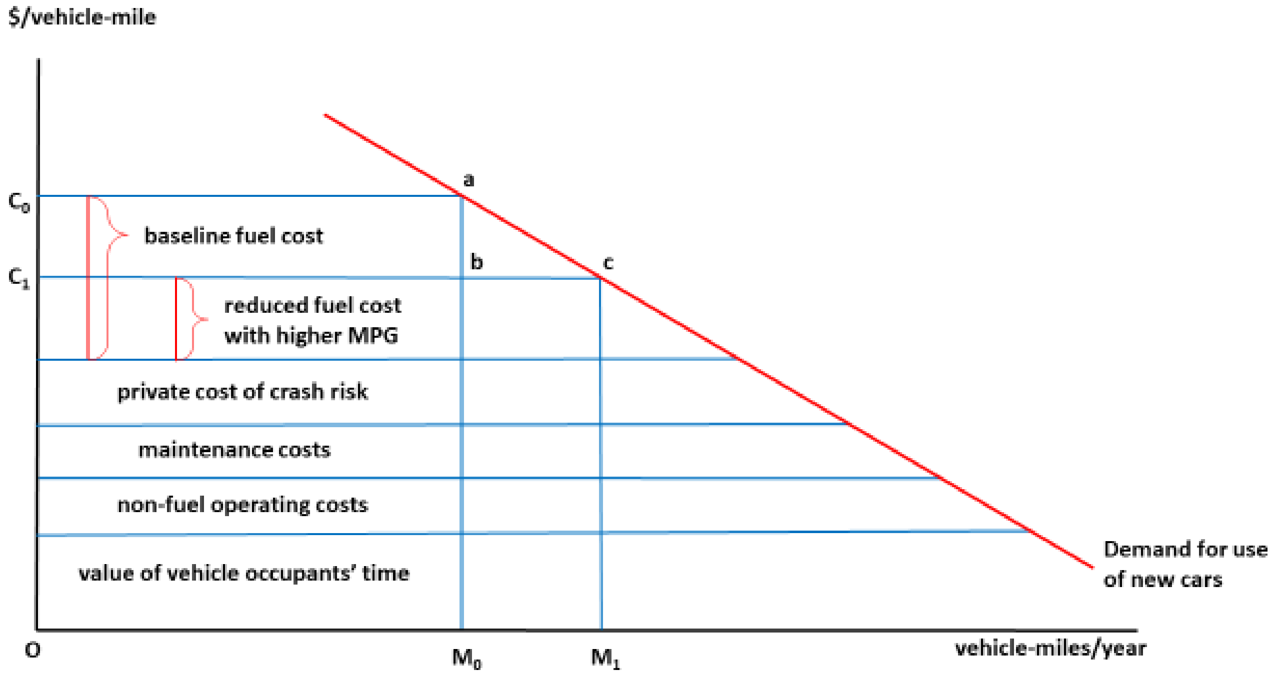

Figure 4-11 – Effect of Relaxing CAFE/GHG Standards on New Car and Light Truck Use

Two direct economic benefits (as well as a variety of indirect economic benefits and costs, which are discussed in subsequent sections) will result from the increase in new vehicles' fuel economy. First, car and light truck buyers' annual outlays for fuel will decline throughout the lifetimes of the models they purchase, as raising CAFE standards leads to higher fuel economy levels and reduces fuel consumption. The magnitude of this benefit depends on how much new vehicles' average fuel economy increases when future standards are raised, how much they are driven each year, and future retail prices for fuel. During the year they are initially sold, it is measured by the difference between drivers' annual driving costs with higher standards in effect, area C_1cM_1O in Figure 4-11, and their driving costs with the lower baseline CAFE standards in effect, or C_0aM_0O. This difference is equal to the savings in fuel costs on driving that would have taken place under the baseline with vehicles with improved fuel economy (area C_0abC_1) minus the cost of fuel consumed by additional driving (area M_0bcM_1).

The agency estimates this savings using improvements in the fuel economy of individual cars and light truck models estimated to result from raising CAFE 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 U.S. Energy Information Administration's *Annual Energy Outlook 2021*. As indicated above, this savings declines over vehicles' lifetimes as they are driven less and gradually retired from use, although its normal decline can be partly or completely offset by rising fuel prices. The savings in fuel costs for each model year required to meet higher CAFE standards will equal to this same area during the year it is initially sold, and decline similarly over its lifetime in the fleet.

Second, the additional mobility associated with increased driving provides benefits to new car and light truck buyers. These benefits must be more than sufficient to offset the costs of their additional driving, including fuel expenses, other operating costs, maintenance, the value of travel time, and the increased safety risks they assume.[80] If they were not, no additional driving would occur. In Figure 4-11, mobility benefits from increased driving are equal to the area M_0acM_1, which exceeds the cost of the additional driving, area M_0bcM_1. The amount by which they do measures the net benefit (or gain in "consumer surplus") to buyers of new cars and light trucks from additional driving; it is shown as the area abc in Figure 4-11. Following the usual procedure, we estimate the dollar value of this welfare gain assuming the demand curve for vehicle use is linear over the relevant range, so its annual value can be calculated as one-half of the product of the decline in driving costs ($C_0 – C_1$) and the increase in vehicle use ($M_1 – M_0$).

4.4.2 Externalities from Increased Rebound-Effect Driving

Vehicle use generates external costs via increased traffic congestion and roadway noise, higher accident risks, adverse health effects from air pollution, and climate-related damages caused by emissions of GHGs. Although these external costs are small for *individual* cars and light trucks, the increase in *total* driving that occurs in response to improved fuel economy can increase these costs significantly. The increase in their total value represents an additional cost of requiring new cars and light trucks to meet higher fuel economy targets. Figure 4-12 illustrates how NHTSA estimates these costs; like the preceding figure, it shows the demand for travel in new cars and light trucks, and illustrates the effect of the reduction in their per-mile driving costs and increase in their use that occur when their fuel economy improves. For simplicity, however, Figure 4-12 omits the detailed breakdown of total driving costs shown previously, and instead shows the combined external costs imposed by new vehicles' contributions to traffic congestion, road noise, injuries and property damage from crashes, air pollution, and climate-related damages.[81] NHTSA assumes that the per-mile value of these costs is unaffected by the change in vehicle use estimated to occur in response to improved fuel economy.

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[80] Even if new vehicles' per-mile depreciation costs, which rise in proportion to their purchase prices, offset part of the decline in their fuel costs, the improvement in their fuel economy will reduce their per-mile driving cost and prompt an increase in their annual use. Empirical estimates of the fuel economy rebound effect isolate the effects of changes in fuel economy and fuel costs by themselves on vehicle use, so they cannot instead be applied to the overall change in vehicles' per-mile driving cost including depreciation to estimate the resulting change in driving. Thus, incorporating depreciation costs would not change the agency's estimate of the increase in vehicle use stemming from higher fuel economy.

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

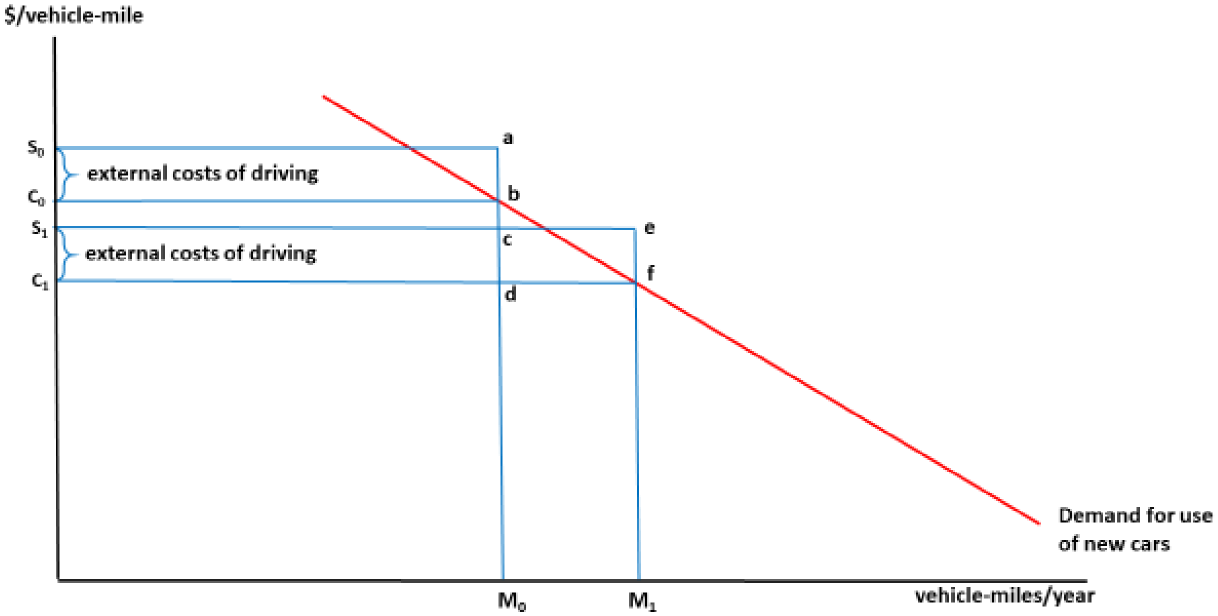

Figure 4-12 – Externalities Resulting from Changes in New Car and Light Truck Use

At the level of new car and light truck use that would occur with the baseline standards in effect, these external costs are equal to the product of their per-mile value (shown as the distance $S_0 - C_0$ in Figure 4-12) and the initial level of vehicle use M_0, or the rectangular area S_0abC_0. At the increased level of driving that results when fuel economy increases (M_1 in Figure 4-12), the total cost of these externalities is again the product of their per-mile value ($S_1 - C_1$) and this higher level of use M_1, or the rectangular area S_1efC_1. If the per-mile value of these externalities is unaffected by the increase in new vehicles' use, as the figure assumes, total external costs will increase by the area of the rectangle cefd, which is equal to the increase in the number of miles driven ($M_1 - M_0$), multiplied by the per-mile value of external costs ($S_1 - C_1$).[82] In words, this additional cost is the difference between the total cost of driving-related externalities caused by new cars and light trucks with higher CAFE standards in effect, and the value of those costs if the baseline CAFE standards had remained in effect. It is a direct consequence of additional driving assumed to be caused by the fuel economy rebound effect.

NHTSA'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 CAFE standards, since this net reduction reflects the decline in fuel production and use after accounting for increased driving. Increases in emissions of criteria air pollutants are calculated from additional driving by new cars and light trucks, together with per-mile emission

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

factors for future model year vehicles derived from EPA's MOVES model (which reflect future changes in emission standards). Increases in costs of congestion and road noise are calculated using incremental per-mile contributions of car and light truck use to delays and noise originally estimated by the Federal Highway Administration and updated for this analysis.[83] Finally, NHTSA assumes that drivers consider only 90 percent of the costs of injuries and property damage resulting from crashes, so 10 percent of the increase in these costs also represents an external cost of added rebound-effect driving.

4.4.3 Measuring the Fuel Economy Rebound Effect

In recent rulemakings, NHTSA has used values of the rebound effect ranging from 10 percent to 20 percent to analyze the effects of changes in CAFE standards on new vehicles' use. For the current evaluation, the agency uses a rebound effect of 15 percent to analyze the effects of alternative increases in CAFE standards. Chapter 4.3.3 of the Technical Support Document accompanying this proposal reviews empirical evidence on the magnitude of the rebound effect and explains that agency's choice of the 15 percent value.

4.5 Effects of Higher CAFE Standards on the Used Vehicle Market

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

The effect that regulations on new cars can have on how long used cars are kept in service and how much they are driven is not speculative – it has previously been well-documented and is the subject of extensive empirical research. It is often referred to as the "Gruenspecht effect," after the author of an early study that examined the effect of price increases for new cars to recover their manufacturers' costs for installing pollution-control equipment on the retirement and use of older cars.[84] Other early analyses include those by Parks (1977), who documented the increase

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

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

in new vehicles' durability and expected lifetimes over successive model years, and Walker (1968), who analyzed the relationship among used car prices, repair and maintenance costs, and the retirement of older cars.[85] More recent research by Greenspan and Cohen (1996), Jacobsen and van Bentham (2015), and Bento, Roth and Zhuo (2016) confirms the significant effect that prices for new cars can have on the number of older models remaining in use, via their effects on the market value of used cars and their owners' efforts to maintain them in working condition.[86] In a 2004 analysis of a proposed regulation on new vehicles' GHG emission rates, the California Air Resources Board (CARB) used a detailed model of households' vehicle ownership decisions to illustrate that higher new vehicle prices reduced the likelihood that households would replace vehicles they retired with newly-purchased models.

4.5.1 Effects of Raising CAFE Standards on Prices and Retirement of Used Cars

Figure 4-13 illustrates the effect of higher CAFE standards on the market for used cars and light trucks. Faced with higher prices for new models that feature improved fuel economy (and perhaps less desirable combinations of other features), some households and businesses will find that relying on a used car or light truck offers an attractive alternative to purchasing a new one. Their decisions will increase demand for used cars and light trucks, shifting the demand curve for used models in the figure from its original position at D_0 outward to D_1. Shifts in demand for used cars and light trucks of different ages in response to changes in the prices and attributes of new models are likely to mirror how closely they substitute for their new counterparts. Nearly-new vehicles offer the closest substitutes for new ones, so their demand is likely to be most responsive to changes in prices and other characteristics of new ones, while the outdated features and accumulated usage of older vehicles make them less satisfactory substitutes. Demand for nearly-new cars and light trucks is likely to increase significantly when prices for new models rise, while increases in the demand for older vehicles are likely to be progressively smaller.

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[85] Parks, R. W. "Determinants of Scrapping Rates for Postwar Vintage Automobiles." *Econometrica*, vol. 45, no. 5, 1977, p. 1099; and Walker, F. V. "Determinants of Auto Scrappage." *The Review of Economics and Statistics*, vol. 50, no. 4, Nov. 1968, pp. 503–06.

[86] Greenspan, A.& Cohen, D. "Motor Vehicle Stocks, Scrappage, and Sales." *Review of Economics and Statistics*, vol. 81, no. 3, 1999, pp. 369–83; Jacobsen, M. and A. van Benthem, "Vehicle Scrappage and Gasoline Policy," *American Economic Review*, Vol. 105, pp. 1312-38 (2015); and Bento, A, et al. "Vehicle Lifetime Trends and Scrappage Behavior in the U.S. Used Car Market." *The Energy Journal*, vol. 39, no. 1, Jan. 2018.

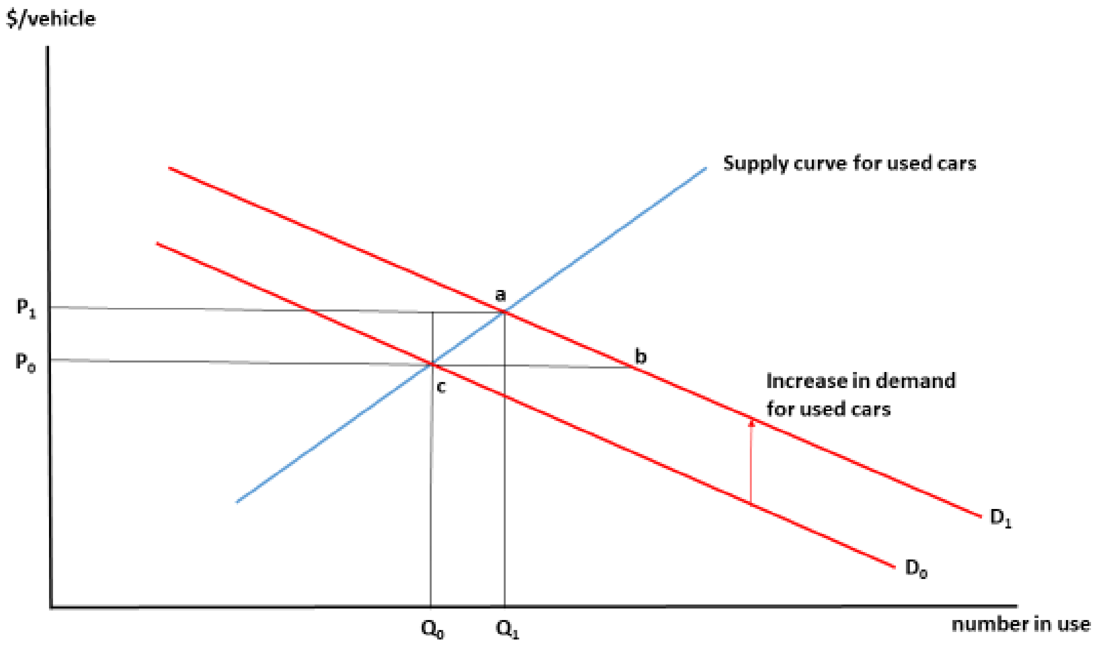

Figure 4-13 – Effect of Increasing CAFE Standards on the Market for Used Cars

The supply of used vehicles is likely to be relatively insensitive to changes in their price (or "inelastic"), but it is not fixed, because owners can increase the number that are available by spending more on the maintenance and repairs necessary to keep older models in service rather than retiring them. This is shown by the upward-sloping supply curve in Figure 4-13, which reflects the fact that the repairs and maintenance necessary to increase the number of used vehicles in usable condition are likely to become progressively costlier. The interaction of higher demand for used car and light truck models and their inelastic supply will cause their average market value and selling price to rise, from P_0 to P_1 in the figure. Some owners who would previously have retired their used vehicles will find that their higher market value justifies the expense of any maintenance and repairs necessary to keep them in service longer, so the increase in their price will raise the number kept in service, from Q_0 to Q_1. Because the market for used vehicles is very active – sales of used cars and light trucks have averaged nearly 40 million in recent years, nearly three times the number of new models sold annually – these responses are likely to occur fairly rapidly.

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

The consequences of changes in the used car 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 4-13 as the area P_1abP_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_1acP_0 in the figure, which offsets much of the loss in consumer surplus to buyers.[87] The remaining loss in consumer surplus is the triangle abc shown in Figure 4-13. Estimating the value of this loss requires 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. While the estimated coefficients of the "scrappage model" described in Chapter 4.2.2 of the Technical Support Document could be used to develop elasticities of supply for used cars and light trucks, NHTSA does not have access to the remaining information necessary to calculate this welfare loss.

At the same time, however, the increase in used car prices causes a secondary increase in demand for new cars and light trucks, which would appear as a further upward shift in the new-car demand curve to a position slightly above D_0 in Figure 4-3. Although not shown in Figure 4-3, this secondary shift would act much like the improvement in fuel economy (which shifted the demand curve upward from D_0 to D_1), by limiting the decline in sales of new cars and light trucks and the accompanying loss in consumer surplus to their 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. Hence NHTSA's analysis omits both effects, under the assumption that including them would have little effect on the comparison of total costs and benefits from imposing higher CAFE standards.[88]

4.5.2 Estimating the Effect of CAFE Standards on Fleet Turnover

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

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[87] Producer surplus, a welfare measure analogous to consumer surplus, is equal to the difference between sales revenue that suppliers receive from selling increased output and their short-run incremental costs for producing it. It corresponds to suppliers' short-term gain in profit on the increased output. For a complete discussion, see Richard E. Just, Darrel L. Hueth, and Andrew Schmitz, *The Welfare Economics of Public Policy*, Northampton MA, Edward Elgar Publishing, Inc., 2004, Sections 4.2 and 4.3.

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

model is described in Chapter 4.2.2 of the Technical Support Document accompanying this proposed rule.

4.6 Effects of Higher CAFE Standards on Fuel Consumption

Requiring new cars and light trucks to achieve higher fuel economy will significantly reduce demand for transportation fuels. Because gasoline and diesel – which account for the vast bulk of energy consumed to power light-duty vehicles – are refined from petroleum, U.S. demand for petroleum will decline, and this will be reflected in some combination of reduced consumption of U.S. produced or imported crude oil.[89] Extracting and refining petroleum into transportation fuels and distributing them for retail sale produces additional emissions of criteria air pollutants and greenhouse gases beyond those from vehicles' consumption of fuel, so reducing the volume of fuel supplied will generate additional benefits in the form of reductions in the climate and health damages these emissions cause. Finally, reduced spending for fuel by drivers of cars and light trucks will lower tax revenues to both federal and state governments, which typically fund spending on transportation infrastructure or other programs.[90]

4.6.1 Impacts on Fuel Use and Spending

Imposing more stringent CAFE standards will reduce U.S. demand for petroleum-based transportation fuels, shown in Figure 4-14 as a downward shift in the demand curve for fuel. Cars and light trucks subject to the higher standards will save fuel throughout their lifetimes, while added rebound-effect driving and the shift of some driving to used cars will partly offset this, but on balance, total fuel demand will decline. The U.S. domestic supply of refined transportation fuels appears to be extremely "price-elastic" – that is, increasing production does not exert significant upward pressure on refining costs and fuel prices – so reducing demand is not expected to lower fuel prices, as the figure indicates. As a consequence of lower demand, total fuel consumption will decline from G_0 to G_1 in Figure 4-14, and spending on fuel will be reduced by the rectangular area G_1beG_0.[91] The dollar value of this area is equal to the retail price of fuel per gallon, labeled P_{retail} in the figure, multiplied by the decline in the number of gallons consumed, or $G_1 - G_0$.

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[89] Petroleum-based fuels currently account for more than 99% of total energy used by light-duty vehicles, and this figure is projected to remain well above 90% for the foreseeable future; see U.S. Energy Information Administration, Annual Energy Outlook 2018 (https://www.eia.gov/outlooks/aeo/tables_ref.php), Table 38.

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

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

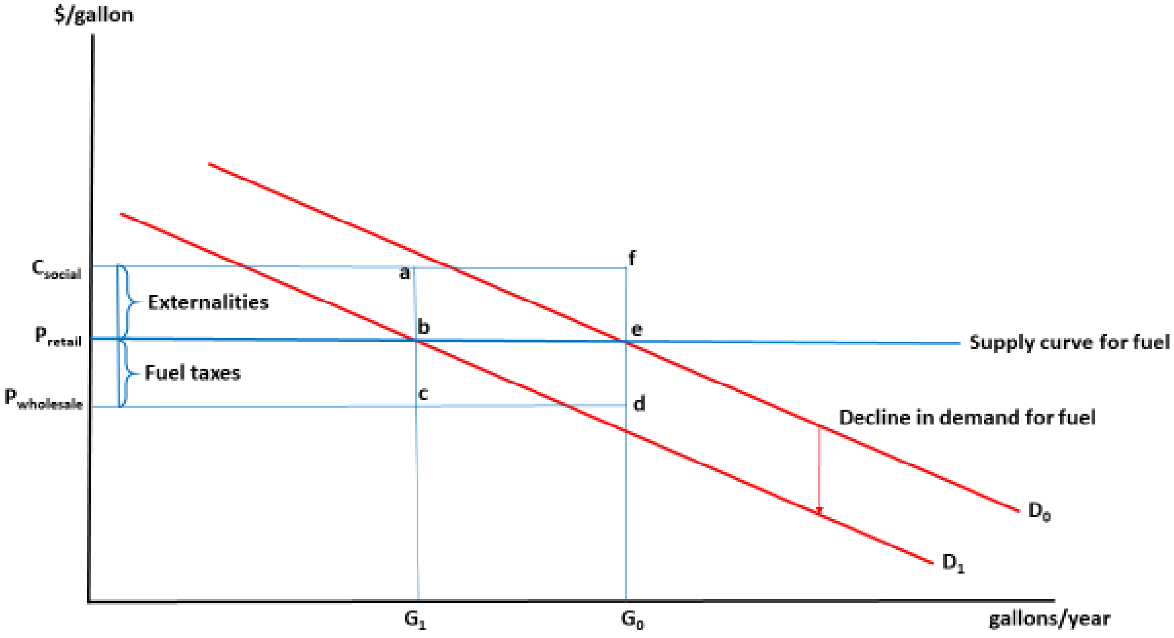

Figure 4-14 – Effect of the Proposed Action on Fuel Consumption and Expenditures

Savings in fuel spending by car and light truck owners are measured using retail fuel prices, which include a significant tax burden – federal, state, and some local governments impose taxes on gasoline and diesel that together average nearly $0.50 per gallon. Thus some fraction of the savings in fuel costs – shown as the rectangle cbed in Figure 4-14 – represents lower tax payments; their dollar value is the product of average fuel taxes per gallon and the decline in the number of gallons consumed annually with higher CAFE standards in effect. Spending funded by fuel tax revenue produces economic benefits to drivers, as well as to users of other transportation services and non-transportation programs funded using fuel tax revenue.[92] Lower spending reduces the benefits these programs generate, and the resulting loss is broadly distributed throughout the economy rather than focused on car and light truck buyers, so NHTSA's analysis treats this as a cost of imposing higher CAFE standards. The loss in fuel tax revenue is exactly offset by the component of savings in retail fuel costs that represents lower fuel tax payments.

4.6.2 Externalities from Refining and Consuming Fuel

Extracting and transporting crude petroleum, refining it to produce transportation fuels, and distributing fuel generate additional emissions of GHGs and criteria air pollutants beyond those from cars' and light trucks' use of fuel. By reducing the volume of petroleum-based fuel produced and consumed, adopting higher CAFE standards will thus mitigate global climate-related economic damages caused by accumulation of GHGs, as well as the more immediate and localized health damages caused by exposure to criteria pollutants. Because they fall broadly on

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[92] Some states impose their general sales taxes on fuel, and the revenue this generates is often used to fund non-transportation spending.

the U.S. – and global, in the case of climate damages –population and economy, reducing them represents an external benefit from requiring higher fuel economy.

In Figure 4-14, the economic costs of climate and health damage externalities is shown as the difference between the social cost of supplying fuel C_{social} and its retail price P_{retail}, and these costs are assumed to be constant on a per-gallon basis. The reduction in economic costs of climate and health damages resulting from lower fuel consumption is the area bafe in the figure, which is equal to the product of their per-gallon value and the reduction in the number of gallons of fuel supplied and consumed.

NHTSA calculates 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 GREET model and procedures described in Chapter 5.2 of the Technical Support Document accompanying this proposed rule. As with GHG emissions resulting from fuel use itself, the agency uses unit damage costs of GHG emissions reported in recent draft guidance issued by the federal Interagency Working Group on the Social Costs of Greenhouse Gas Emissions to convert these reductions in GHG emissions to economic benefits.[93]

NHTSA's evaluation also accounts for benefits from reducing domestic emissions of criteria air pollutants that occur during fuel refining and distribution, again using emission rates for different fuels derived from Argonne's GREET model. Health damage costs resulting from increased population exposure to harmful accumulations of these pollutants were obtained from recent EPA analyses; these costs differ between vehicle and upstream emissions, reflecting differences in their geographic dispersal, accumulation, and resulting population exposure. Detailed descriptions of the sources used to develop all of these inputs also appear in Chapter 5.4 of the Technical Support Document.

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

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

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

These three effects are usually referred to collectively as "energy security externalities" caused by U.S. petroleum consumption, and reducing them is often cited as a potential economic benefit of lowering U.S. oil demand. To the extent that they represent real economic costs and would decline in response to reductions in U.S. petroleum consumption and imports of the size likely to result from tightening CAFE standards, these effects represent potential benefits of NHTSA's proposed action. Chapter 6.2.4 of the Technical Support Document assesses the extent to which lowering domestic gasoline use will directly reduce each of these effects, whether reducing it represents a real economic benefit, and how such benefits would be measured. Briefly, it concludes that only reducing potential external costs from sudden increases in petroleum prices represents a real economic benefit from tightening CAFE standards, but that this benefit can be significant. NHTSA thus includes only the reduction in the probability-weighted or "expected" value of those external costs as its measure of the improvement in U.S. energy security from imposing stricter CAFE standards.

4.7 Discounting Future Costs and Benefits

OMB Circular A-4 directs Federal agencies to discount future benefits and costs of proposed regulatory actions that affect opportunities for business investment using a 7 percent rate; in contrast, it advises agencies to discount the economic effects of regulations that will primarily affect households' future consumption opportunities at a 3 percent rate. Increases in costs to produce new cars and light trucks that meet higher CAFE targets will initially be borne by vehicle manufacturers, but NHTSA assumes that they will protect their profitability by passing these cost increases on to buyers by raising selling prices for some models. Fuel savings and most other benefits from tightening standards will be experienced directly by owners of vehicles that offer higher fuel economy, and benefits or costs that are experienced more widely will also primarily affect future consumption. This implies that future costs and benefits anticipated to result from NHTSA's proposed action should be discounted using a 3 percent rate.[94]

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

4.8 Reporting Benefits and Costs

NHTSA believes it is important to report the benefits and costs of its proposal in a format that illustrates *how* its action would generate economic impacts, and distinguishes the economic

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[94] One important exception is reductions in climate damages resulting from lower GHG emissions. Since these are likely to occur in the distant future and there is some uncertainty about whether 3% is the correct consumption discount rate, it is appropriate to discount reductions in climate damages at a lower "certainty equivalent" rate that is consistent with the 3% near-term value. To reflect this, NHTSA uses the Interagency Working Group's estimates of the social costs of GHG emissions that incorporate a 2.5% discount rate. For a discussion of this issue, see pp. 15-16 of the Working Group's Guidance cited previously, and Chapter 6.2.1 of the Technical Support Document.

consequences of higher standards for private businesses and households from its effects on the remainder of the U.S. economy. Table 4-1 presents the economic benefits and costs of NHTSA's proposed action to establish higher CAFE standards for model years 2024-2026. For both costs and benefits, the table distinguishes between those experienced by private businesses and households (labeled private costs and benefits), and those experienced more widely throughout the U.S. economy (labeled "external" costs and benefits). The agency believes it is important to distinguish these categories because private households and businesses can readily obtain most or all of the benefits from the higher fuel economy levels its proposed action would require by purchasing models that are now available, so the main motivation for requiring higher fuel economy must be to provide benefits to the broader population and U.S. economy. Alternative versions of Table 4-1 that include dollar estimates of costs and benefits for the regulatory alternatives NHTSA considered when selecting its proposed action appear in Chapter 6.5.6 of this regulatory analysis, reflecting differing perspectives for measuring benefits and costs, time horizons, and discount rates.

Table 4-1 – Benefits and Costs Resulting from the Agencies' Proposed Action

Entry	Explanation Location in PRIA
Private Costs	
Technology Costs to Increase Fuel Economy	Chapter 4.3.2
Increased Maintenance and Repair Costs	Chapter 4.3.2
Sacrifice in Other Vehicle Attributes	Chapter 4.3.1
Consumer Surplus Loss from Reduced New Vehicle Sales	Chapter 4.4.1
Safety Costs Internalized by Drivers	Chapter 5.3
Subtotal - Private Costs	Sum of above entries
External Costs	
Congestion and Noise Costs from Rebound-Effect Driving	Chapter 4.5.2
Safety Costs Not Internalized by Drivers	Chapter 5.3
Loss in Fuel Tax Revenue	Chapter 4.6.1
Subtotal - External Costs	Sum of above entries
Social Costs	Sum of private and external costs
Private Benefits	
Savings in Retail Fuel Costs[95]	Chapter 4.6.1
Benefits from Additional Driving	Chapter 4.5.1
Less Frequent Refueling	Chapter 4.5.1
Subtotal – Private Benefits	Sum of above entries
External Benefits	
Reduction in Petroleum Market Externality	Chapter 4.6.3
Reduced Climate Damages	Chapters 4.5.2 and 4.6.2
Reduced Health Damages	Chapters 4.5.2 and 4.6.2
Subtotal - External Benefits	Sum of above entries
Social Benefits	Sum of private and external benefits
Net Private Benefits	Private Benefits – Private Costs
Net External Benefits	External Costs – External Benefits
Net Social Benefits	Social Benefits – Social Costs

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

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[95] 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.

that the agency lacks sufficient information to confidently estimate them, rather than to suggest that their true value is zero. Other privately-borne costs include losses in consumer surplus to would-be new car and light truck buyers who are deterred by their higher prices and the economic cost of safety risks that drivers consider when deciding whether to travel additional miles.

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

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

Finally, the table reports social costs, or the sum of private and external costs, and social benefits, the sum of private and external benefits from requiring higher fuel economy. Net social benefits are simply the difference between social benefits and costs with positive values indicating that raising CAFE standards generates benefits exceeding its social costs, and negative values suggesting the opposite. It also reports net private benefits, the difference between private benefits and private costs, as well as net external benefits, the difference between population and economy-wide or external benefits and external costs. Reporting the private and external components of net benefits separately enables readers of this Regulatory Impact Analysis to see the extent to which the economic value of NHTSA's proposed action depends on providing benefits to buyers of new cars and light trucks they could readily obtain for themselves simply by purchasing the higher fuel economy models that are now available in today's vehicle market.

5. Impacts on Motor Vehicle Safety

The primary objective of CAFE standards is to achieve maximum feasible fuel economy, thereby reducing fuel consumption. In setting standards to achieve this intended effect, the potential of the standards to affect vehicle safety is also considered. As a safety agency, NHTSA has long considered the potential for adverse safety consequences when establishing CAFE standards.

Safety consequences include all impacts from motor vehicle crashes, including fatalities, nonfatal injuries, and property damage.

Safety trade-offs associated with increases in fuel economy standards have occurred in the past—particularly before CAFE standards became attribute-based—because manufacturers chose to comply with stricter standards by building smaller and lighter vehicles.[96] In cases where fuel economy improvements were achieved through reductions in vehicle size and mass, the smaller, lighter vehicles did not protect their occupants as effectively in crashes as larger, heavier vehicles, on average. Although NHTSA now uses attribute-based standards, in part to reduce the incentive to downsize vehicles to comply with CAFE standards, the agency continues to be mindful of the possibility of safety-related trade-offs.

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

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

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

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

   The standards also influence the composition of the light-duty fleet. As the safety provided by light trucks, SUVs and passenger cars responds differently to technology that manufacturers employ to meet the standards—particularly mass reduction—fleets with different compositions of body styles will have varying numbers of fatalities, so changing the share of each type of light-duty vehicle in the projected future fleet impacts safety outcomes.

3. Increased driving because of better fuel economy. The "rebound effect" predicts consumers will drive more when the cost of driving declines. More stringent standards reduce vehicle operating costs, and in response, some consumers may choose to drive

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

more. Additional driving increases exposure to risks associated with motor vehicle travel, and this added exposure translates into higher fatalities and injuries.

The contributions of the three factors described above generate the differences in safety outcomes among regulatory alternatives.[97] The agency's analysis makes extensive efforts to allocate the differences in safety outcomes between the three factors. Fatalities expected during future years under each alternative are projected by deriving a fleet-wide fatality rate (fatalities per vehicle mile of travel) that incorporates the effects of differences in each of the three factors from baseline conditions and multiplying it by that alternative's expected VMT. Fatalities are converted into a societal cost by multiplying fatalities with the DOT-recommended value of a statistical life (VSL) supplemented by economic impacts that are external to VSL measurements. Traffic injuries and property damage are also modeled directly using the same process and valued using costs that are specific to each injury severity level.

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

The agency categorizes safety outcomes through three measures of light-duty vehicle safety: fatalities to occupants occurring in crashes, serious injuries sustained by occupants, and the number of vehicles involved in crashes that cause property damage but no injuries. Counts of fatalities to occupants of automobiles and light trucks are obtained from NHTSA's Fatal Accident Reporting System (FARS). Estimates of the number of serious injuries to drivers and passengers of light-duty vehicles are tabulated from NHTSA's General Estimates System (GES), an annual sampling of motor vehicle crashes occurring throughout the U.S. Weights for different types of crashes were used to expand the samples of each type to estimates of the total number of crashes occurring during each year. Finally, estimates of the number of automobiles and light trucks involved in property damage-only (PDO) crashes each year were also developed using GES.

5.1 Mass Reduction Impacts

As a safety agency, NHTSA has long considered the potential for adverse safety consequences when establishing CAFE standards. Vehicle mass reduction can be one of the more cost-effective means of improving fuel economy, particularly for makes and models not already built

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

with much high-strength steel or aluminum closures or low-mass components. Manufacturers have stated that they will continue to reduce vehicle mass to meet more stringent standards, and therefore, this expectation is incorporated into the modeling analysis supporting the standards. Newer vehicles incorporate design and hardware improvements that may mitigate some of the direct safety effects to occupants associated with lightweighting, but historical relationships between vehicle weight societal fatalities persist to a large extent. Likewise, safety rules that have reduced fatality and injury risk (e.g., first-event rollover risk reduction through ESC) have placed downward pressure on safety effects associated with mass reduction. This relationship is likely a key driver of decreasing magnitudes of estimated effects of mass reduction on societal fatality risk over time. To the extent that safety rules have had an impact on crashes evaluated in the analysis summarized below (i.e., fewer fatalities in the sample for first-event rollovers due to mandatory ESC), this impact is accounted for directly in NHTSA's analysis through a lower weight being placed on such crashes in the estimation of the effects of mass reduction on societal fatality risk.

Historically, as shown in FARS data analyzed by NHTSA,[98] mass reduction concentrated among the heaviest vehicles (chiefly, the largest LTVs, CUVs and minivans) is estimated to reduce overall fatalities, while mass reduction concentrated among the lightest vehicles (chiefly, smaller passenger cars) is estimated to increase overall fatalities. Past NHTSA analyses have consistently indicated that increasing the disparity of the masses of vehicles is harmful to safety, and that decreasing the disparity of the masses of vehicles improves safety. In collisions among vehicles, mass reduction in heavier vehicles alone is more beneficial to the occupants of lighter vehicles than it is harmful to the occupants of the heavier vehicles. Mass reduction in lighter vehicles alone is more harmful to the occupants of lighter vehicles than it is beneficial to the occupants of the heavier vehicles. Reducing mass simultaneously across multiple vehicles can have a range of net effects; for example, proportional mass reduction across the vehicle fleet would be expected to have a roughly neutral effect on societal fatality rates for two-vehicle crashes. This highlights the role of mass disparity in societal fatality risk: as the overall vehicle fleet moves closer together is in terms of mass (or, as measured in our analysis, curb weight), the impacts of changes in vehicle mass on fatality risk decrease for crashes involving two or more vehicles. However, many fatalities and injuries occur in single vehicle crashes and collisions

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

between light-duty vehicles and cyclists or pedestrians and these must also be taken into account in representing the effects of mass reduction on societal fatality rates.

This is most apparent when considering mass reduction in the heaviest and lightest vehicles. Mass reduction in heavier vehicles is more beneficial to the occupants of lighter vehicles than it is harmful to the occupants of the heavier vehicles. Mass reduction in lighter vehicles is more harmful to the occupants of lighter vehicles than it is beneficial to the occupants of the heavier vehicles. In response to questions of whether designs and materials of more recent model year vehicles may have weakened the historical statistical relationships between mass, size, and safety, NHTSA has periodically updated its database for statistical analysis consisting of crash data. The database incorporates the full range of real-world crash types. NHTSA also sponsored a study conducted by George Washington University to develop a fleet simulation model and study the impact and relationship of light-weighted vehicle design with crash injuries and fatalities. That study is discussed in Chapter 7.1.5 of the TSD.

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

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

The basic analytical method used to analyze the impacts of weight reduction on safety for this proposed rule is the same as in the 2016 Puckett and Kindelberger report.[99] NHTSA released the 2016 Puckett and Kindelberger report as a preliminary report on the relationship between fatality risk, mass, and footprint in June 2016 in advance of the Draft TAR. The 2016 Puckett and Kindelberger report covered the same scope as previous NHTSA reports, offering a detailed description of the crash and exposure databases, modeling approach, and analytical results on relationships among vehicle size, mass, and fatalities that informed the Draft TAR. The modeling approach described in the 2016 Puckett and Kindelberger report was developed with the collaborative input of NHTSA, EPA and DOE, and subject to extensive public review, scrutiny in two NHTSA-sponsored workshops, and a thorough peer review that compared it with the methodologies used in other studies.

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

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

As in the 2012 Kahane report, 2016 Puckett and Kindelberger report, the Draft TAR, and the 2020 CAFE rule, the vehicles are grouped into three classes: passenger cars (including both two-door and four-door cars); CUVs and minivans; and truck-based LTVs. The curb weight of passenger cars is formulated, as in the 2012 Kahane report, 2016 Puckett and Kindelberger

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

report, Draft TAR, and 2020 CAFE rule, as a two-piece linear variable to estimate one effect of mass reduction in the lighter cars and another effect in the heavier cars.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Including passenger cars with AWD in the analysis has little effect on the point estimate for lighter passenger cars (increase in societal fatality rates of approximately 1.1% per 100-pound mass reduction, versus 1.2% in the central analysis). However, this revision has a strong effect on the point estimate for heavier passenger cars (increase in societal fatality rates of between

0.84% and 0.89% per 100-pound mass reduction, versus 0.42% in the central analysis). This result supports a hypothesis that, after taking AWD status into account, mass reduction in heavier passenger cars is a more important driver of societal fatality rates than previously estimated. Although this result could be spurious, estimated confidence bounds (presented below) indicate that accounting for AWD status reduces uncertainty in the point estimate. NHTSA seeks comment on the inclusion of passenger cars with AWD when estimating the effects of mass reduction on societal fatality rates.

Splitting CUVs and minivans into two vehicle classes yields point estimates that are consistent with the point estimate for the consolidated CUV-minivan vehicle class (an average decrease in societal fatality rates of approximately 0.16% to 0.18% per 100-pound mass reduction across the two vehicle classes, versus a decrease of 0.25% in the central analysis). However, sample sizes half as large in the two vehicle classes relative to the consolidated vehicle class lead to very large estimated confidence bounds, as shown below. Due to this uncertainty, NHTSA does not feel that the current databases contain a large enough sample of CUVs and minivans to split these vehicles into two classes in the analysis; however, this issue will be re-examined when the next iteration of the databases is complete.

Extending the range of CYs and MYs used to establish the distribution of fatalities across crash types has a negligible effect on the point estimates. Based on the narrow ranges of results in Table 5-2, NHTSA finds evidence supporting a flexible approach in the choice of CYs and MYs used in this manner. All else being equal, extending the range helps to mitigate the potential for individual crash types with large estimated effects to drive spurious effects on overall estimates through unrepresentatively high estimated shares of overall fatalities. As a hedge in this direction, NHTSA applied the estimates from the alternative specification with two additional CYs and MYs (i.e., the second column from the right in Table 5-2) when evaluating 95-percent confidence bounds for the alternative models considered here. NHTSA seeks comment on this approach to representing the distribution of fatalities across crash types.

NHTSA believes the most recent analysis represents the best estimate of the impacts of mass reduction that results in increased mass disparities on crash fatalities; and, that it is appropriate for the analysis to use the best and most likely estimates for safety, even if the estimates are not statistically significant at the 95-percent confidence level. Significance at the 85-percent confidence level is important evidence that the relevant point estimates are meaningfully different from zero (e.g., approximately five to six times more likely to be non-zero than zero). NHTSA believes it would be misleading to ignore these data or to use values of zero for the rulemaking analysis, as doing so would not properly inform decision makers on the safety impacts of the regulatory alternatives and final standards. Similar to past analyses, the most recent analysis uses the best available data and estimates. NHTSA feels it is inappropriate to ignore likely impacts of the standards simply because the best available estimates have confidence levels below 95 percent; uniform estimates of zero are statistically weaker than the estimates identified in the analysis, and thus are not the best available. Because the point estimates are derived from the best-fitting estimates for each crash type (all of which are non-zero), the confidence bounds around an overall estimate of zero would necessarily be larger than the corresponding confidence bounds around the point estimates presented here. Ultimately, the point estimates for the lightest and heaviest vehicles in the sample are the estimates that have shown consistent directionality (and, to a lesser extent, magnitude) across studies, and these estimates are the most important in representing the effects of changes in mass disparity. Thus, the point estimates for lighter passenger cars and heavier LTVs offer the highest informative value among the estimates in the analysis; the smaller estimates corresponding to vehicles near the median of the fleet curb weight distribution are likely to be less informative.

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

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

5.2 Sales/Scrappage Impacts

The sales response discussed above impacts the number of vehicles produced in a given model year and, consequently, in service in subsequent years. Setting aside other responses, then, the sales response changes the absolute numbers of estimated fatalities by simply changing the size of the fleet. Related, the dynamic fleet share model discussed above also impacts the relative shares of passenger cars and light trucks produced in each model year (because as the fuel economy levels of both passenger cars and light trucks improve, the improvements add more value to the latter, the effect being amplified as fuel prices increase over time), and this impacts the absolute numbers of fatalities because our estimates of impacts of changes in mass reduction on fatality risk are different for passenger cars and light trucks. The scrappage response discussed above also impacts safety because it changes the rate at which we estimate the fleet will "turn over" to newer vehicles, which tend to be safer than older vehicles.[100]

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

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

At the highest level, the agency calculates the impact of the sales and scrappage effects by multiplying the VMT of a vehicle by the fatality risk of that vehicle. The estimation of VMT involves three steps: First, we apply a model (developed for FHWA and discussed in Chapter 3.3.1 to estimate total light-duty vehicle VMT in the no-action alternative, accounting for the elasticity of VMT with respect to the per-mile cost of driving. Second, for each of the action alternatives, we adjust this VMT to account for the fact that more efficient new vehicles will be less costly to drive (i.e., the rebound effect discussed in Chapter 4.4). Third, for each regulatory alternative, we distribute estimated VMT in each calendar year among vehicles estimated to be in service in that year, as discussed in TSD Chapter 7.2. The fatality risk measures the likelihood that a vehicle will be involved in a fatal accident per mile driven. NHTSA calculates the fatality risk of a vehicle based on the vehicle's model year, age, and style, while controlling for factors that are independent of the intrinsic nature of the vehicle, such as behavioral characteristics.

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

To simplify forecasting baseline future rates for fatalities, non-fatal injuries, and involvement in property damage only crashes, we utilize the versions of each model that include fixed effects for safety regimes, vehicle age and its squared value, the time trend measure (including any significant change in the trend), and indicator variables for recession years. Specifically, we use model 10 from Table 7-9, Table 7-10, and Table 7-11 in the accompanying TSD.

Starting with the relevant rate for the latest model year when it was new (e.g., the fatality rate for model year 2019 during calendar year 2019, when most vehicles from that model year were sold and placed into service), we apply estimates of the shares of new vehicles produced during future model years that will be equipped with various crash avoidance technologies and the effectiveness of each of those technologies in reducing crashes (fatal, non-fatal, or property damage, as appropriate). The nature of these technologies, projections of the shares of new cars and light trucks that will be equipped with each of them, and estimates of the effectiveness of those technologies in preventing these three different types of crashes are discussed in the following section. This generates forecasts of fatality, non-fatal injury, and property damage crash involvement rates for future model years during their initial year of use, which for simplicity is assumed to be the same calendar year.

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

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

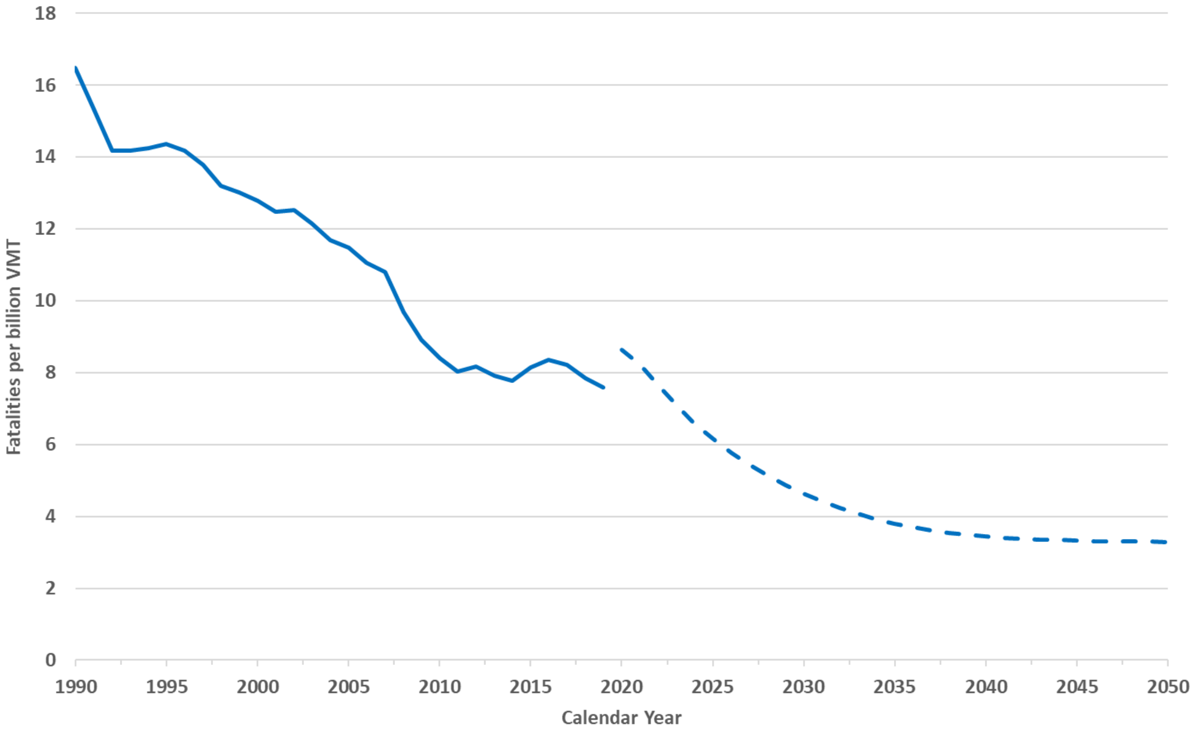

Figure 5-1 – Recent and Projected Future Fatality Rates for Cars and Light Trucks

5.2.1 Future Safety Trends Predicted by Advanced Safety Technologies

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

Reduced new vehicle sales would cause an increase in fatalities due primarily to slower adoption of safer vehicles while increased vehicle sales would have the opposite effect. Added driving because of less costly vehicle operating costs is expected to increase fatalities. The development of advanced crash avoidance technologies in recent years indicates some level of safety improvement is almost certain to occur going forward. Moreover, autonomous vehicles offer the possibility of significantly reducing the effect of human perception, judgment or error in crash causation, a contributing factor in roughly 94% of all crashes. However, there is insufficient information and certainty regarding the eventual impact of autonomous vehicles eventual impact to include them in this analysis.

Advanced technologies that are currently deployed or in development include:

1. Forward Collision Warning (FCW) systems passively assist drivers in avoiding or mitigating the impact of rear-end collisions (i.e., a vehicle striking the rear portion of a vehicle traveling in the same direction directly in front of it). FCW uses forward-looking vehicle detection capability, such as RADAR, LIDAR (laser), camera, etc., to detect other vehicles ahead and use the information from these sensors to warn the driver and to prevent crashes. FCW systems provide an audible, visual, or haptic warning, or any combination thereof, to alert the driver of an FCW-equipped vehicle of a potential collision with another vehicle or vehicles in the anticipated forward pathway of the vehicle.

2. Crash Imminent Braking (CIB) systems actively assist the drivers by mitigating the impact of rear-end collisions. These safety systems have forward-looking vehicle detection capability provided by sensing technologies such as RADAR, LIDAR, video camera, etc. CIB systems mitigate crash severity by automatically applying the vehicle's brakes shortly before the expected impact (i.e., without requiring the driver to apply force to the brake pedal).

3. Dynamic Brake Support (DBS) is a technology that actively increases the amount of braking provided to the driver during a rear-end crash avoidance maneuver. If the driver has applied force to the brake pedal, DBS uses forward-looking sensor data provided by technologies such as RADAR, LIDAR, video cameras, etc. to assess the potential for a rear-end crash. Should DBS ascertain a crash is likely (i.e., the sensor data indicate the driver has not applied enough braking to avoid the crash), DBS automatically intervenes. Although the manner in which DBS has been implemented differs among vehicle manufacturers, the objective of the interventions is largely the same - to supplement the driver's commanded brake input by increasing the output of the foundation brake system. In some situations, the increased braking provided by DBS may allow the driver to avoid a crash. In other cases, DBS interventions mitigate crash severity.

4. Pedestrian AEB (PAEB) systems provide automatic braking for vehicles when pedestrians are in the forward path of travel and the driver has taken insufficient action to

avoid an imminent crash. Like CIB, PAEB safety systems use information from forward-looking sensors to automatically apply or supplement the brakes in certain driving situations in which the system determines a pedestrian is in imminent danger of being hit by the vehicle.

5. Rear Automatic Braking features have the ability to sense the presence of objects behind a reversing vehicle, alert the driver of the presence of the object(s) via auditory and visual alerts, and automatically engage the available braking system(s) to stop the vehicle.

6. Semi-automatic Headlamp Beam Switching devices provide either automatic or manual control of headlamp beam switching at the option of the driver. When the control is automatic, headlamps switch from the upper beam to the lower beam when illuminated by headlamps on an approaching vehicle and switch back to the upper beam when the road ahead is dark. When the control is manual, the driver may obtain either beam manually regardless of the conditions ahead of the vehicle.

7. Lane Departure Warning (LDW) is a driver assistance system that monitors lane markings on the road and alerts the driver when their vehicle is about to drift beyond a delineated edge line of their current travel lane.

8. Lane Keep Assist (LKA) utilizes LDW sensors to monitor lane markings but, in addition to warning the driver, provides gentle steering adjustments to prevent drivers from unintentionally drifting out of their lane.

9. Lane Centering keeps the vehicle centered in its lane and typically comes with steering assist to help the vehicle take gentle turns at highway speeds. These systems also work together with adaptive cruise control and lane keeping assist to give the car semi-autonomous capability.

10. Blind Spot Detection (BSD) systems use digital camera imaging technology or radar sensor technology to detect one or more vehicles in either of the adjacent lanes that may not be apparent to the driver. The system warns the driver of an approaching vehicle's presence to help facilitate safe lane changes.

11. Lane Change Alert (LCA) systems use digital camera imaging technology or radar sensor technology to detect vehicles either in or rapidly approaching in adjacent lanes that may not be apparent to the driver. The system warns the driver of an approaching vehicle's presence to help facilitate safe lane changes.

Beginning with the 2020 CAFE final rule, NHTSA augmented the sales-scrappage safety analysis with recent research into the effectiveness of specific advanced crash avoidance safety technologies (also known as ADAS or advanced driver assistance systems) that are expected to drive future safety improvement to estimate the impacts of crash avoidance technologies. The analysis analyzes six crash avoidance technologies that are currently being produced and commercially deployed in the new vehicle fleet. These include FCW, Automatic Emergency

Braking (AEB),[101] LDW, LKA, BSD, and LCA. These are the principal technologies that are being developed and adopted in new vehicle fleets and will likely drive vehicle-based safety improvements for the coming decade. These technologies are being installed in more and more new vehicles; in fact, manufacturers recently reported that they voluntarily installed AEB systems in more than 70 percent of their new vehicles sold in the year ending August 31, 2019.[102] The agencies note that the terminology and the detailed characteristics of these systems may differ across manufacturers, but the basic system functions are generally similar.

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

1. Forward collisions, typically involving a crash into the rear of a stopped vehicle;
2. Lane departure crashes, typically involving inadvertent drifting across or into another traffic lane; and
3. Blind spot crashes, typically involving intentional lane changes into unseen vehicles driving in or approaching the driver's blind spot.

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

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

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[101] AEB is a combination of CIB, DBS, and sometimes PAEB.

[102] NHTSA Announces Update to Historic AEB Commitment by 20 Automakers, NHTSA press release December 17, 2019. https://www.nhtsa.gov/press-releases/nhtsa-announces-update-historic-aeb-commitment-20-automakers.

5.3 Rebound Effect Impacts

The "rebound effect" is a measure of the additional driving that occurs when the cost of driving declines. More stringent standards reduce vehicle operating costs, and in response, some consumers may choose to drive more. Driving more increases exposure to risks associated with on-road transportation, and this added exposure translates into higher fatalities. NHTSA has calculated this impact by estimating the change in VMT that results from alternative standards. Estimates of the rebound effect in the literature differ significantly. For this analysis, we use a rebound effect of 15%. A full discussion of the basis for selecting this rate is provided in Chapter 4.3.3 of the accompanying TSD.

Rebound miles are not imposed on consumers by regulation. They are a freely chosen activity resulting from reduced vehicle operational costs. As such, the agencies believe a large portion of the safety risks associated with additional driving are offset by the benefits drivers gain from added driving. The level of risk internalized by drivers is uncertain. For the purposes of this analysis, the agency assumes that drivers internalize 90% of the risk associated with additional driving. As such, the agency calculates that 90% of the costs of crashes attributable to additional mobility are offset by a corresponding benefit, and only the remaining 10% of costs are passed through as a net cost to society. Additional discussion of internalized risk is contained in TSD Chapter 7.4.

5.4 Value of Safety Impacts

Fatalities, nonfatal injuries, and property damage crashes are valued as a societal cost within the CAFE Model's cost and benefit accounting. Their value is based on the comprehensive value of a fatality, which includes lost quality of life and is quantified in the value of a statistical life (VSL) as well as economic consequences such as medical and emergency care, insurance administrative costs, legal costs, and other economic impacts not captured in the VSL alone. These values were derived from data in Blincoe et al. (2015), adjusted to 2018 economics, and updated to reflect the official DOT guidance on the value of a statistical life.[103] Nonfatal injury costs, which differ by severity, were weighted according to the relative incidence of injuries across the Abbreviated Injury Scale (AIS). To determine this incidence, the agency applied a KABCO/MAIS translator to GES KABCO based injury counts from 2010 through 2015. This produced the MAIS based injury profile. This profile was used to weight nonfatal injury unit costs derived from Blincoe et al, adjusted to 2018 economics and updated to reflect the official DOT guidance on the value of a statistical life. Property-damaged vehicle costs were also taken from Blincoe et al and adjusted to 2018 economics. VSL does not impact property damage. This gives societal values of $10.8 million for each fatality, $132,000 for each nonfatal injury, and $7,100 for each property damaged vehicle. NHTSA seeks comment on $10.8 million VSL value, which differs from the $10.4 million used in the 2020 *Safer Affordable Fuel Efficient (SAFE) Vehicles Final Rule for Model Years 2021 2026* and by EPA in the 2021

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[103] https://www.transportation.gov/office-policy/transportation-policy/revised-departmental-guidance-on-valuation-of-a-statistical-life-in-economic-analysis.

Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions Standards NPRM.

5.5 Summary of Safety Impacts

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

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

Generally, the stricter alternative requirements have increasingly higher safety impacts. Changes to improve increasing levels of fuel efficiency trigger more use of mass reduction and the resulting reductions in driving costs produce more rebound driving. Fleet composition changes due to the impact of higher prices on sales/scrappage are also accelerated with higher CAFE requirement alternatives. These composition changes reflect both slower turnover of older vehicles and a shift towards more light trucks and fewer passenger cars over time.

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

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

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

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

Alternative:	**1**	**2**	**3**
Fatalities			
Fatalities from Mass Changes	64	115	142
Fatalities from Rebound Effect	449	584	801
Fatalities from Sales/Scrappage	506	1,123	1,681
Total Changes in Fatalities	1,019	1,822	2,624
Fatality Costs ($b)			
Fatality Costs from Mass Changes	0.4	0.8	1.0
Fatality Costs from Rebound Effect	3.0	3.9	5.4
Fatality Costs from Sales/Scrappage	4.4	9.8	14.8
Total - Fatality Costs ($b)	7.8	14.5	21.1
Non-Fatal Crash Costs ($b)			
Non-Fatal Crash Costs from Mass Changes	0.5	0.9	1.1
Non-Fatal Crash Costs from Rebound Effect	3.2	4.3	5.9
Non-Fatal Crash Costs from Sales/Scrappage	1.2	2.8	4.1
Total - Non-Fatal Crash Costs ($b)	4.9	8.0	11.1
Property Damage Costs ($b)			
Property Damage Costs from Mass Changes	0.1	0.2	0.2
Property Damage Costs from Rebound Effect	0.7	0.9	1.2
Property Damage Costs from Sales/Scrappage	0.2	0.5	0.7
Total - Property Damage Costs ($b)	1.0	1.6	2.2
Total Crash Costs ($b)			
Crash Costs from Mass Changes	1.0	1.9	2.3
Crash Costs from Rebound Effect	6.9	9.1	12.5
Crash Costs from Sales/Scrappage	5.8	13.0	19.6
Total - Societal Crash Costs ($b)	13.7	24.0	34.4

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

Alternative:	**1**	**2**	**3**
Fatalities			
Fatalities from Mass Changes	64	115	142
Fatalities from Rebound Effect	449	584	801
Fatalities from Sales/Scrappage	506	1,123	1,681
Total Changes in Fatalities	1,019	1,822	2,624
Fatality Costs ($b)			
Fatality Costs from Mass Changes	0.3	0.5	0.6
Fatality Costs from Rebound Effect	1.7	2.2	3.1
Fatality Costs from Sales/Scrappage	3.3	7.2	11.0
Total - Fatality Costs ($b)	5.2	9.9	14.7
Non-Fatal Crash Costs ($b)			
Non-Fatal Crash Costs from Mass Changes	0.3	0.6	0.7
Non-Fatal Crash Costs from Rebound Effect	2.0	2.7	3.7
Non-Fatal Crash Costs from Sales/Scrappage	1.0	2.3	3.5
Total - Non-Fatal Crash Costs ($b)	3.3	5.6	7.9
Property Damage Costs ($b)			
Property Damage Costs from Mass Changes	0.1	0.1	0.1
Property Damage Costs from Rebound Effect	0.4	0.6	0.8
Property Damage Costs from Sales/Scrappage	0.2	0.4	0.6
Total - Property Damage Costs ($b)	0.7	1.1	1.5
Total Crash Costs ($b)			
Crash Costs from Mass Changes	0.6	1.2	1.4
Crash Costs from Rebound Effect	4.1	5.5	7.5
Crash Costs from Sales/Scrappage	4.5	9.9	15.1
Total - Societal Crash Costs ($b)	9.2	16.6	24.0

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

Alternative:	1	2	3
Non-Fatal Injuries			
Non-Fatal Injuries from Mass Changes	5,537	10,048	12,377
Non-Fatal Injuries from Rebound Effect	36,587	48,618	66,522
Non-Fatal Injuries from Sales/Scrappage	9,723	22,269	32,249
Total Changes in Non-Fatal Injuries	51,847	80,936	111,147
Property Damaged Vehicles			
Property Damaged Vehicles from Mass Changes	21,195	38,471	47,389
Property Damaged Vehicles from Rebound Effect	139,798	185,800	254,194
Property Damaged Vehicles from Sales/Scrappage	29,900	69,638	99,711
Total Changes in Property Damaged Vehicles	190,892	293,909	401,294

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

Calendar Year	Incremental Fatalities - Alt. 1				Incremental Fatalities - Alt. 2				Incremental Fatalities - Alt. 3			
	Mass	Rebound	Sales / Scrap	Total	Mass	Rebound	Sales / Scrap	Total	Mass	Rebound	Sales / Scrap	Total
2020	0	0	0	0	0	0	0	0	0	0	0	0
2021	0	0	0	0	0	0	0	0	0	0	0	0
2022	0	0	0	0	0	0	0	0	0	0	0	0
2023	0	0	4	4	0	0	7	8	0	1	10	10
2024	0	2	19	22	1	2	30	33	1	3	44	48
2025	1	4	38	43	1	5	59	65	2	7	91	100
2026	1	7	48	56	2	9	90	102	3	12	138	154
2027	2	10	53	64	3	13	113	130	4	18	173	195
2028	2	14	53	69	4	19	119	141	5	25	182	213
2029	3	18	53	74	5	24	121	150	7	33	186	225
2030	3	23	50	76	6	31	117	154	8	42	181	231
2031	4	27	46	78	8	37	110	155	10	50	172	232
2032	5	32	41	78	9	44	101	153	11	59	157	227
2033	5	37	36	78	10	50	89	149	13	68	139	219
2034	6	41	30	78	11	56	76	143	14	76	118	208
2035	6	46	24	76	12	62	62	136	15	84	95	194

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

Calendar Year	Incremental Non-Fatal Injuries - Alt. 1				Incremental Non-Fatal Injuries - Alt. 2				Incremental Non-Fatal Injuries - Alt. 3			
	Mass	Rebound	Sales / Scrap	Total	Mass	Rebound	Sales / Scrap	Total	Mass	Rebound	Sales / Scrap	Total
2020	0	0	0	0	0	0	0	0	0	0	0	0
2021	0	0	0	0	0	0	0	0	0	0	0	0
2022	0	0	0	0	0	0	0	0	0	0	0	0
2023	0	45	171	216	22	59	318	399	22	89	412	523
2024	58	286	755	1,099	128	332	1,166	1,626	149	487	1,690	2,325
2025	97	628	1,388	2,113	217	750	2,135	3,101	259	1,046	3,305	4,610
2026	157	1,005	1,633	2,795	323	1,269	3,117	4,709	400	1,748	4,774	6,923
2027	230	1,412	1,671	3,313	445	1,837	3,649	5,932	554	2,515	5,577	8,645
2028	305	1,884	1,551	3,740	567	2,508	3,528	6,602	707	3,413	5,410	9,529
2029	381	2,341	1,406	4,128	693	3,150	3,276	7,119	857	4,293	5,033	10,183
2030	444	2,903	1,192	4,539	805	3,938	2,864	7,607	1,010	5,361	4,417	10,788
2031	513	3,360	965	4,837	922	4,564	2,391	7,877	1,163	6,202	3,718	11,082
2032	577	3,854	733	5,164	1,034	5,239	1,873	8,147	1,310	7,096	2,917	11,323
2033	638	4,286	521	5,445	1,140	5,832	1,377	8,349	1,451	7,894	2,130	11,475
2034	661	4,709	322	5,691	1,205	6,390	893	8,488	1,549	8,631	1,355	11,535
2035	679	5,066	144	5,889	1,263	6,848	441	8,552	1,638	9,243	625	11,506

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

Calendar Year	Incremental Property Damage - Alt. 1				Incremental Property Damage - Alt. 2				Incremental Property Damage - Alt. 3			
	Mass	Rebound	Sales / Scrap	Total	Mass	Rebound	Sales / Scrap	Total	Mass	Rebound	Sales / Scrap	Total
2020	0	0	0	0	0	0	0	0	0	0	0	0
2021	0	0	0	0	0	0	0	0	0	0	0	0
2022	0	0	0	0	0	0	0	0	0	0	0	0
2023	1	181	552	734	87	239	1,029	1,355	87	361	1,333	1,781
2024	233	1,154	2,411	3,797	517	1,340	3,709	5,566	600	1,964	5,384	7,948
2025	389	2,524	4,431	7,344	871	3,015	6,817	10,703	1,039	4,203	10,556	15,798
2026	626	4,024	5,225	9,876	1,290	5,078	9,985	16,353	1,600	6,997	15,289	23,885
2027	919	5,625	5,344	11,888	1,772	7,323	11,691	20,786	2,204	10,020	17,860	30,084
2028	1,209	7,476	4,946	13,631	2,246	9,952	11,264	23,462	2,800	13,540	17,264	33,605
2029	1,507	9,249	4,465	15,221	2,735	12,448	10,410	25,592	3,381	16,962	15,981	36,325
2030	1,747	11,426	3,761	16,934	3,161	15,503	9,039	27,703	3,971	21,097	13,929	38,997
2031	2,009	13,173	3,021	18,203	3,608	17,897	7,483	28,988	4,553	24,312	11,622	40,487
2032	2,251	15,062	2,272	19,585	4,033	20,470	5,799	30,302	5,112	27,716	9,011	41,840
2033	2,483	16,693	1,591	20,767	4,432	22,711	4,196	31,340	5,641	30,733	6,468	42,843
2034	2,558	18,286	957	21,802	4,666	24,807	2,648	32,121	6,002	33,498	3,989	43,489
2035	2,618	19,619	397	22,634	4,872	26,510	1,220	32,601	6,327	35,770	1,679	43,776

5.6 Sensitivity Analysis – Safety Impacts

Table 5-9 through Table 5-14 present sensitivity analysis isolating the uncertainty parameters of each of the three safety impacts. The content of each table is comparable to Table 5-3, which examines economic impacts using a 3% discount rate. Each set of two consecutive tables examine first the low and then the high end of the safety parameters examined in this analysis. For mass/safety, these parameters are noted in Table 5-1 of this chapter. For Rebound impacts, the low parameter assumes a 10% rebound rate and the high parameter assumes a 20% rebound rate. For Sales/Scrappage, the low and high parameters are noted in Table 7-15 of the accompanying Technical Support Document. In each of these following tables, all inputs are kept constant except the noted factor safety parameter. Generally mass parameters that cause more mass disparity would increase fatalities while those that decrease this disparity would tend to decrease fatalities. A lower rebound effect decreases risk exposure which results in fewer fatalities while a higher rebound effect increases risk exposure and fatalities. Higher technology effectiveness rates would tend to increase the impact of delaying new vehicle purchases while lower effectiveness rates would tend to decrease these impacts. However, note that there are interactive impacts among these factors which are applied simultaneously, and these interactive impacts are lumped with sales/scrappage impacts, which is calculated as the difference between the total interactive impact and the mass and rebound impacts. This obscures the actual sales/scrappage impacts somewhat and makes their sensitivity results less predictable.

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

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

Table 5-9 – Low Mass Safety Parameters

Alternative:	1	2	3
Fatalities			
Fatalities from Mass Changes	-327	-496	-620
Fatalities from Rebound Effect	427	548	755
Fatalities from Sales/Scrappage	500	1,119	1,682
Total Changes in Fatalities	600	1,170	1,817
Fatality Costs ($b)			
Fatality Costs from Mass Changes	-2.2	-3.3	-4.1
Fatality Costs from Rebound Effect	2.8	3.7	5
fatality Costs from Sales/Scrappage	4.4	9.7	14.8
Total - Fatality Costs ($b)	5	10.1	15.7
Non-Fatal Crash Costs ($b)			
Non-Fatal Crash Costs from Mass Changes	-2.4	-3.6	-4.6
Non-Fatal Crash Costs from Rebound Effect	3.1	4	5.5
Non-Fatal Crash Costs from Sales/Scrappage	1.2	2.7	4.1
Total - Non-Fatal Crash Costs ($b)	1.8	3.1	5.1
Property Damage Costs ($b)			
Property Damage Costs from Mass Changes	-0.5	-0.8	-0.9
Property Damage Costs from Rebound Effect	0.6	0.8	1.1
Property Damage Costs from Sales/Scrappage	0.2	0.5	0.7
Total - Property Damage Costs ($b)	0.3	0.6	0.9
Societal Crash Costs ($b)			
Crash Costs from Mass Changes	-5.1	-7.7	-9.6
Crash Costs from Rebound Effect	6.5	8.5	11.7
Crash Costs from Sales/Scrappage	5.7	12.9	19.6
Total - Societal Crash Costs ($b)	7.2	13.8	21.7

Table 5-10 – High Mass Safety Parameters

Alternative:	1	2	3
Fatalities			
Fatalities from Mass Changes	452	723	899
Fatalities from Rebound Effect	471	620	847
Fatalities from Sales/Scrappage	512	1,126	1,679
Total Changes in Fatalities	1,436	2,469	3,425
Fatality Costs ($b)			
Fatality Costs from Mass Changes	3	4.9	6
Fatality Costs from Rebound Effect	3.1	4.1	5.7
Fatality Costs from Sales/Scrappage	4.4	9.8	14.8
Total - Fatality Costs ($b)	10.6	18.8	26.5
Non-Fatal Crash Costs ($b)			
Non-Fatal Crash Costs from Mass Changes	3.4	5.4	6.8
Non-Fatal Crash Costs from Rebound Effect	3.4	4.6	6.2
Non-Fatal Crash Costs from Sales/Scrappage	1.2	2.8	4.1
Total - Non-Fatal Crash Costs ($b)	8	12.8	17.1
Property Damage Costs ($b)			
Property Damage Costs from Mass Changes	0.7	1.1	1.4
Property Damage Costs from Rebound Effect	0.7	0.9	1.3
Property Damage Costs from Sales/Scrappage	0.2	0.5	0.7
Total - Property Damage Costs ($b)	1.6	2.5	3.4
Societal Crash Costs ($b)			
Crash Costs from Mass Changes	7.1	11.4	14.2
Crash Costs from Rebound Effect	7.2	9.7	13.2
Crash Costs from Sales/Scrappage	5.9	13	19.6
Total - Societal Crash Costs ($b)	20.2	34.1	46.9

Table 5-11 – Low Rebound Assumption

Alternative:	1	2	3
Fatalities			
Fatalities from Mass Changes	64	115	142
Fatalities from Rebound Effect	313	410	563
Fatalities from Sales/Scrappage	506	1,123	1,681
Total Changes in Fatalities	883	1,648	2,386
Fatality Costs ($b)			
Fatality Costs from Mass Changes	0.4	0.8	1
Fatality Costs from Rebound Effect	2.1	2.7	3.8
Fatality Costs from Sales/Scrappage	4.4	9.8	14.8
Total - Fatality Costs ($b)	6.9	13.3	19.5
Non-Fatal Crash Costs ($b)			
Non-Fatal Crash Costs from Mass Changes	0.5	0.9	1.1
Non-Fatal Crash Costs from Rebound Effect	2.2	3	4.1
Non-Fatal Crash Costs from Sales/Scrappage	1.2	2.8	4.1
Total - Non-Fatal Crash Costs ($b)	3.9	6.7	9.3
Property Damage Costs ($b)			
Property Damage Costs from Mass Changes	0.1	0.2	0.2
Property Damage Costs from Rebound Effect	0.5	0.6	0.8
Property Damage Costs from Sales/Scrappage	0.2	0.5	0.7
Total - Property Damage Costs ($b)	0.8	1.3	1.8
Societal Crash Costs ($b)			
Crash Costs from Mass Changes	1	1.9	2.3
Crash Costs from Rebound Effect	4.8	6.3	8.7
Crash Costs from Sales/Scrappage	5.8	13	19.6
Total - Societal Crash Costs ($b)	11.6	21.2	30.6

Table 5-12 – High Rebound Assumption

Alternative:	1	2	3
Fatalities			
Fatalities from Mass Changes	64	115	142
Fatalities from Rebound Effect	610	788	1,080
Fatalities from Sales/Scrappage	506	1,123	1,681
Total Changes in Fatalities	1,179	2,026	2,903
Fatality Costs ($b)			
Fatality Costs from Mass Changes	0.4	0.8	1
Fatality Costs from Rebound Effect	4	5.3	7.2
Fatality Costs from Sales/Scrappage	4.4	9.8	14.8
Total - Fatality Costs ($b)	8.9	15.8	23
Non-Fatal Crash Costs ($b)			
Non-Fatal Crash Costs from Mass Changes	0.5	0.9	1.1
Non-Fatal Crash Costs from Rebound Effect	4.4	5.9	8
Non-Fatal Crash Costs from Sales/Scrappage	1.2	2.8	4.1
Total - Non-Fatal Crash Costs ($b)	6.1	9.5	13.2
Property Damage Costs ($b)			
Property Damage Costs from Mass Changes	0.1	0.2	0.2
Property Damage Costs from Rebound Effect	0.9	1.2	1.7
Property Damage Costs from Sales/Scrappage	0.2	0.5	0.7
Total - Property Damage Costs ($b)	1.2	1.9	2.6
Societal Crash Costs ($b)			
Crash Costs from Mass Changes	1	1.9	2.3
Crash Costs from Rebound Effect	9.3	12.3	16.9
Crash Costs from Sales/Scrappage	5.8	13	19.6
Total - Societal Crash Costs ($b)	16.2	27.2	38.8

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

Alternative:	**1**	**2**	**3**
Fatalities			
Fatalities from Mass Changes	64	115	142
Fatalities from Rebound Effect	450	585	803
Fatalities from Sales/Scrappage	499	1,106	1,656
Total Changes in Fatalities	1,013	1,807	2,601
Fatality Costs ($b)			
Fatality Costs from Mass Changes	0.4	0.8	1
Fatality Costs from Rebound Effect	3	3.9	5.4
Fatality Costs from Sales/Scrappage	4.3	9.6	14.6
Total - Fatality Costs ($b)	7.8	14.3	20.9
Non-Fatal Crash Costs ($b)			
Non-Fatal Crash Costs from Mass Changes	0.5	0.9	1.1
Non-Fatal Crash Costs from Rebound Effect	3.3	4.4	6
Non-Fatal Crash Costs from Sales/Scrappage	1.8	4	6
Total - Non-Fatal Crash Costs ($b)	5.6	9.4	13.2
Property Damage Costs ($b)			
Property Damage Costs from Mass Changes	0.1	0.2	0.2
Property Damage Costs from Rebound Effect	0.7	0.9	1.3
Property Damage Costs from Sales/Scrappage	0.2	0.5	0.7
Total - Property Damage Costs ($b)	1	1.6	2.2
Societal Crash Costs ($b)			
Crash Costs from Mass Changes	1.1	1.9	2.4
Crash Costs from Rebound Effect	7	9.2	12.7
Crash Costs from Sales/Scrappage	6.4	14.1	21.3
Total - Societal Crash Costs ($b)	14.4	25.3	36.3

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

Alternative:	**1**	**2**	**3**
Fatalities			
Fatalities from Mass Changes	64	115	141
Fatalities from Rebound Effect	447	581	798
Fatalities from Sales/Scrappage	501	1,111	1,663
Total Changes in Fatalities	1,012	1,807	2,602
Fatality Costs ($b)			
Fatality Costs from Mass Changes	0.4	0.8	1
Fatality Costs from Rebound Effect	3	3.9	5.3
Fatality Costs from Sales/Scrappage	4.4	9.7	14.6
Total - Fatality Costs ($b)	7.8	14.3	20.9
Non-Fatal Crash Costs ($b)			
Non-Fatal Crash Costs from Mass Changes	0.5	0.9	1.1
Non-Fatal Crash Costs from Rebound Effect	3.1	4.2	5.7
Non-Fatal Crash Costs from Sales/Scrappage	1.9	4.2	6.3
Total - Non-Fatal Crash Costs ($b)	5.5	9.3	13.2
Property Damage Costs ($b)			
Property Damage Costs from Mass Changes	0.1	0.2	0.2
Property Damage Costs from Rebound Effect	0.6	0.9	1.2
Property Damage Costs from Sales/Scrappage	0.2	0.5	0.8
Total - Property Damage Costs ($b)	1	1.6	2.2
Societal Crash Costs ($b)			
Crash Costs from Mass Changes	1	1.9	2.3
Crash Costs from Rebound Effect	6.7	8.9	12.2
Crash Costs from Sales/Scrappage	6.5	14.4	21.8
Total - Societal Crash Costs ($b)	14.2	25.2	36.3

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

Change in Safety Parameters from Alternative 0 (Baseline) for MY 1981-2029 for Total Fleet, 3% Percent Discount Rate, by Alternative			
Alternative:	**1**	**2**	**3**
Fatalities			
Fatalities from Mass Changes	31	79	109
Fatalities from Rebound Effect	273	509	692
Fatalities from Sales/Scrappage	299	772	1,405
Total Changes in Fatalities	603	1,360	2,206
Fatality Costs ($b)			
Fatality Costs from Mass Changes	0.2	0.5	0.8
Fatality Costs from Rebound Effect	1.8	3.4	4.6
Fatality Costs from Sales/Scrappage	2.8	6.8	12.7
Total - Fatality Costs ($b)	4.8	10.8	18
Non-Fatal Crash Costs ($b)			
Non-Fatal Crash Costs from Mass Changes	0.2	0.6	0.9
Non-Fatal Crash Costs from Rebound Effect	1.9	3.7	5
Non-Fatal Crash Costs from Sales/Scrappage	0.7	1.8	3.2
Total - Non-Fatal Crash Costs ($b)	2.8	6.1	9.2
Property Damage Costs ($b)			
Property Damage Costs from Mass Changes	0.1	0.1	0.2
Property Damage Costs from Rebound Effect	0.4	0.8	1
Property Damage Costs from Sales/Scrappage	0.1	0.3	0.5
Total - Property Damage Costs ($b)	0.6	1.2	1.8
Societal Crash Costs ($b)			
Crash Costs from Mass Changes	0.5	1.3	1.8
Crash Costs from Rebound Effect	4.1	7.9	10.7
Crash Costs from Sales/Scrappage	3.6	8.9	16.4
Total - Societal Crash Costs ($b)	8.2	18.1	28.9

6. Effects of Regulatory Alternatives

6.1 Overview

CAFE standards produce wide-ranging effects in the vehicles market, in society, and in the environment, and NHTSA considers such impacts when making decisions about new CAFE standards. Like past rulemakings, the current proposed rule is supported by the analysis of many potential impacts of changing CAFE standards. The NPRM proposes standards for model years

2024 through 2026; explicitly estimates manufacturers' responses to those standards through model year 2029; and considers impacts throughout those vehicles' lives. The analysis should be interpreted not as a forecast, but rather as an assessment—reflecting in some cases best judgments regarding different and often uncertain factors—of impacts that could occur. As discussed in Chapter 7, the analysis explores the sensitivity of this assessment to a variety of potential changes in key analytical inputs (*e.g.*, fuel prices).

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

As discussed in the TSD, the underlying CAFE Model accounts explicitly for each of model years 2020-2050, simulating fleet turnover and mileage accumulation until all of these vehicles are projected to have been scrapped (i.e., through calendar year 2089, when the last of the MY 2050 vehicles are projected to be in service). The current rulemaking addresses CAFE standards during each of model years 2024-2026, and many impacts are most meaningfully understood by considering the vehicles produced in those *model years*, and the adjacent years in which manufacturers take early or late actions to comply with the CAFE standards (through model year 2029). On the other hand, an understanding of the proposal'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 greenhouse gas (GHG) emissions, which would correspond to a "calendar year" approach rather than a "model year" approach. Accordingly, today's analysis presents most physical impacts on a *calendar year* basis—that is, showing projected total or incremental quantities through calendar year 2050, accounting for all vehicles projected in service in each calendar year (including vehicles produced during model years 2030-2050).

Underlying CAFE Model output files are available (along with input files, model, source code, and documentation) on NHTSA's website.[104] A comprehensive appendix of detailed manufacturer and model-year tables is also available in Appendix I.

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[104] https://www.nhtsa.gov/corporate-average-fuel-economy/compliance-and-effects-modeling-system.

Additional and more detailed analysis of environmental impacts is provided for CAFE regulatory alternatives in the accompanying Supplemental Environmental Impact Statement (SEIS). NHTSA has prepared a SEIS estimating environmental impacts of the regulatory alternatives under consideration in this proposal. Results presented herein for the CAFE standards differ slightly from those presented in the SEIS; while EPCA/EISA requires that the Secretary (by delegation, NHTSA) determine the maximum feasible levels of CAFE standards in a manner that, as presented here, sets aside the potential use of CAFE credits or application of alternative fuels toward compliance with new standards,[105] NEPA does not impose such constraints on analysis presented in corresponding EISs, and the SEIS presents results of an "unconstrained" analysis that considers manufacturers' potential application of alternative fuels and use of CAFE credits. Detailed manufacturer and model-year tables of results for the SIES are available in Appendix II..

Throughout this section, figures and tables report outcomes for a three percent and seven percent discount rate, as directed by OMB Circular A-4. And while those discount rates have been applied to all social and private benefits and costs in the analysis, the social cost of carbon (SC-CO_2), and corresponding social costs of high global warming potential gases (methane and nitrous oxide, in particular), are discounted at the same discount rates that were used to construct them.[106] Under the 3 percent social discount rate, the analysis assumes a social cost of GHG emissions based on a 2.5 percent discount rate, and the 7 percent social discount rate assumes a social cost of GHG emissions based on a 3 percent discount rate. The discount rates referenced in this section refer to the social discount rate applied to non-GHG cost streams. Unless otherwise noted, the compliance simulation portion of the analysis is limited to all model years up to 2029. This is an effort to capture any residual product line adjustments manufacturers make on existing redesign schedules. That is, stringency levels mandated in 2026 may have effects on model offerings out to 2029 as related product refresh and redesign activities conclude.

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

6.2 Summary of Benefits and Costs

To assess the effect of the considered regulatory alternatives, NHTSA aggregates outputs of the CAFE Model and compares the resulting cost and benefit values for each proposed alternative to those of the no-action alternative. Figure 6-1 reports the outcome of this calculation for model years 1981[107] through 2029 at both a 3 and 7 percent social discount rate. Costs and benefits

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[105] 49 U.S.C. 32902(h).

[106] These rates are selected in accordance with guidance from the IWG on the Social Cost of Greenhouse Gases, as discussed in Chapter 4.7 of this PRIA.

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

increase across alternatives, corresponding with increased stringency. Relative to the baseline, program net benefits are positive for Alternatives 1 and 2 at a three percent discount rate. Alternative 1 also produces positive benefits at the seven percent discount rate.

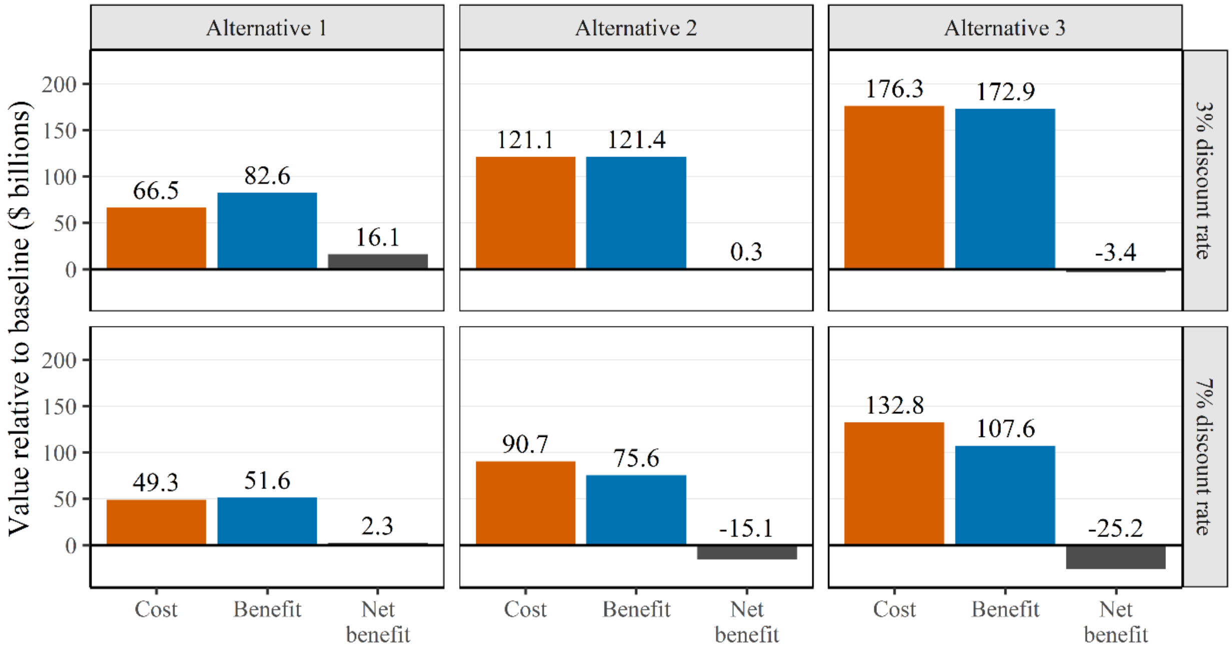

Figure 6-1 – Costs and Benefits for Overall Vehicle Fleet, MY 1981-2029

Chapter 6.5 outlines the main categories of costs and benefits aggregated to produce Figure 6-1. The largest component of these estimated costs is the technology cost that manufacturers pay to improve fleet fuel economy and meet the CAFE targets under each alternative. Reductions in fuel costs for consumers who purchase more fuel-efficient vehicles is the largest benefit component. We turn next to modeled manufacturer compliance and technology application before exploring consumer-side impacts and overall social costs and benefits.

6.3 Effects on Vehicle Manufacturers

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

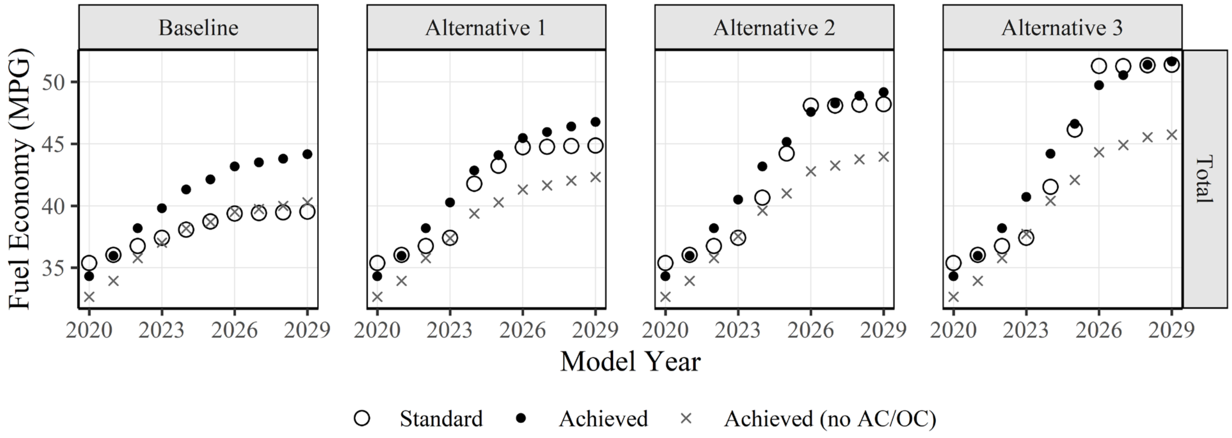

Figure 6-2 – Fleet Modeled Fuel Economy

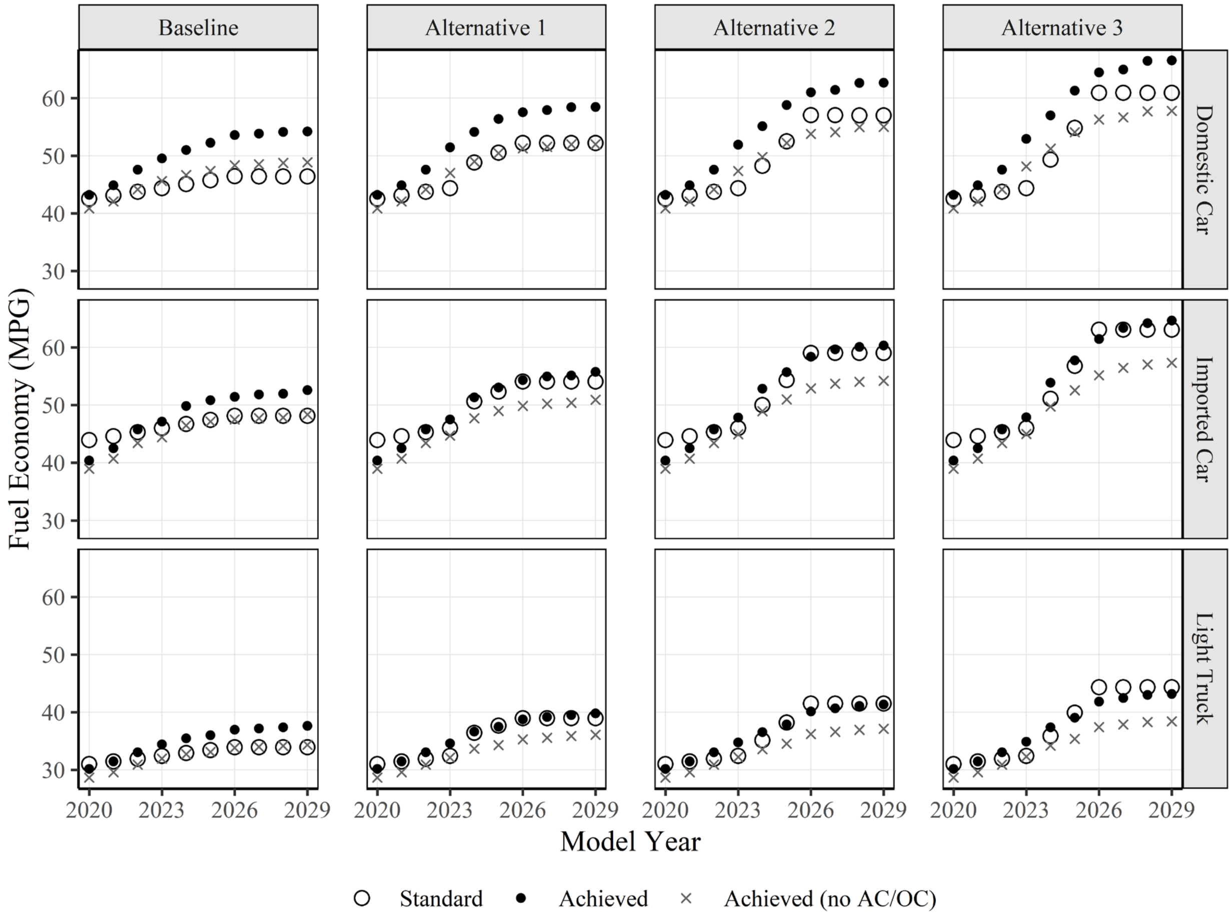

Figure 6-3 – Fleet Modeled Fuel Economy by Regulatory Class

Figure 6-4 presents manufacturer-level differences between achieved and required fuel economy levels on a fleet-wide basis. Lighter colored shading represents manufacturer-years with small, estimated deviations between standards and achieved efficiency levels. Regions shaded blue indicate manufacturer fleets that are more efficient than required and those shaded red fall short of their compliance thresholds.[108] By statute, the CAFE program allows manufacturers to fall short of their compliance obligations in a given model year, though the difference must be made up through the use of compliance credits or civil penalty payments, as discussed in Section VII of the NPRM. The vertical line in the figure indicates the start of model year 2024, the first period of the proposed standards.

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

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[108] Figure 6-4 and Figure 6-5 exclude Tesla and Ford's import car fleet, as both far exceeded standards—Ford due to a limited number of vehicles in the segment and Tesla due to their BEV-only fleet.

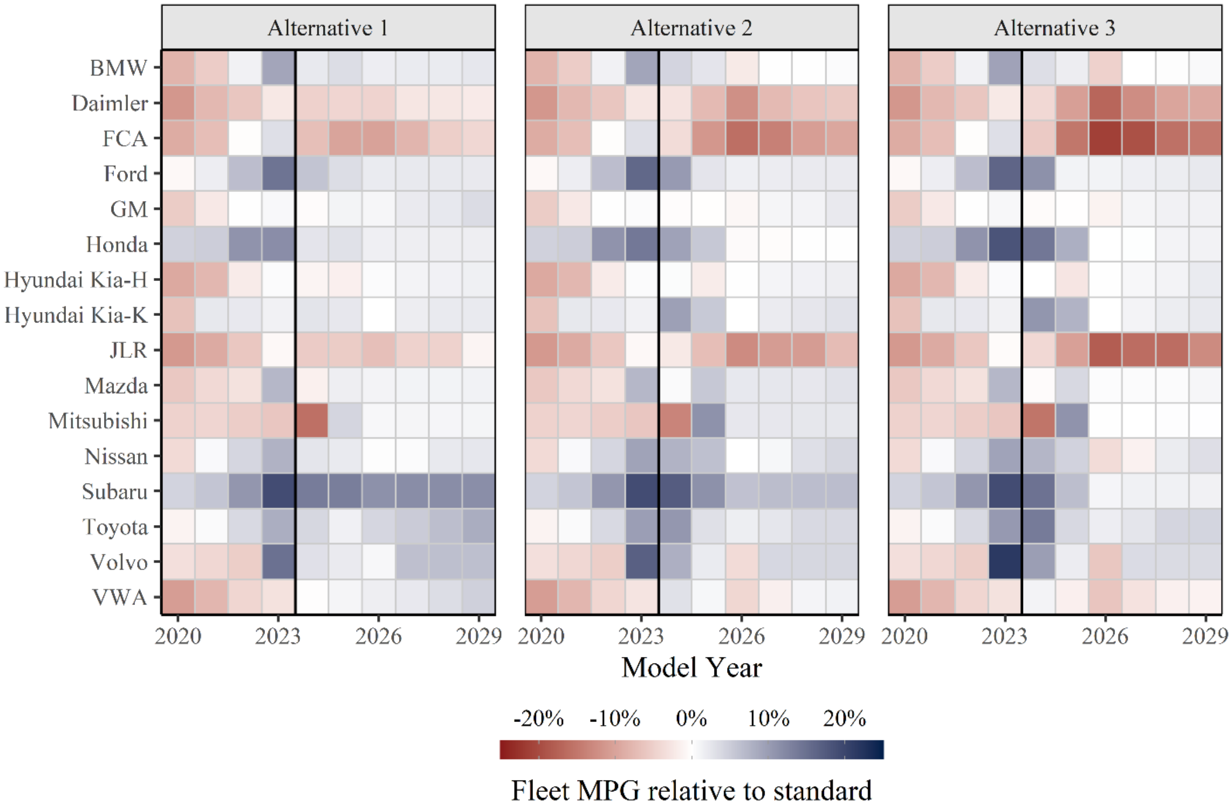

Figure 6-4 – Modeled Fleet-wide Achieved CAFE by Manufacturer

Within manufacturer fleets, there is heterogeneity in modeled response by regulatory class. Figure 6-5 separates achieved fuel economy levels by manufacturer and fleet. Each individual panel represents a manufacturer's achieved fuel economy levels relative to the standard within a regulatory class. Gray cells indicate a manufacturer has little or no presence in a given regulatory class. Examining results across columns in the figure illustrates that some manufacturers achieve vastly different levels of compliance with standards. FCA, for instance, produces an imported car fleet that exceeds its required standards, but does not meet required levels in the light truck or domestic car fleet. Similarly, Volvo offers relatively high fuel economy in its light truck fleet but falls below its standard for its imported and domestic car fleets. Toyota, Honda, and Nissan indicate generally consistent performance across regulatory classes and stringency alternatives, though Toyota and Nissan see efficiency levels drop slightly below standards in the higher stringency alternatives in MY 2026. Manufacturers generally meet efficiency standards by MY 2029. The exceptions to this are Daimler and FCA in the light truck fleet and JLR in both imported cars and light trucks. This result is consistent across the regulatory alternatives.

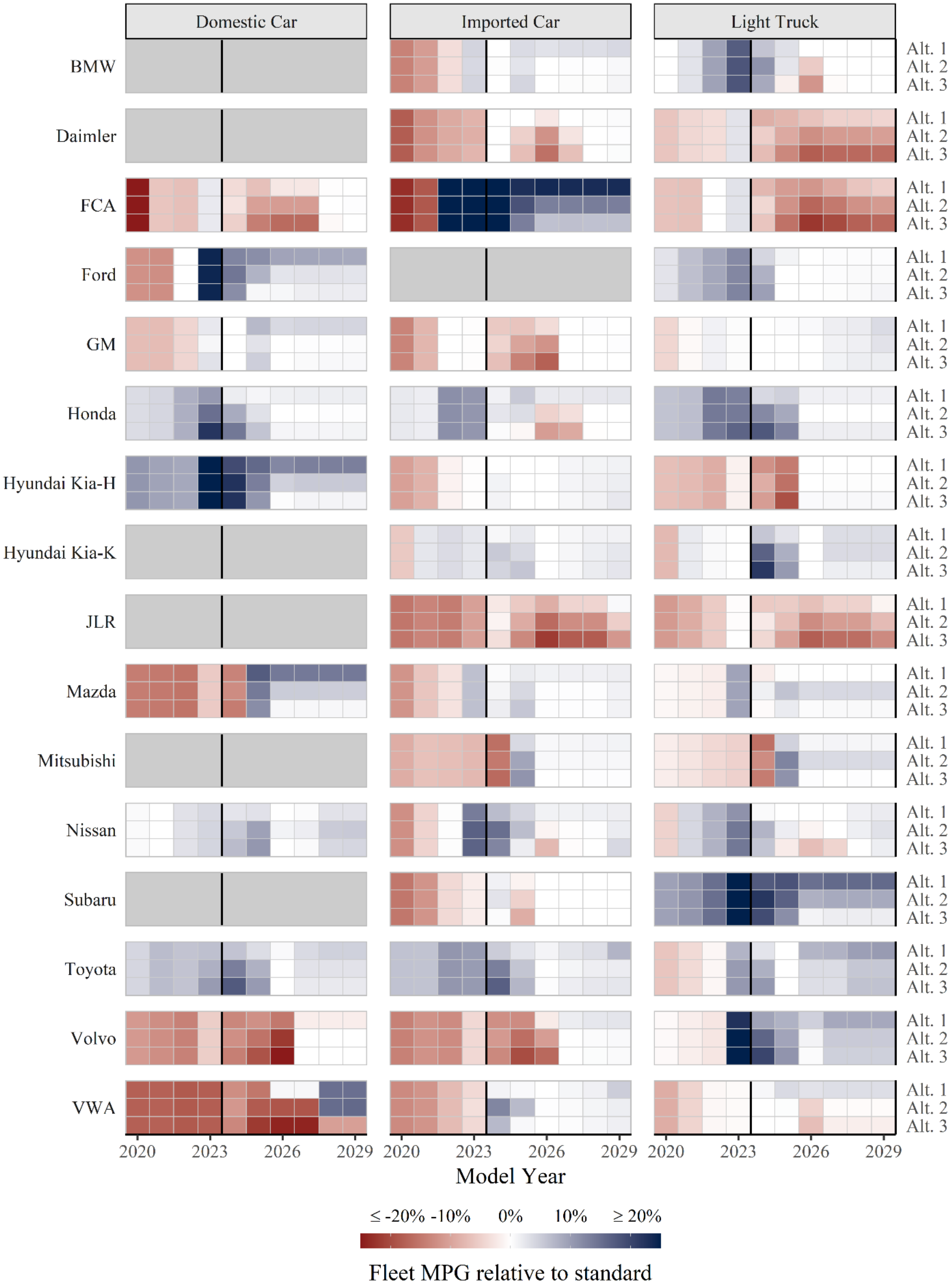

Figure 6-5 – Modeled Achieved CAFE Levels by Manufacturer and Regulatory Class

6.3.1 Technology Application

To meet the required CAFE levels under each regulatory alternative, the CAFE Model simulates compliance in part by applying various technologies to vehicle models in a given manufacturer's regulated fleet. As shown in Figure 6-6, the majority of this technology application occurs for model years 2021 through 2026 in the regulatory alternatives. Technology application in model years 2021 and 2022 is nearly identical to the no-action alternative in all alternative scenarios. The action alternatives estimate more technology application in most years beyond MY 2022 with a few exceptions (MY 2029 and MY 2034). At these points, some technologies are inexpensive enough that application is economical even in the absence of binding CAFE standards.

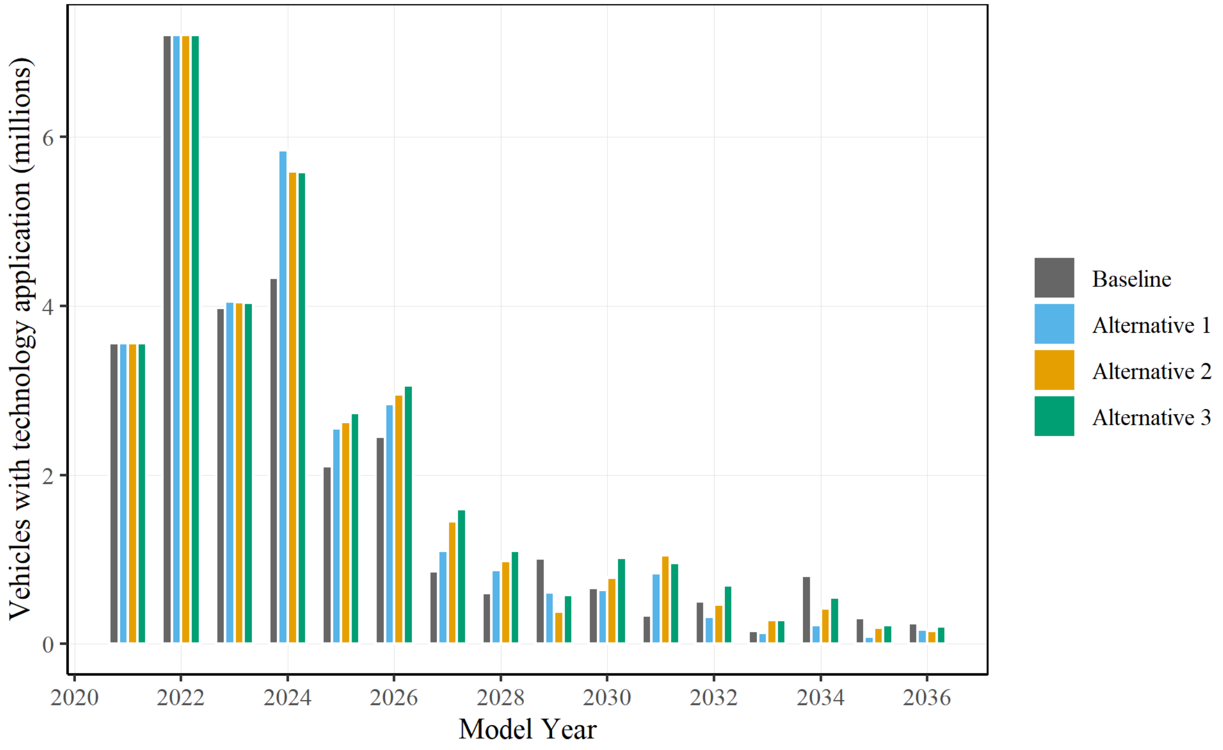

Figure 6-6 – Timing of Technology Application in Response to Regulatory Alternatives

Figure 6-7 through Figure 6-10 present the resulting industry-wide technology penetration rates. Each horizontal line segment in the figure represents the change in technology penetration between 2020 (represented by a short vertical line segment) and 2029 (represented by a circle). Arrows indicate the direction of the change and line colors represent the proposed alternative. Between 2020 and 2029, CAFE Model estimates reveal a number of trends, including:

Engine technology (Figure 6-7):

- Basic engine technology (including VVT, VVL, SGDI, and SDGI) decreases significantly between the base 2020 fleet and MY 2029 across all alternatives.

Penetration rates of these technologies decline slightly more in Alternatives 2 and 3 than Alternative 1.

- Engine advancements including Turbo, HCR, and other advanced gas technologies (VCR, VTG, and VTGE) all increase between MY 2020 and MY 2029 in each of the proposed alternatives.

- Turbo engines are slightly less common in MY 2029 vehicles for Alternatives 2 and 3 than they are in the baseline and Alternative 1.

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

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

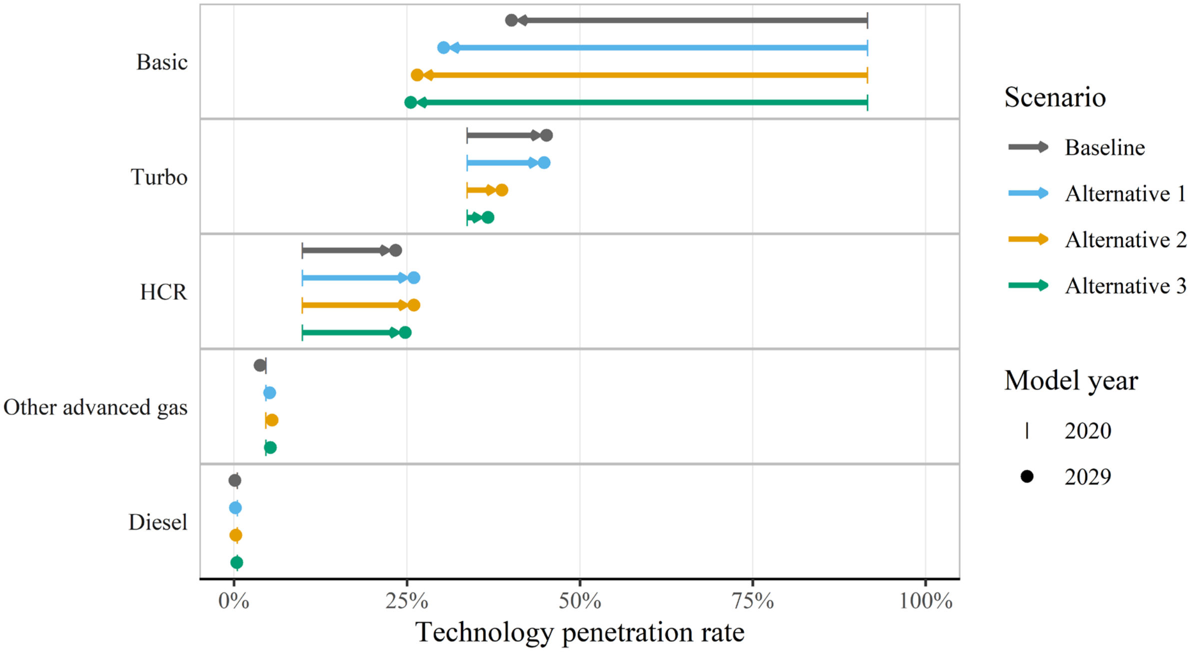

Figure 6-7 – Prevalence of Engine Technology in the Fleet Under Different Regulatory Alternatives

Transmission technology (Figure 6-8):

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

- The most significant difference in transmission choices across alternatives is the prevalence of 8-speed transmissions. All three proposed alternatives see 8-speed automatic transmission penetration rates drop into the single digits by 2029, while the baseline remains at approximately 20 percent.

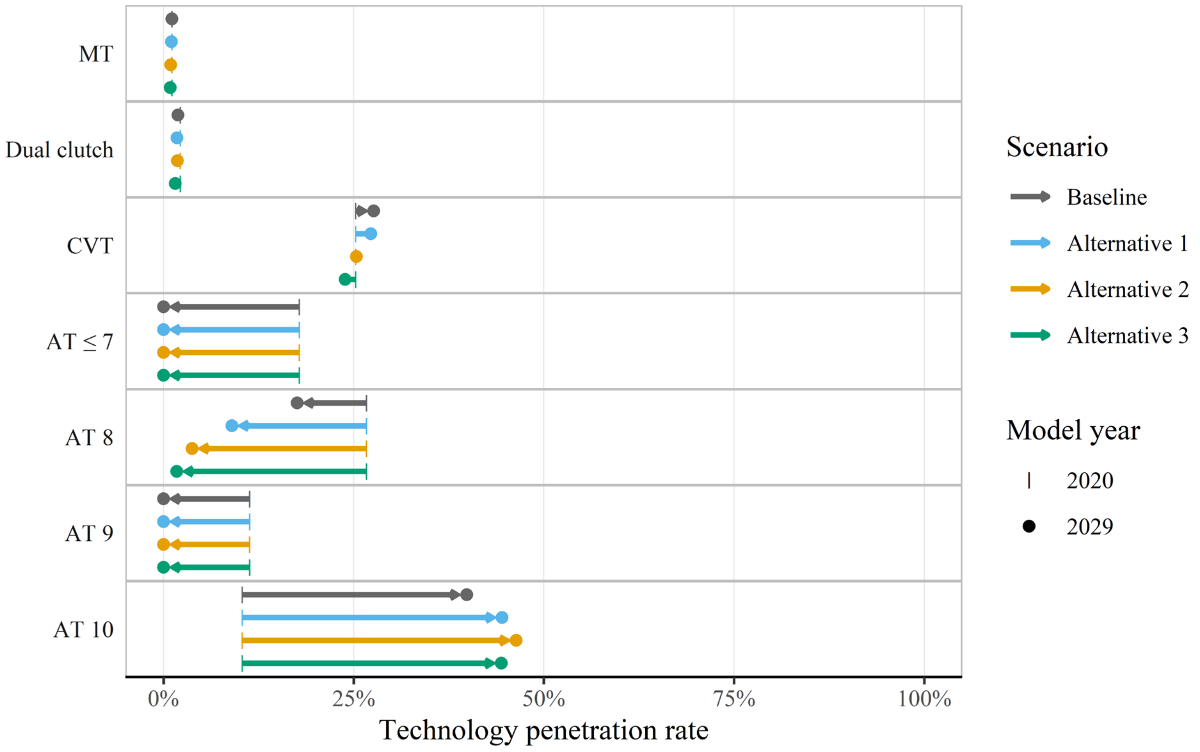

Figure 6-8 – Prevalence of Transmission Technology in the Fleet Under Different Regulatory Alternatives

Powertrain technology (Figure 6-9):

- Conventional powertrains decrease across all scenarios, and to greater degrees than in the baseline case. Application of alternative powertrain technology similarly increases as alternative stringency increases.
- In all scenarios, the use of stop-start technology declines and is replaced with either integrated starter generator or various hybrid or BEV technologies.
- More stringent alternatives, especially alternatives 2 and 3, see higher application rates of PHEV and BEV powertrains.
- BEV powertrains above a 300-mile range and fuel-cell vehicle technology see limited application out to 2029, although this is due to statutory restrictions on considering the fuel economy of dedicated alternative fueled vehicles.

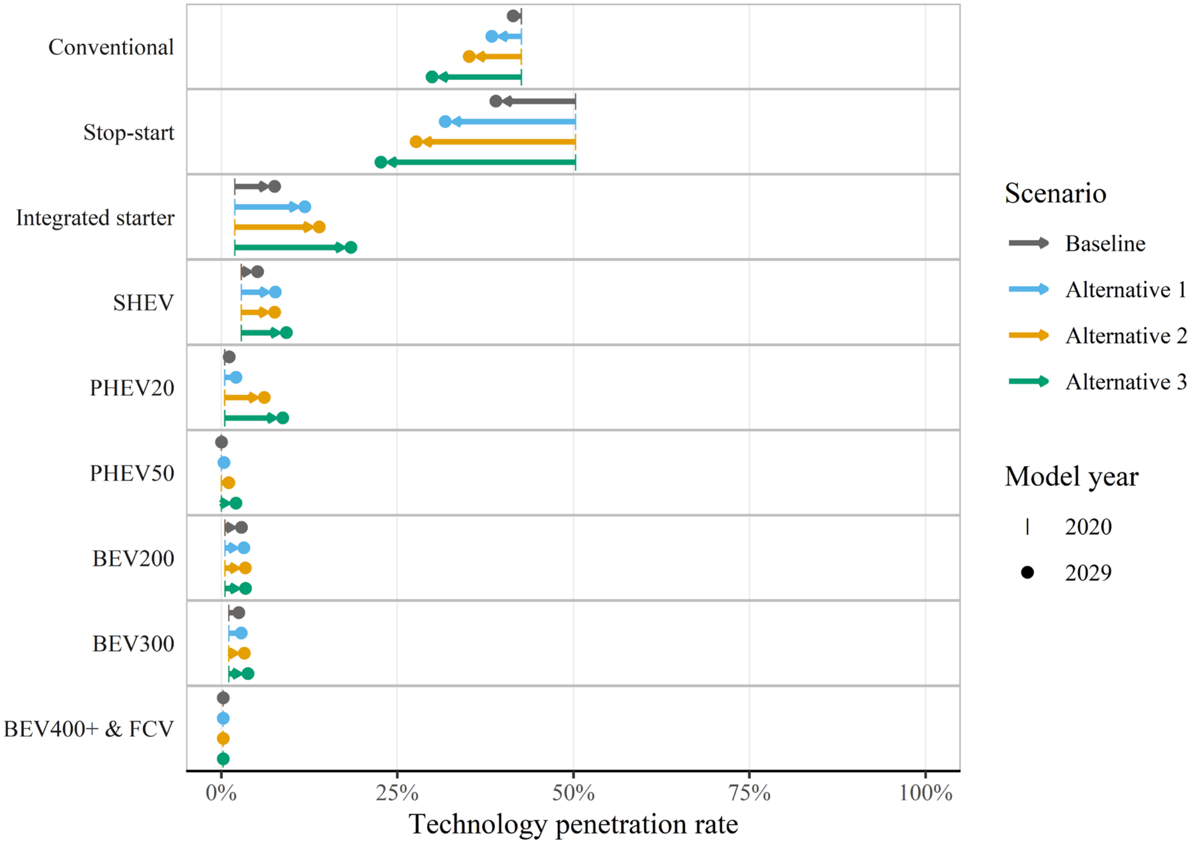

Figure 6-9 – Prevalence of Powertrain Technology in the Fleet Under Different Regulatory Alternatives

Tire rolling resistance, aerodynamics, and mass reduction technologies (Figure 6-10):

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

- Higher stringency alternatives rely on more aggressive aerodynamic improvements than the no-action alternative does. Alternatives 2 and 3 employ 20 percent aero reductions at much higher rates (e.g., Alternative 3 has a technology penetration rate approximately 20 percentage points higher than that of Alternative 1).

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

- Mass reduction greater than 20 percent is applied sparingly in all scenarios, due in part to modeled cost parameters and limits imposed on application due to feasibility concerns.

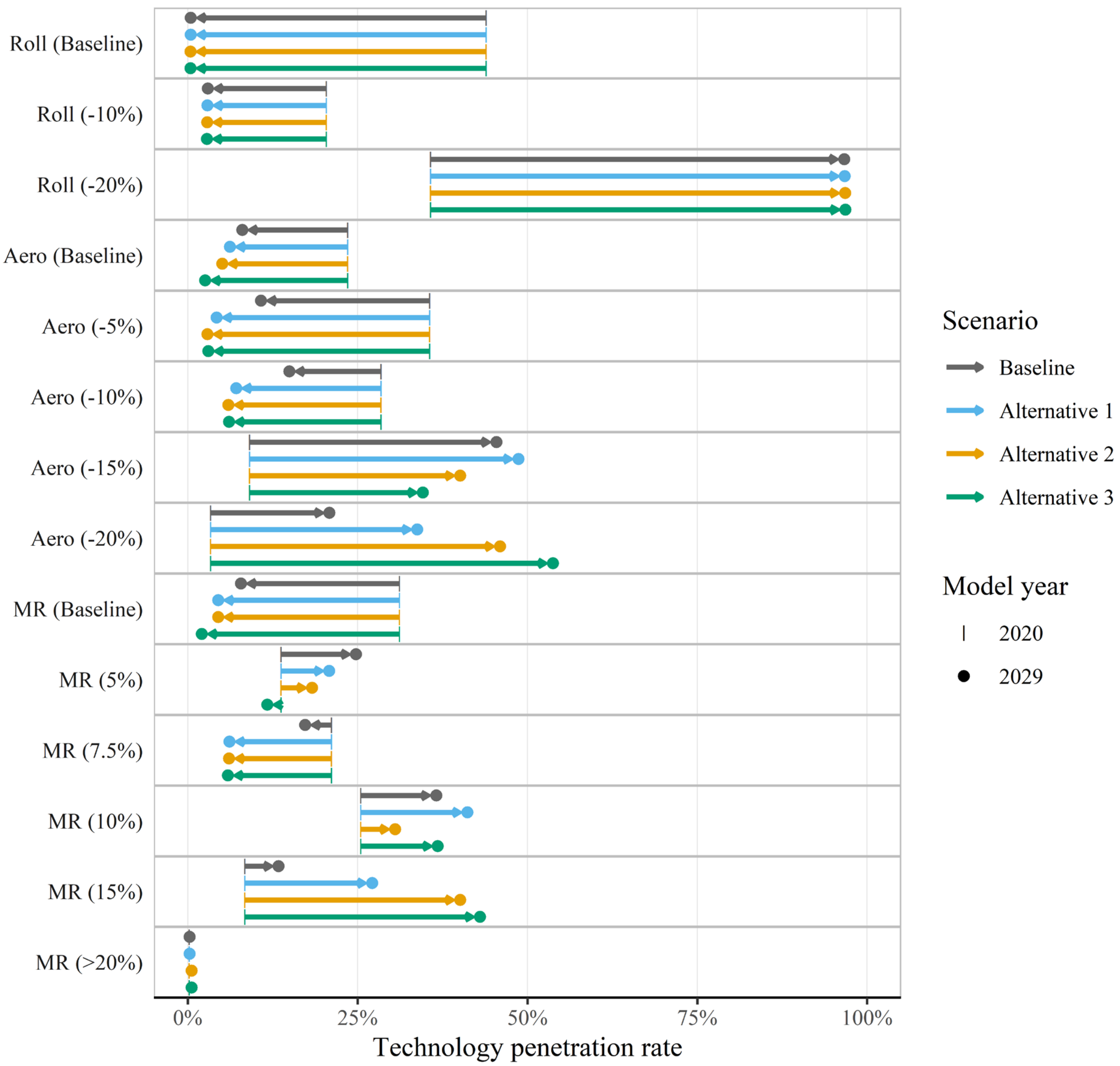

Figure 6-10 – Prevalence of Tire Rolling Resistance, Aerodynamics, and Mass Reduction Technologies in the Fleet Under Different Regulatory Alternatives

6.3.2 Compliance Costs

Manufacturers comply with CAFE regulations by applying fuel-economy-improving technologies, or use over-compliance credits (whether earned or purchased), or pay civil penalties for non-compliance. The CAFE Model computes both aggregate and per-vehicle values of these costs. Model outputs report regulatory costs—the combination of technology costs and total civil penalties across all regulatory classes—and technology costs alone. Technology costs are a major component of regulatory costs. Figure 6-11 reports industry-wide, model year trends in per-vehicle technology costs.

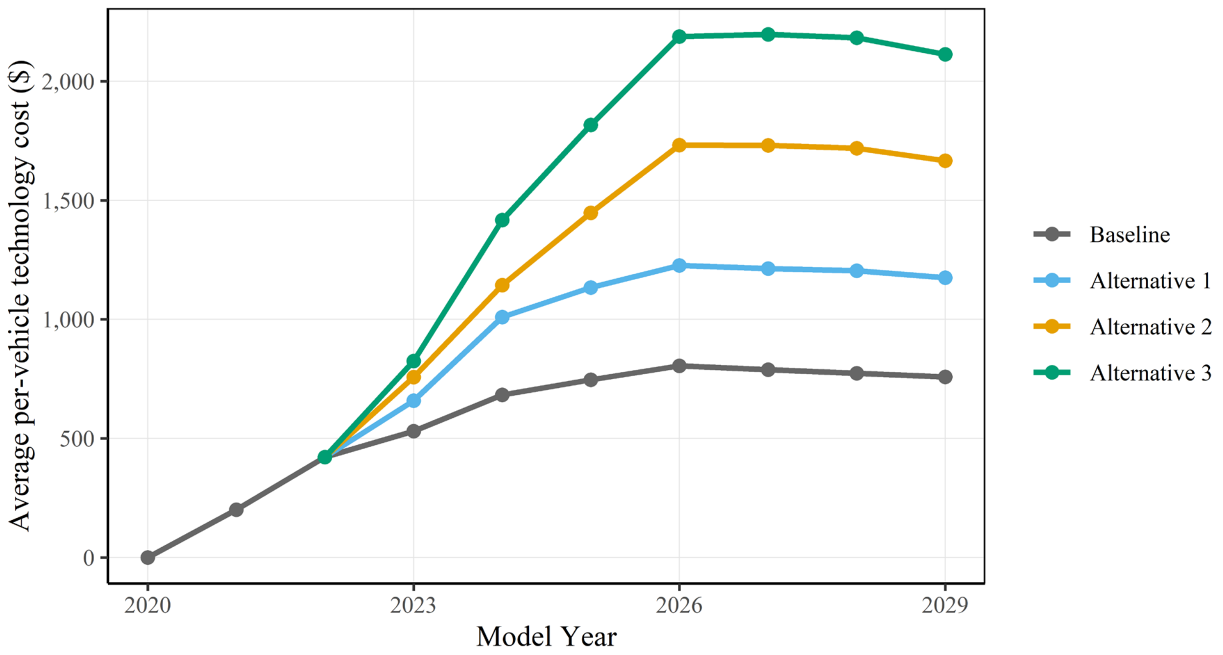

Figure 6-11 – Average Per-vehicle Technology Cost

Per-vehicle technology costs vary widely by manufacturer and across alternatives due in part to estimated technology application choices. Additionally, NHTSA cannot model compliance via electric powertrains, as it is statutorily prohibited from doing so. In the case that electrification is less costly than alternative technology options, modeled technology costs may overstate actual costs. This affects both technology cost levels and the resulting margin between benefits and costs; this margin may be lower than in the absence of NHTSA's statutory restriction.

Figure 6-12 presents baseline per-vehicle technology costs for a model year 2029 vehicle. Gray bars in the figure are costs in the No-Action alternative. Total No-Action alternative costs are listed in the data labels in the "baseline" panel. The portions of the bar in color represent the changes in manufacturer technology costs for each action alternative. For example, average per-vehicle technology costs for VWA in the No-Action alternative are $2,020. Under Alternative 1, these costs decrease by $50 per vehicle to $1,970.[109] Under Alternative 2, technology costs increase by $90 to $2,110. Manufacturers including Honda, BMW, Nissan, and Ford substantially increase per-vehicle technology costs between Alternative 1 and Alternative 2. Relative to the No-Action alternative, Alternative 1 represents an average industry-wide increase in per-vehicle technology costs of $420—an increase of 55%. Technology costs increase by $910 per vehicle in Alternative 2 (120% over the No-Action alternative) and $1,350 per vehicle in Alternative 3 (a 178% increase).

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[109] This is a rare instance where a stringency increase produces a technology cost reduction. Note that this means costs are reduced on average, across the full fleet of VWA vehicles. This particular change is the result of decreased application of HEV technology in Alternative 1 compared to the No-Action alternative. For detail, see Figure 6-16 later in this section.

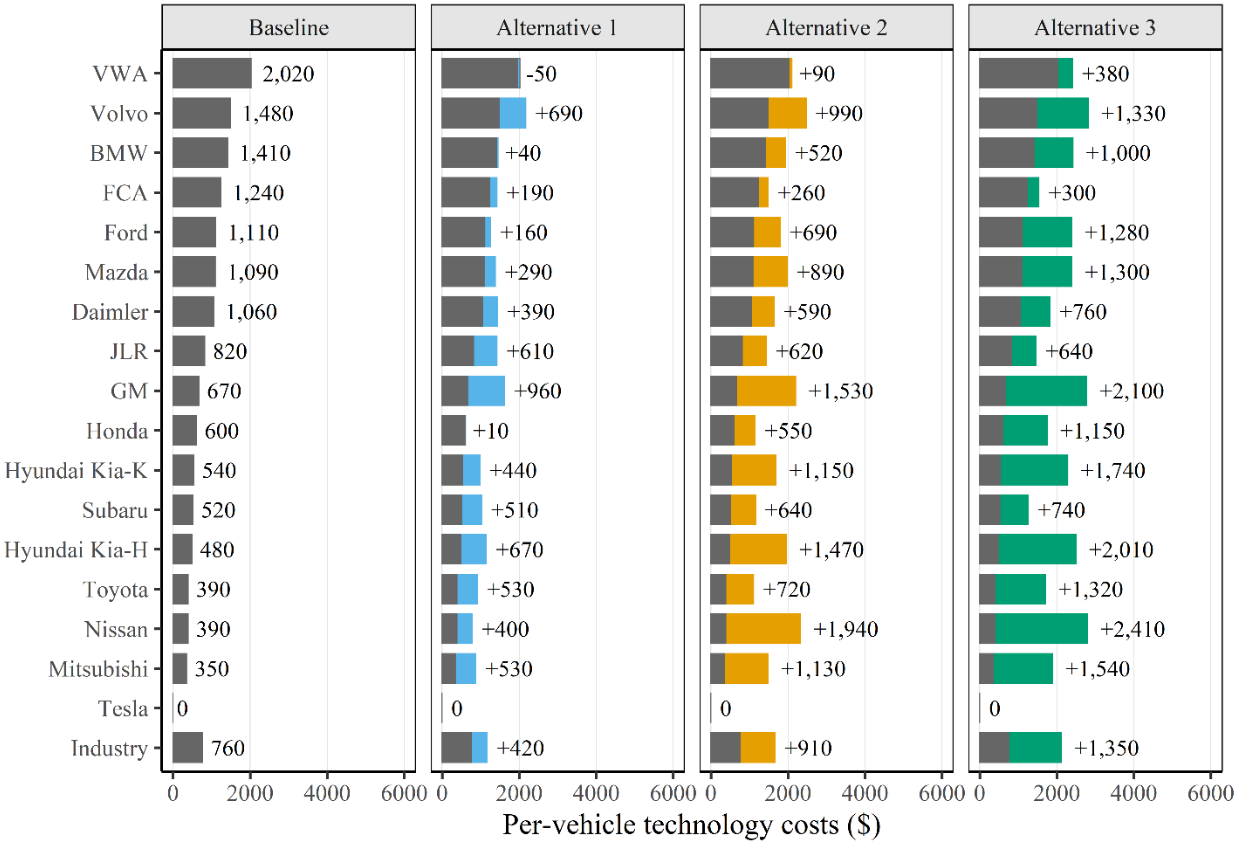

Figure 6-12 – Per-vehicle Technology Cost, MY 2029 Vehicle

Figure 6-13 reports total technology costs for model years 2020 through 2029 in the No-Action alternative alongside labeled aggregate technology cost increases for each action alternative. In most cases, differences in manufacturer rankings between Figure 6-12 and Figure 6-13 are the result of production-scale variation (e.g., GM's large production volumes means it has the third largest total technology cost even though GM's average per-vehicle costs place it in the middle of the manufacturer ranking in Figure 6-12). However, in a few instances differences in technology application play a significant role in determining aggregate manufacturer costs. This causes a portion of the estimated increases in cost between Alternative 1 and the higher stringency alternatives and can be seen by examining cost changes attributed to particular technologies.

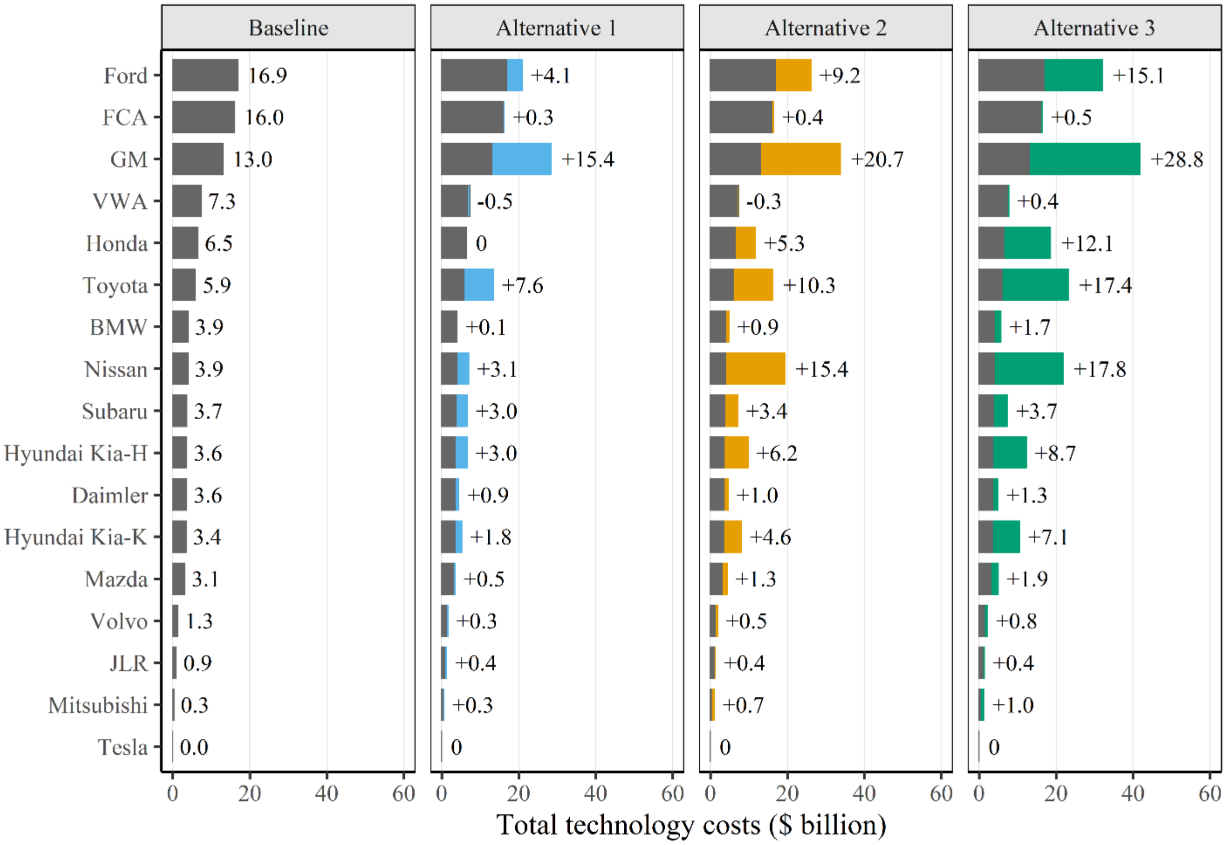

Figure 6-13 – Technology Costs by Manufacturer, MY 2020 – 2029

At an industry level, approximately half of all technology cost expenditure comes from powertrain electrification or mass reduction. Figure 6-14 presents these technology categories as a percent of total technology application cost within each modeled scenario. Across alternatives, aggregate costs attributable to the application of PHEV technology increase significantly. Alternatives 2 and 3 see more application of high-level mass reduction (e.g., MR6). On a per-vehicle basis, costs of applied PHEV technology increase by nearly a factor of 5—from $160 to $780—between Alternatives 1 and 3 (Figure 6-15), while per-vehicle BEV costs increase by 30 percent. Readers should note that across alternatives, input cost values do not change (e.g., PHEV application costs the same regardless of CAFE stringency), so these per-vehicle cost increases are due to greater reliance on the technology for compliance.

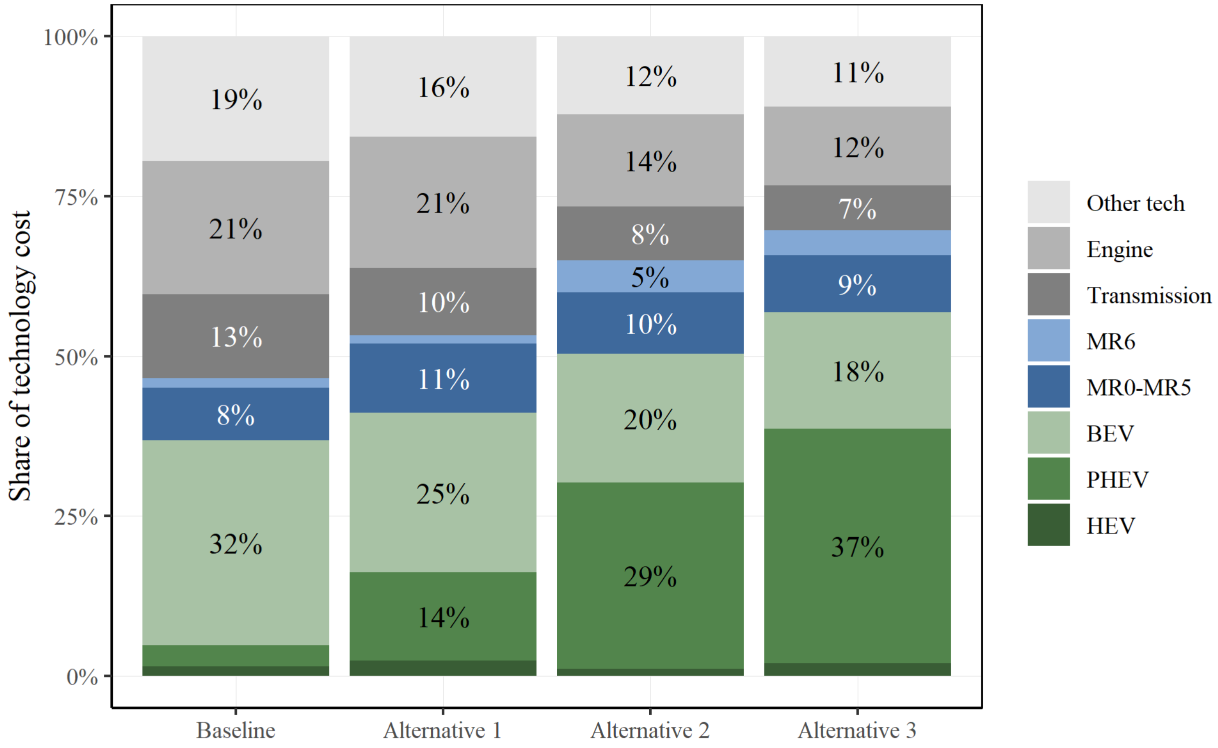

Figure 6-14 – Applied Technology Cost for Selected Technologies (MY 2029)

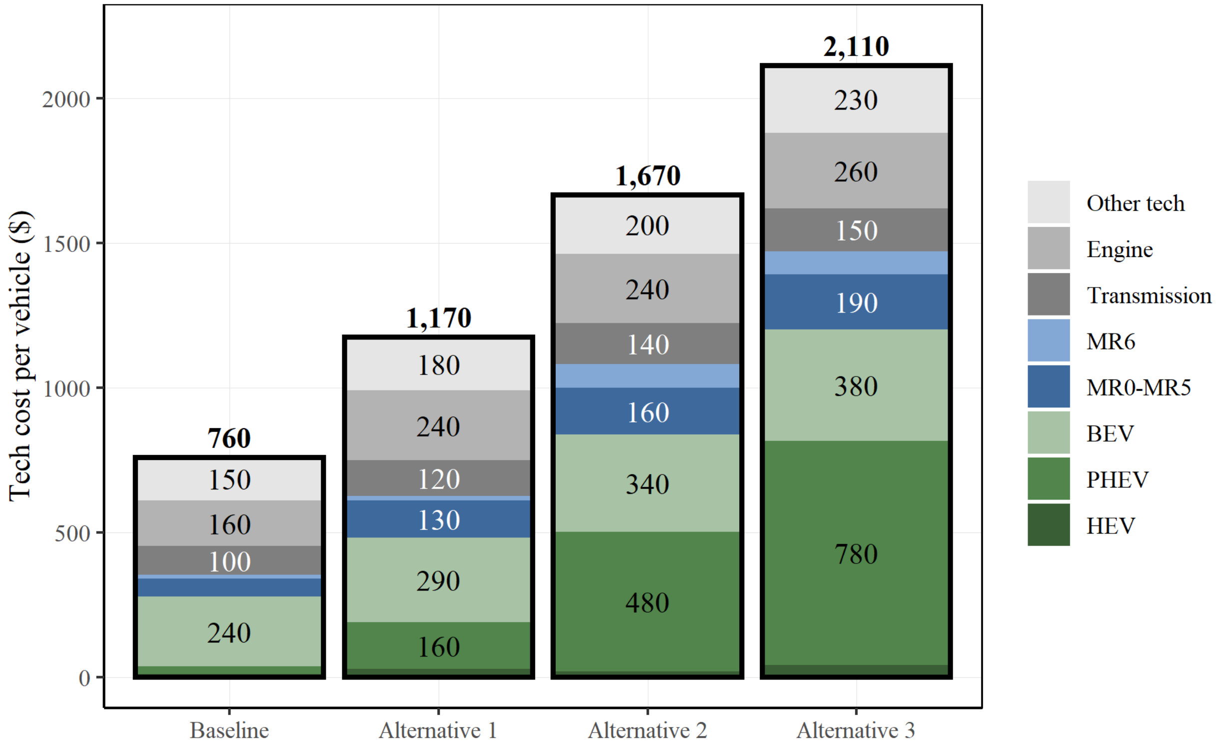

Figure 6-15 – Per-vehicle Technology Cost by Technology Category (MY 2029)

Manufacturers that rely on these advanced technology options to meet program compliance goals have a higher per-vehicle technology cost burden during the rulemaking timeframe. Figure 6-16 illustrates the relationship between these technology choices and per-vehicle technology costs by manufacturer. It highlights the technology application behavior that drives differences in per-vehicle cost across manufacturer and alternative presented in Figure 6-12.[110] In most instances, these estimated cost increases are associated with plug-in vehicle technology costs. For example, BMW, GM, Honda, Hyundai, and Kia all see a large cost increase from PHEV technology from the baseline and Alternative 1 to Alternatives 2 and 3. Mazda, Nissan, and Volvo all choose to apply MR6 to meet compliance limits, with a notably large jump in MR6 for Nissan in Alternatives 2 and 3. The levels of mass reduction that these manufacturers are applying in MY 2029 is likely a consequence of the modeling restrictions intended to reflect statutory restrictions. Because the model limits application of BEV technology and these manufacturers are constrained in their credit use and civil penalty payment in the "standard setting" runs, manufacturers instead apply MR6. In practice, achieving weight reductions consistent with MR6 nearly always requires a vehicle's primary structure be wholly made from carbon fiber reinforced plastics (CFRP). The current state of the art in this regard is a CFRP monocoque structure where all exterior and interior surfaces are structural. Such primary structures have been successful at mass reduction in the upper echelons of Formula and LeMans racing cars, but have found only sparse application thus far in passenger vehicles. Besides the

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

BMW i3, in the 2020 fleet, CFRP primary structure exists only in the highest strata of quasi-racing car passenger vehicles. Monocoque structures made from CFRP cost in the tens of thousands of dollars alone. It is currently difficult to foresee how their application in cars or trucks with retail prices at roughly the same amount would lead to a positive business case. Moreover, the supply base in this area is quite limited and for a car manufacturer to build in-house capability would require billions of dollars and decades of sustained commitment. If fuel savings is the aim, such effort and expense on the part of OEMs could perhaps be better spent on developing electric powertrains. And while the NPRM analysis is restricted in ways that prohibit the consideration of electric powertrains as a compliance strategy during action years (MYs 2024-2026), the analysis that supports the EIS is not. In those simulations, the same manufacturers that apply MR6 in the figure (with the exception of Mazda, who still applies MR6 but in smaller volumes) opt instead to produce additional electric vehicles.

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

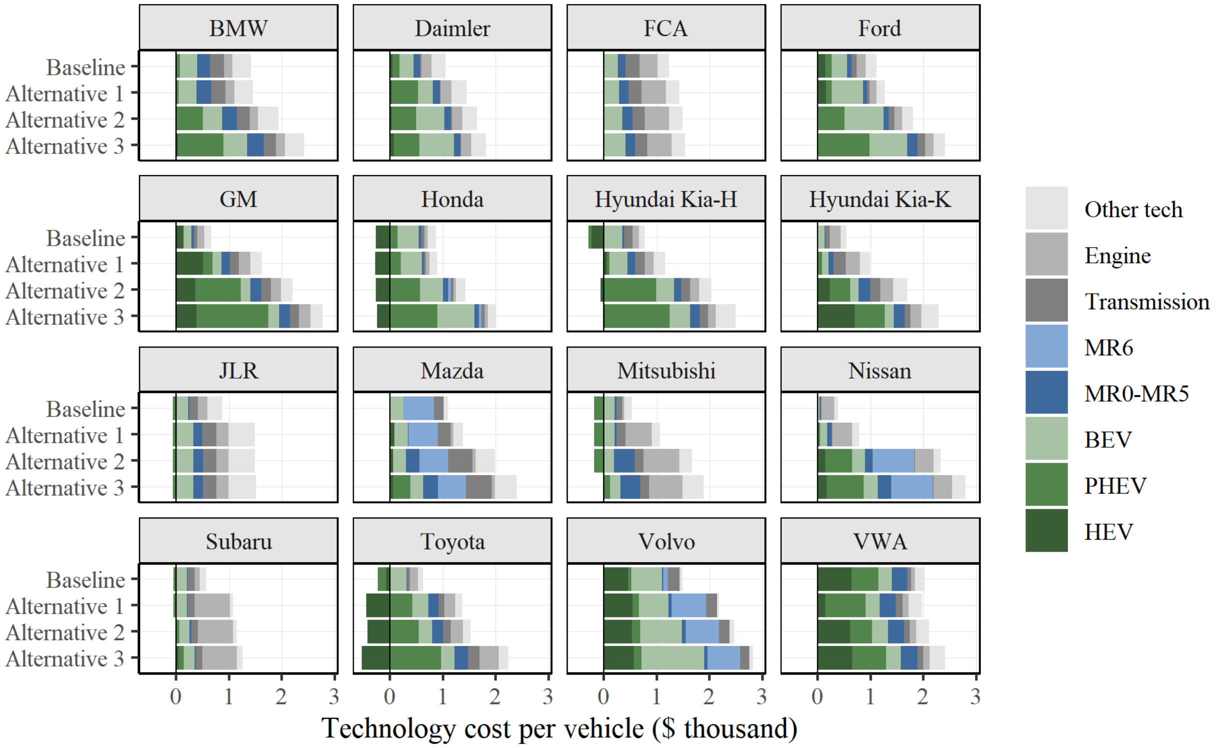

Figure 6-16 – Per-vehicle Technology Cost by Manufacturer (MY 2029)[111]

6.3.3 Sales and Employment Impacts

As manufacturers modify their vehicle offerings and utilize fuel-efficient technologies in response to CAFE standards, vehicle costs increase. The analysis assumes that these cost increases are passed on to consumers and higher retail prices decrease vehicle sales. Because each of the action alternatives leads to technology costs above those of the no-action baseline, sales decline more in each alternative than in the No-Action alternative. Figure 6-17 illustrates the magnitude of this effect. For context, sales in the proposed alternative in MY 2029 are 2 percent lower than those in the No-Action alternative. Readers should note that the steep increase in total sales, across all the alternatives, between MY 2020 and MY 2023 represents a recovery from the sales shock caused by the pandemic.

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[111] In some cases, costs to apply a technology may be negative. In these instances, the aggregate cost of a new technology is less than the current cost of the existing technology. For example, moving to BEV200 from a PHEV may reduce cost if removing the cost of the engine is greater than the cost of increasing the battery capacity.

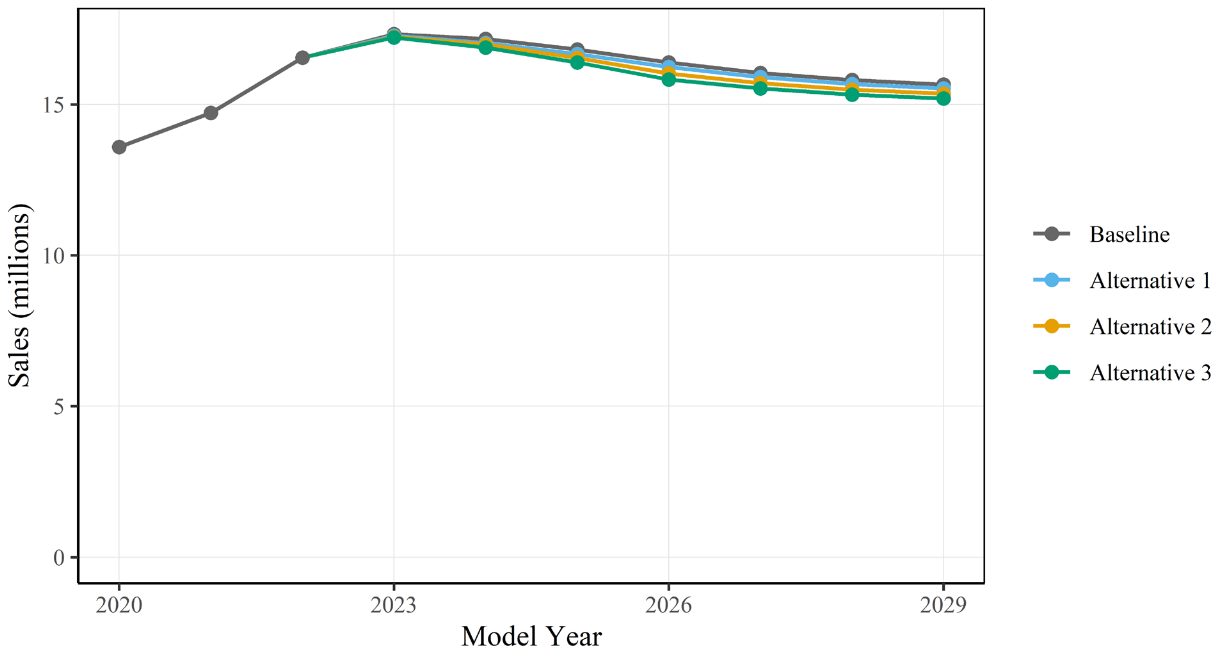

Figure 6-17 – Industry-wide Sales

When fewer vehicles are sold, manufacturers require fewer labor hours to satisfy demand. Hence, the decline in sales shown in Figure 6-17 reduces industry-wide labor hours. However, development and deployment of new fuel-efficient technologies increases demand for labor. Overall estimated CAFE program impacts on employment utilization depend on the relative magnitude of these two forces. Table 6-1 reports total employment utilization in full-time equivalent job units (i.e., the number of individuals working a full-time position that are required to meet new vehicle demand). Chapter 6.2.5 of the Technical Support Document offers further detail on this measure and how it is calculated. In the No-Action alternative, sales declines drive reductions in labor utilization beyond MY 2023. In each of the action alternatives, labor utilization initially decreases in amounts greater than the baseline. These early declines are temporary, however. By MY 2028, labor utilization in the action alternatives declines by less than in the No-Action alterative. This trend in labor effects indicates sales effects outweigh technology effects in the initial compliance period, but technology effects ultimately result in higher labor utilization than in the baseline case beyond MY 2027.

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

Model Year	Baseline	Difference from Baseline		
		Alt. 1	Alt. 2	Alt. 3
2020	942,950	0	0	0
2021	1,026,017	0	0	0
2022	1,158,854	0	0	0
2023	1,214,635	-943	-2,871	-2,131
2024	1,206,772	-571	-2,087	-327
2025	1,184,899	493	-2,575	-1,613
2026	1,156,206	1,108	-2,623	-2,890
2027	1,130,705	2,432	-32	661
2028	1,112,697	3,076	1,590	2,780
2029	1,100,689	3,440	2,228	3,533

6.3.4 Manufacturer Effects Under Differing Assumptions

Each of the estimated effects above relies on numerous modeling assumptions. Table 6-2 through Table 6-5 report key output values for a set of additional model runs. To explore the relative influence of these assumptions, these runs vary the values of key input parameters. For the purposes of this chapter, inputs of interest include technology costs (specifically, battery costs), assumed payback period, and oil prices. A comprehensive list of alternative assumptions and selected impact measures is presented in Chapter 7.

Each of the tables presents technology penetration rates in the full vehicle fleet for MY 2029. There are three topline metrics to compare across scenarios. First, differences in technology penetration levels in the no-action alternative (the “Baseline” column). This represents estimated differences in the MY 2029 fleet due to input assumption variation and not a change in program stringency. Second, how the simulated fleet appears under the proposed alternative in each scenario (the “Alt. 2” column). And third, the difference between the no-action alternative and the preferred alternative, indicating the percentage point increase resulting from new fuel economy standards (the “Diff.” column).

For example, in the case of hybridization and electrification, baseline results in Table 6-2 indicate that BEVs make up 5.6 percent of the MY 2029 vehicle fleet in the reference case. This value increases to 6.4 percent in a regime where battery direct costs are 20 percent lower than reference levels. Hence, under the no-action alternative, lower battery costs lead to more BEVs. As expected, a similar story holds for lower battery learning costs and high oil prices. The impact direction is reversed for low oil prices and high battery technology costs.

Under the proposed alternative, BEV penetration rates increase from 7 percent to 8.4 percent under lower battery direct cost assumptions, 7.2 percent under lower battery learning costs, and 7.8 percent in the high oil price case. Again, lower battery costs and higher oil prices lead to a higher portion of BEVs. After accounting for differing baseline penetration levels, the proposed alternative produces an increase in BEV share of one to two percentage points over baseline levels. This value is stable across selected scenarios.

Across hybridization and electrification technologies, oil and battery price assumptions produce relatively similar estimates of the proposed policy's effect. Two notable deviations are i) lower battery cost assumptions and SHEV penetration, and ii) SHEV and PHEV technology penetration under the expanded 60-month payback period. SHEV application is more economical under longer payback periods as SHEVs represent smaller incremental fuel savings over prior steps on the hybrid/electrification pathway, but also smaller incremental technology costs. Smaller incremental fuel savings require longer payback periods to recoup the incurred cost. To meet standards set in Alternative 2, manufacturers are therefore more likely to choose a broader application of SHEVs and reduce the number of PHEVs offered.

Values in the tables in this section may not add up perfectly due to rounding.

Table 6-2 – Technology Penetration Rates Under Selected Scenarios, Hybrid/Electrification Pathway, MY 2029

	SHEV			PHEV			BEV		
	Baseline	**Alt. 2**	**Diff.**	**Baseline**	**Alt. 2**	**Diff.**	**Baseline**	**Alt. 2**	**Diff.**
Reference case	5.2%	7.6%	2.4	1.2%	7.2%	6.0	5.6%	7.0%	1.4
60-month payback	5.6%	12.4%	6.8	0.3%	3.2%	2.9	6.0%	7.1%	1.1
Oil price (EIA low)	5.0%	7.5%	2.4	1.3%	7.5%	6.2	4.7%	6.3%	1.6
Oil price (EIA high)	4.8%	7.9%	3.1	0.8%	6.0%	5.1	6.7%	7.8%	1.1
Battery direct costs (-20%)	4.4%	8.7%	4.3	0.9%	5.7%	4.8	6.4%	8.4%	2.0
Battery direct costs (+20%)	5.3%	6.7%	1.5	1.3%	7.4%	6.1	4.7%	5.9%	1.3
Battery learning costs (-20%)	4.7%	7.7%	3.0	1.1%	7.0%	6.0	6.0%	7.2%	1.3
Battery learning costs (+20%)	4.9%	7.2%	2.3	1.1%	7.3%	6.2	5.2%	6.4%	1.2

Table 6-3 – Technology Penetration Rates Under Selected Scenarios, Engine Pathways, MY 2029

	Basic			Turbo			HCR		
	Baseline	**Alt. 2**	**Diff.**	**Baseline**	**Alt. 2**	**Diff.**	**Baseline**	**Alt. 2**	**Diff.**
Reference case	40.1%	26.5%	-13.6	45.2%	38.7%	-6.5	23.4%	26.0%	2.6
60-month payback period	20.0%	15.6%	-4.4	47.0%	42.6%	-4.5	30.8%	29.6%	-1.2
Oil price (EIA low)	61.1%	28.8%	-32.3	38.4%	38.4%	-0.1	20.3%	25.4%	5.2
Oil price (EIA high)	19.6%	16.4%	-3.3	45.5%	40.8%	-4.7	30.3%	29.9%	-0.4
Battery direct costs (-20%)	40.9%	27.9%	-13.1	44.4%	39.3%	-5.1	23.0%	26.7%	3.7
Battery direct costs (+20%)	37.8%	24.3%	-13.6	46.1%	40.2%	-5.9	23.4%	25.9%	2.5
Battery learning costs (-20%)	37.1%	26.6%	-10.5	46.1%	38.7%	-7.4	23.4%	25.9%	2.6
Battery learning costs (+20%)	43.9%	24.0%	-19.9	44.1%	39.8%	-4.3	23.4%	26.0%	2.6

Results for the engine technology pathways in Table 6-3 indicate basic engine technology (VVT, VVL, SGDI, and DEAC) penetrations vary significantly across the selected scenarios. Differences in oil price assumptions produce the greatest deviation from the reference case. High oil prices result in baseline basic engine technologies in only 19.6 percent of MY 2029 vehicles. This increases to 61 percent under low oil prices. The role of Alternative 2 differs as well, producing a 32-percentage point decline in basic technologies under the low oil price assumptions and a decline of only 3.3 percentage points in the case of high oil prices. This is consistent with historical observation that has shown higher demand for fuel economy, and fuel-efficient technology, during periods of higher fuel prices.

Shifts to other engine advancements are not as large as the reductions in use of basic engine technologies. Turbo engines, for example, decline by roughly 5 percentage points under Alternative 2 relative to the baseline except in the case of low oil prices, where turbo application is essentially flat. The proposed alternative spurs increased application of HCR technology in the low single digits, with slightly higher penetration in the case of low oil prices. Under high oil price assumptions and longer payback periods, HCR engine application is flat or decreases slightly, though in both cases baseline levels of this technology are higher.

Changes to aerodynamics and mass reduction are generally constant for the selected scenarios with a few exceptions. As indicated in Table 6-4, high oil prices and longer paybacks produce larger declines in AERO (-15%), though both start at much higher baseline levels in both scenarios. Longer payback periods and higher battery costs result in larger declines in MR (10%), but these are offset by greater increases in application of MR (15%).

Table 6-5 presents the effect of different model input assumptions on other manufacturer-relevant metrics, including technology cost, sales, and employment. Input changes produce outcomes in the expected direction (e.g., higher battery and learning costs increase technology cost, higher GDP assumptions increase sales and jobs and vice versa). The largest difference in the effect of the preferred alternative on technology cost comes in the oil price scenarios. Where in the reference case the preferred alternative increases average technology costs per vehicle by 20 percent, the oil price scenarios see increases of 32 percent (low oil price) and 2 percent (high oil price). In a setting with high oil prices, manufacturers likely respond in the baseline and the fuel efficiency levels of Alternative 2 are not binding. The opposite occurs (i.e., Alternative 2 is binding) in the case of low oil prices, leading to a larger increase in technology costs. A longer payback period decreases technology cost under Alternative 2, though this comes from a much higher baseline at $935 per vehicle versus $759 in the reference case. The effect of the preferred alternative on sales and jobs is relatively stable across scenarios in Table 6-5. The largest differences arise in the case of a longer payback period and high oil price. Both instances see smaller reductions in sales and higher levels of technology application relative to the baseline. The scenarios that vary the sales-scrappage response also produce notable changes in modeled labor utilization. Here, technology application does not differ significantly from the reference case, but sales responses do. This outcome demonstrates the role that sales changes play in dictating labor effects.

Table 6-4 – Technology Penetration Rates Under Selected Scenarios, Aerodynamics and Mass Reduction Pathways, MY 2029

	Aero (-15%)			MR (10%)			MR (15%)		
	Baseline	Alt. 2	Diff.	Baseline	Alt. 2	Diff.	Baseline	Alt. 2	Diff.
Reference case	45.4%	40.1%	-5.3	36.6%	30.5%	-6.1	13.4%	40.1%	26.8
60-month payback period	63.1%	39.1%	-24.0	39.4%	23.9%	-15.5	17.0%	49.8%	32.8
Oil price (EIA low)	38.1%	38.1%	0.1	34.5%	26.3%	-8.2	15.0%	41.0%	26.0
Oil price (EIA high)	56.7%	42.9%	-13.8	36.3%	29.9%	-6.5	15.5%	43.5%	28.0
Battery direct costs (-20%)	48.1%	44.1%	-4.0	34.8%	30.2%	-4.5	12.9%	36.7%	23.8
Battery direct costs (+20%)	43.8%	38.0%	-5.8	34.4%	23.1%	-11.3	17.6%	49.4%	31.8
Battery learning costs (-20%)	46.9%	42.5%	-4.3	37.1%	31.4%	-5.6	12.9%	39.2%	26.3
Battery learning costs (+20%)	45.2%	40.2%	-5.0	34.7%	28.4%	-6.3	15.6%	42.4%	26.9

Table 6-5 – Technology Cost, Sales, and Labor Utilization Under Selected Scenarios, MY 2029

	Technology cost ($/vehicle)			Sales (thousands)			Labor Utilization (Full-Time Equivalent Jobs)		
	Baseline	Alt. 2		Baseline	Alt. 2		Baseline	Alt. 2	
		Diff.	% diff.		Diff.	% diff.		Diff.	% diff.
Reference case	759	149	20%	15,654	-299	-1.9%	1,100,689	2,228	0.2%
60-month payback period	935	-246	-26%	15,655	-224	-1.4%	1,105,727	4,153	0.4%
Oil price (EIA low)	728	236	32%	15,655	-345	-2.2%	1,109,487	18	0.0%
Oil price (EIA high)	790	15	2%	15,655	-217	-1.4%	1,087,468	5,797	0.5%
Battery direct costs (-20%)	620	169	27%	15,654	-249	-1.6%	1,097,196	3,490	0.3%
Battery direct costs (+20%)	847	143	17%	15,654	-332	-2.1%	1,102,669	2,350	0.2%
Battery learning costs (-20%)	718	155	22%	15,655	-285	-1.8%	1,099,809	2,317	0.2%
Battery learning costs (+20%)	785	166	21%	15,655	-316	-2.0%	1,101,084	2,423	0.2%
Low GDP	762	152	20%	15,096	-293	-1.9%	1,062,377	1,999	0.2%
High GDP	767	127	17%	16,706	-307	-1.8%	1,172,754	2,785	0.2%
Sales-scrappage response (-20%)	759	151	20%	15,654	-240	-1.5%	1,100,689	6,598	0.6%
Sales-scrappage response (+20%)	759	148	20%	15,654	-359	-2.3%	1,100,689	-2,070	-0.2%

6.4 Effects on New Car and Truck Buyers

6.4.1 Vehicle Purchasing Price

The CAFE Model uses vehicle-level MSRP values provided in the input fleet as the starting point for modeling vehicle purchase prices. These initial MSRPs are revised over successive model years to produce final MSRP values that incorporate the regulatory cost of compliance. Figure 6-18 displays trends in these MSRPs for model years 2020 through 2029 and reports values separately for light trucks and passenger cars. For both regulatory classes, Alternative 3 produces the largest deviation from the No-Action Alternative, an increase of approximately five percent on average for MY 2026 through MY 2029 passenger cars and 3.4 percent for light trucks. For Alternative 2, these values are 3.5 and 2.1 percent, respectively. Because these prices are influenced in large part by technology costs, the overall price trends are similar to those found in Figure 6-11, which presents average technology cost per vehicle, especially between MY 2023 and 2026. After MY 2026, sales-weighted MSRP values decline slightly. Once most manufacturers apply technologies to respond to the new CAFE standards, vehicles retain these technologies. The associated costs of these technologies gradually decline due to the model's assumed technology learning rates and, to a lesser extent, to declining real civil penalty costs.[112] As higher stringency alternatives apply more advanced technologies and more civil penalty costs, this gradual decline beyond MY 2026 is more pronounced than in lower stringency alternatives and the No-Action Alternative.

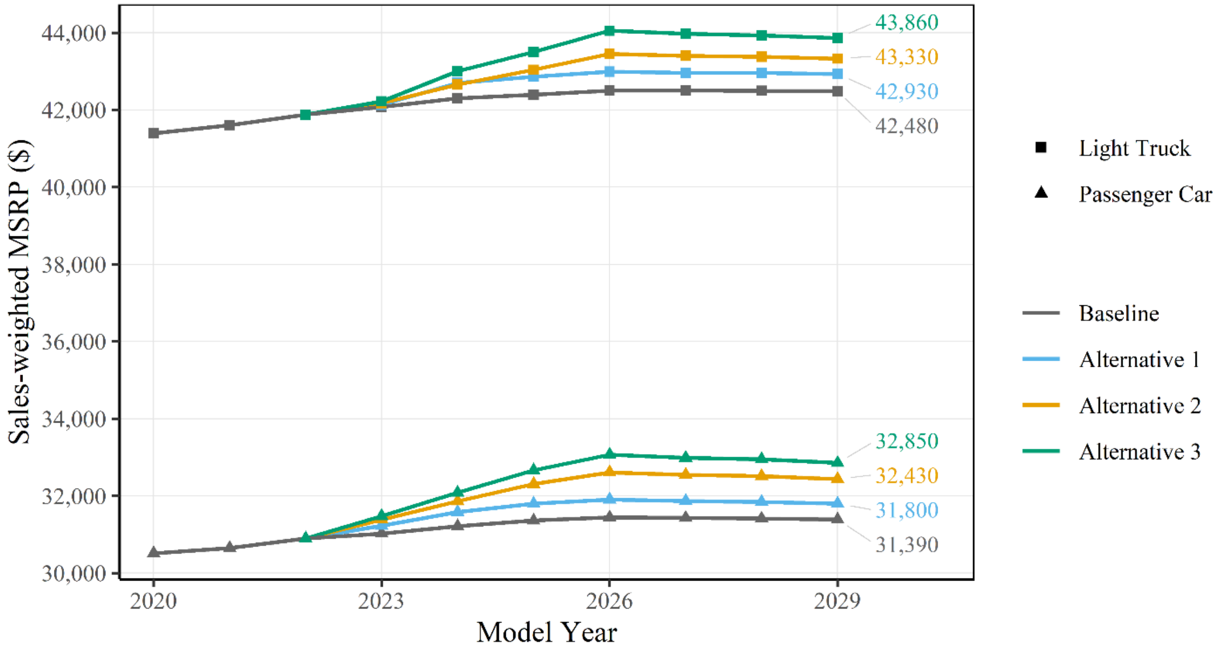

Figure 6-18 – Sales-weighted MSRP by Regulatory Class

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[112] Civil penalties are included at a fixed nominal rate. This means that the real dollar civil penalty rate declines over time. *See* the discussion in Section VII of the Preamble for additional detail.

6.4.2 Additional Consumer Purchasing Costs and Benefits

In addition to vehicle price effects, the CAFE Model computes various categories of consumer costs and benefits.[113] Table 6-6 summarizes these cost and benefit categories for MY 2029 and MY 2039 vehicles. The table includes per-vehicle aggregate values for the no-action alternative and differences from the no-action alternative for each of the regulatory alternatives.[114] Insurance cost, finance cost, and vehicle taxes and fees are all derived as a portion of modeled MSRP levels and hence vary directly with MSRP across alternatives. Regulatory costs are composed primarily of compliance costs due to technology application and therefore increase as alternative stringency increases. As shown in Table 6-6, this regulatory cost component increases by nearly 40 percent over the no-action alternative for Alternative 1 and more than doubles for Alternative 3 in MY 2029.

Estimated private benefits include decreased fuel expenditures, time saved due to less frequent fueling, and realized benefits from rebound travel miles. As presented in Table 6-6, fuel savings benefits are the largest component of estimated consumer benefits. Estimates for the no-action alternative indicate average retail fuel outlay costs of approximately $15,500 per vehicle. Fuel-economy improvements implemented under Alternative 1 produce estimated retail fuel savings of $581 per vehicle. Alternative 3 increases these savings on a per vehicle basis by more than a factor of 2.

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[113] This section considers only private consumer costs and benefits. Chapter 6.5 presents model results for costs and benefits attributable to society as a whole.

[114] Results for additional regulatory fleet aggregations and discount rates is included in Appendix I and II.

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

	MY 2029				MY 2039			
	Baseline	Relative to Baseline			Baseline	Relative to Baseline		
		Alt. 1	Alt. 2	Alt. 3		Alt. 1	Alt. 2	Alt. 3
Consumer costs								
Insurance cost	4,353	61	131	195	4,301	50	97	139
Financing cost	3,874	55	117	173	3,828	45	86	124
Taxes and fees	2,016	28	61	90	1,992	23	45	64
Regulatory cost	1,120	437	960	1,444	924	324	645	934
Foregone consumer sales surplus	0	1	7	17	0	0	-1	-3
Maintenance and repair cost	0	0	0	0	0	0	0	0
Implicit opportunity cost	0	0	0	0	0	0	0	0
Total consumer costs	*11,362*	*582*	*1,276*	*1,920*	*11,044*	*443*	*874*	*1,263*
Consumer benefits								
Retail fuel outlay	15,510	-581	-937	-1,332	15,652	-648	-1,287	-1,866
Refueling time cost	834	0	-1	-12	951	13	72	145
Drive value	546	97	125	171	622	108	128	161
Total consumer benefits	*16,890*	*679*	*1,063*	*1,516*	*17,226*	*743*	*1,343*	*1,882*
Net benefit	5,527	96	-213	-404	6,182	300	469	619

Note: Totals may not sum due to rounding

Note: Retail fuel outlay and refueling time cost are reported as negative numbers as they are lower than the baseline values, however these are treated as positive values when aggregating relative total consumer benefits (i.e., consumers paying less for fuel and spending less time refueling accrue positive private benefits).

Overall, private consumer benefits as estimated outweigh private consumer costs in the no-action alternative.[115] Relative to this baseline, net benefits to the consumer are positive for Alternative 1 and mixed or slightly negative for Alternatives 2 and 3. Comparing MY 2029 and MY 2039 in Table 6-6 illustrates the differences in cost and benefit components across model years. Figure 6-19 reports net benefits results from MY 2020 through MY 2050. Across model years, private net benefits vary significantly. In early model years for all three scenarios, net consumer benefits are negative as technology application costs of compliance outweigh consumer benefits. As these technology costs decline after the initial compliance period, residual consumer benefits from reduced fuel expenditure, refueling time, and additional drive time continue to accrue. This produces positive net private benefits in later model years. Net benefits become positive in MY 2027 for Alternative 1 and in MY 2031 and MY 2032 for Alternatives 2 and 3, respectively. Section 6.4.4 explores the sensitivity of these results to alternate modeling assumptions. Additional sensitivity results are included in Chapter 7.

Figure 6-19 – Private Consumer Net Benefits, 3% Social Discount Rate

Figure 6-20 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., initial increases followed by gradual declines). Figure 6-21 breaks out the other cost and benefit components of the private net benefit calculation. Fluctuations in foregone consumer sales surplus and refueling time cost are relatively small compared to the retail fuel outlay and drive value magnitudes. As expected, retail fuel outlay and drive value move in opposite directions over time, retail fuel outlay decreasing with more efficient fleets and drive value increasing with

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

a larger number of rebound miles traveled. Note, as above, private consumer benefits due to avoided retail fuel savings are substantial, especially in the cases of Alternative 2 and 3.

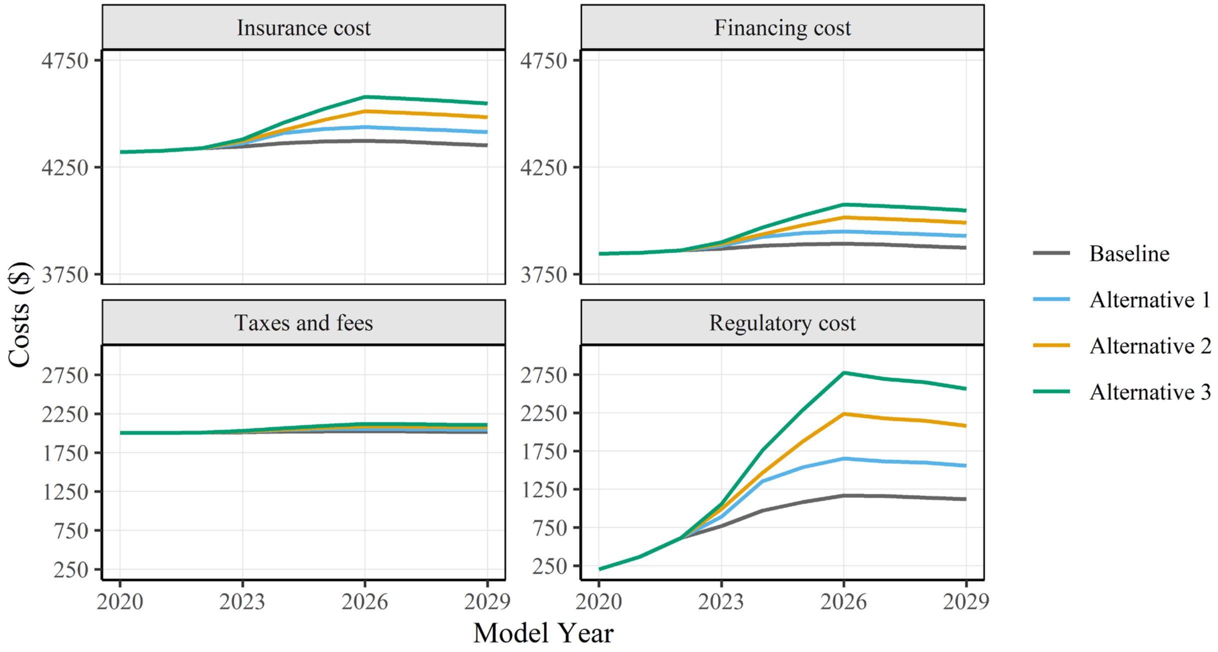

Figure 6-20 – MSRP-based Consumer Costs, 3% Social Discount Rate

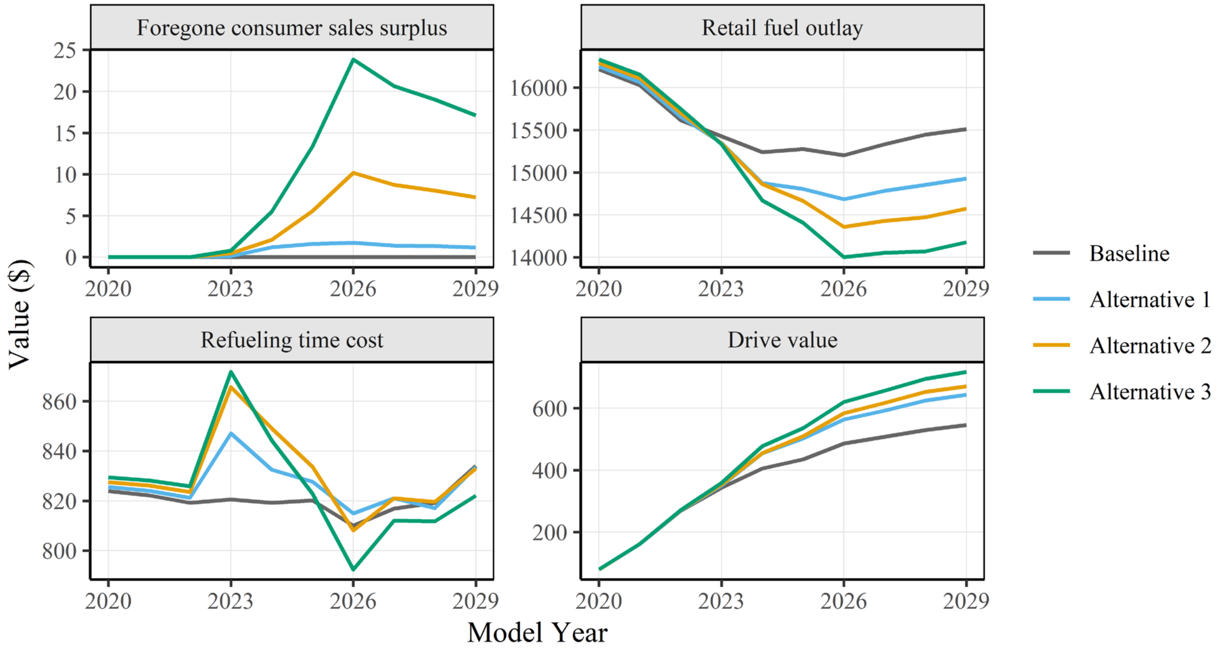

Figure 6-21 – Consumer Costs and Benefits, 3% Social Discount Rate

6.4.3 Total Cost of Ownership Payback Period

An alternative metric for evaluating relative costs and benefits of fuel efficiency regulations is to compute the time required for fuel economy improvements to produce positive returns from resulting fuel savings. To estimate the payback period for total cost of ownership (TCO) changes, the model aggregates regulatory costs–including the cost of applied technology and civil penalties—and maintenance and repair costs for new technologies. It then compares these to a running total of fuel savings and ownership cost changes (e.g., vehicle taxes and fees, finance and insurance costs). The vehicle age at which estimated benefits outweigh estimated costs is the payback period. Figure 6-22 illustrates the distribution of payback periods across all modeled vehicle sales.

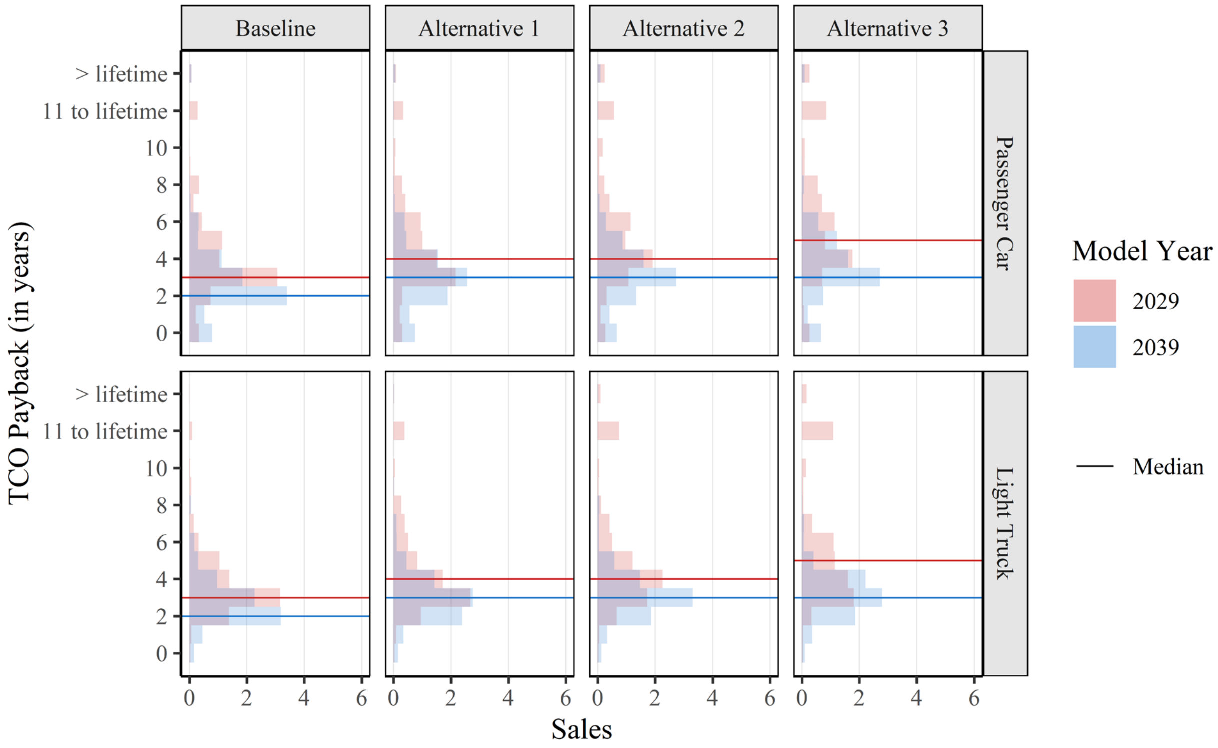

Figure 6-22 – Distribution of Vehicle TCO Payback

Figure 6-22 summarizes payback periods for undiscounted costs from the CAFE Model's vehicles report.[116] Payback periods in the Baseline are relative to MY 2020 vehicles. Passenger

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[116] In instances where costs outweigh benefits over the full vehicle lifetime, the payback period for individual models is reported as 99 years in the CAFE Model outputs. Because these values do not represent the full payback period, they were excluded from mean and median calculations in Table 6-7. As presented in Figure 6-22, 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 increase's payback periods. For example, for MY 2029 passenger cars, the baseline average TCO payback period is 4.9 years and increases to 8.5 years in Alternative 2. As this payback value is censored at 99 years, average and median payback periods presented above underestimate true fleet-wide payback, though the fraction of total vehicles with long payback periods is small.

car payback periods are slightly longer than light truck payback periods on average in MY 2029 and are nearly identical by MY 2039. Overall, payback times are longer in MY 2029, likely due to larger regulatory costs closer to the modeled CAFE regulation period.

Table 6-7 – Payback Times by Regulatory Class (in Years)

	MY 2029				**MY 2039**			
	Baseline	**Relative to Baseline**			**Baseline**	**Relative to Baseline**		
		Alt. 1	**Alt. 2**	**Alt. 3**		**Alt. 1**	**Alt. 2**	**Alt. 3**
Mean TCO Payback								
Passenger Car	4.0	0.6	1.5	2.3	2.6	0.3	0.5	0.9
Light Truck	3.7	0.7	1.6	2.3	2.7	0.2	0.3	0.4
Median TCO Payback								
Passenger Car	3.0	1.0	1.0	2.0	2.0	1.0	1.0	1.0
Light Truck	3.0	1.0	1.0	2.0	2.0	1.0	1.0	1.0

6.4.4 Consumer Effects Under Differing Assumptions

As in other sections of this chapter, the model estimates are contingent on chosen input parameter values. Assumptions about these values may influence simulated outcomes. This subsection investigates the effect of varying the values of a number of key input parameters on private costs and benefits. The majority of private costs derive from manufacturer regulatory cost of compliance that is passed on to the consumer. Retail fuel savings account for the majority of private benefits. As these regulatory costs vary based on manufacturer response to stringency changes, we choose to examine the same set of model sensitivity cases presented in Chapter 6.3.4. A full set of sensitivities is included in Chapter 7.

Table 6-8 presents sales-weighted MSRP values for MY 2029 vehicles by regulatory class across model runs. Fuel economy standards under Alternative 2 increase this MSRP measure in all presented scenarios. Price changes across scenarios are relatively stable, ranging from $700 to $1,100, or 2 to 4 percent over levels in the No-Action Alternative. Price increases for passenger cars are consistently larger than those for light trucks on both a dollar and percentage basis. Higher oil prices and lower battery costs lead to smaller effects of Alternative 2 on vehicle prices for the same reasons mentioned in Chapter 6.3.4: higher oil prices spur more manufacturer investment in fuel efficiency technologies in the baseline, leading to a muted effect of Alternative 2 stringency, and lower battery costs directly reduce technology cost for powertrains on the hybridization/electrification pathway (e.g., PHEVs, BEVs).

Table 6-8 – **Sales-weighted MSRP Under Selected Scenarios, MY 2029**

	Passenger Car			Light Truck		
	Baseline	Alt. 2		Baseline	Alt. 2	
		Diff.	% diff.		Diff.	% diff.
Reference case	31,391	1,044	3.3%	42,484	845	2.0%
60-month payback period	31,522	737	2.3%	42,697	680	1.6%
Oil price (EIA low)	31,282	1,120	3.6%	42,415	923	2.2%
Oil price (EIA high)	31,537	869	2.8%	42,544	778	1.8%
Battery direct costs (-20%)	31,292	826	2.6%	42,308	822	1.9%
Battery direct costs (+20%)	31,490	1,109	3.5%	42,560	950	2.2%
Battery learning costs (-20%)	31,358	989	3.2%	42,436	825	1.9%
Battery learning costs (+20%)	31,434	1,088	3.5%	42,492	896	2.1%

Table 6-9 through Table 6-11 examine variation in private net benefits and components of the private net benefits calculation. Results in Table 6-9 cover overall private costs and benefits for MY 2029 and MY 2039. As in the Reference case, net private benefits are negative in the presented sensitivity cases except for under high oil price assumptions and low direct battery costs. In both instances, private cost totals are notably lower and benefits higher than the reference case. Table 6-10 reveals the main drivers behind these differences. Consumer savings on retail fuel purchases increase (i.e., retail fuel expenditures decline) relative to the No-Action alternative by larger amounts than in the Reference case, though in percentage terms these values are similar to the Reference case. Simultaneously, regulatory costs increase less under Alternative 2 relative to the baseline than they do in the Reference case. These factors combine to produce positive net benefits in MY 2029 in these scenarios. For MY 2039, benefits are positive in all battery cost scenarios and the high oil price case. Costs outweigh benefits under a longer payback period and the low oil price case, though the total net benefit for the latter is relatively small. Values in the tables below may not total perfectly due to rounding.

Table 6-9 – **Private Costs and Benefits Under Selected Scenarios, Relative to the No-Action Alternative, 3% Discount Rate**

	MY 2029			MY 2039		
	Costs	Benefits	Net Benefits	Costs	Benefits	Net Benefits
Reference case	1,276	1,063	-213	874	1,343	469
60-month payback period	972	798	-173	340	237	-103
Oil price (EIA low)	1,370	833	-537	938	937	-1
Oil price (EIA high)	1,119	1,412	293	463	748	285
Battery direct costs (-20%)	1,121	1,138	18	499	727	229
Battery direct costs (+20%)	1,398	1,031	-367	1,045	1,196	152
Battery learning costs (-20%)	1,228	1,066	-162	589	906	317
Battery learning costs (+20%)	1,339	1,070	-269	1,029	1,282	252

Table 6-10 – Components of Private Costs and Benefits Under Selected Scenarios, MY 2029

	Retail Fuel Outlay			Regulatory Costs		
	Baseline	Alt. 2		Baseline	Alt. 2	
		Diff.	% Diff.		Diff.	% Diff.
Reference case	15,510	-937	-6.0%	1,120	960	86%
60-month payback period	14,996	-717	-4.8%	1,297	726	56%
Oil price (EIA low)	12,076	-753	-6.2%	1,093	1,030	94%
Oil price (EIA high)	20,310	-1,191	-5.9%	1,146	843	74%
Battery direct costs (-20%)	15,534	-994	-6.4%	982	840	86%
Battery direct costs (+20%)	15,563	-919	-5.9%	1,209	1,048	87%
Battery learning costs (-20%)	15,478	-934	-6.0%	1,080	922	85%
Battery learning costs (+20%)	15,570	-942	-6.0%	1,146	1,008	88%

Table 6-11 – Components of Private Costs and Benefits Under Selected Scenarios, MY 2039

	Retail Fuel Outlay			Regulatory Costs		
	Baseline	Alt. 2		Baseline	Alt. 2	
		Diff.	% Diff.		Diff.	% Diff.
Reference case	15,652	-1,287	-8.2%	924	645	70%
60-month payback period	13,069	-206	-1.6%	1,834	242	13%
Oil price (EIA low)	12,085	-928	-7.7%	879	694	79%
Oil price (EIA high)	17,572	-646	-3.7%	1,484	342	23%
Battery direct costs (-20%)	14,081	-632	-4.5%	942	373	40%
Battery direct costs (+20%)	15,921	-1,087	-6.8%	1,023	773	76%
Battery learning costs (-20%)	14,489	-819	-5.7%	1,007	433	43%
Battery learning costs (+20%)	15,904	-1,212	-7.6%	988	767	78%

6.5 Effects on Society

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

The CAFE Model records costs and benefits for particular model years but also reports these measures over the lifetime of the vehicle. Examining program effects through this lens illustrates the temporal differences in major cost and benefit components. Figure 6-23 displays values for model year 1981 through 2029 vehicles over their lifetimes. For calendar years 2029 and earlier, costs exceed benefits, driven mostly by costs for applying efficiency-improving technologies. From 2029 onward, benefits exceed costs.

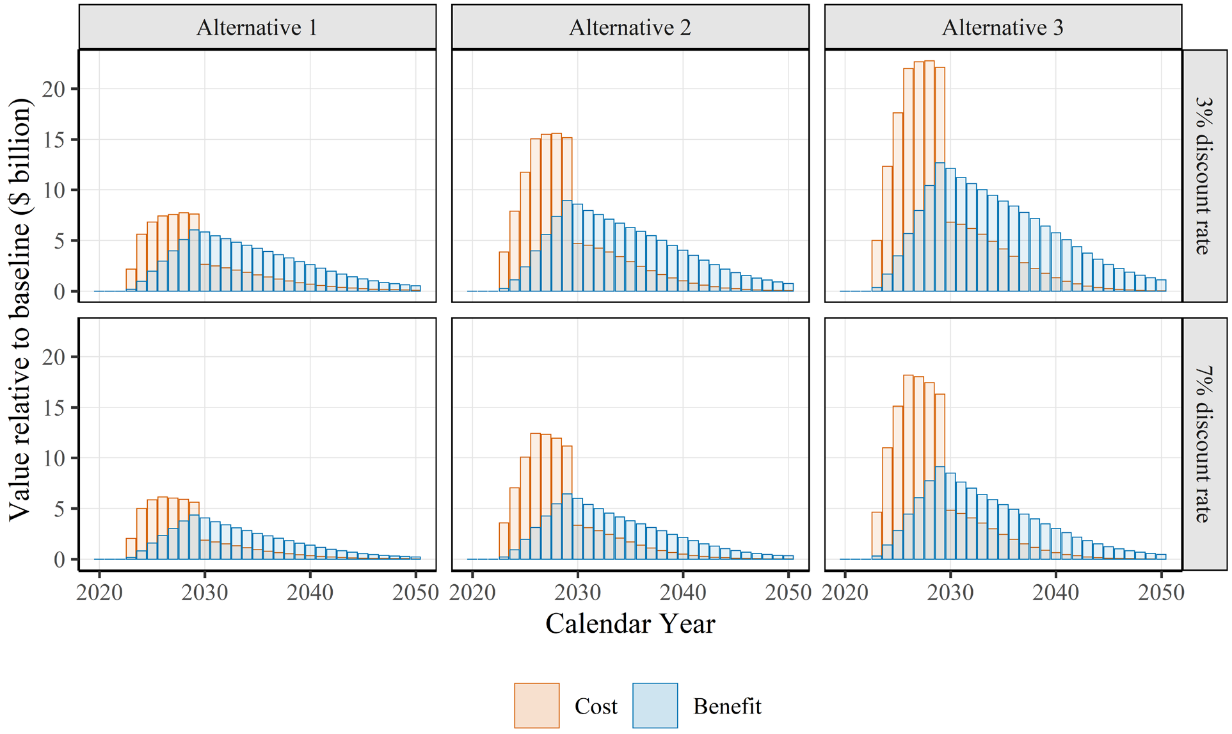

Figure 6-23 – Annual Costs and Benefits, MY 1981-2029 (Total fleet)[117]

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

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

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

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

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

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

While the legal justification for the proposal (discussed in detail in Section VI of the preamble) relies primarily on the model year accounting of costs and benefits, this section presents some results from both perspectives – particularly where the external nature of the cost or benefit more readily lends itself to a calendar year accounting structure. Figure 6-24 aggregates annual cost and benefit streams to produce cumulative net benefits, by calendar year, for the three modeled alternatives. Estimated program compliance and outcomes indicate the industry reaches cumulative positive net benefits for Alternative 1 in 2039 using a 3 percent discount rate (this is pushed to 2040 using a 7 percent discount rate). At the 3 percent discount rate, Alternative 2 reaches this threshold in 2042 – and while the depth of the decline in cumulative net benefits is greater for Alternative 3 than either of the others, the net benefits also grow faster once they finally turn positive. The figure illustrates exactly the point above about the calendar year accounting perspective; the years closest to the action years look different than years much later, but those later years can be sufficient to dominate the calculation of net benefits (particularly at the 3 percent discount rate).

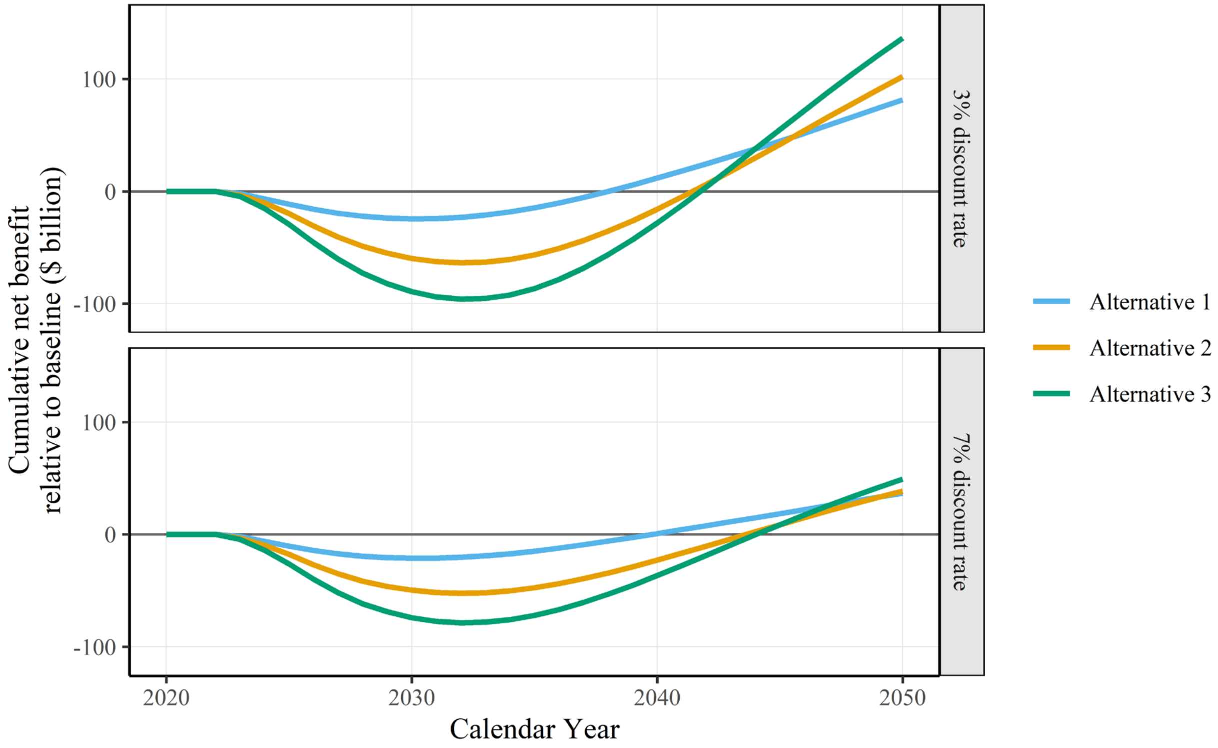

Figure 6-24 – Cumulative Net Benefits, MY 2020-2029

The graphs in this section present certain effects in absolute terms, while others show incremental costs and benefits relative to the baseline, the No-Action Alternative. Both model year and calendar year perspectives are used in this section depending on the effects discussed. Unless otherwise stated, the model year perspective includes model years 1981-2029 and the calendar years that correspond to the full lifetimes of models produced in those model years, while the calendar year perspective includes calendar years 2020-2050 and all of the model years present in the on-road fleet in each of them.

6.5.1 Social Benefits of Reducing Greenhouse Gas Emissions

NHTSA uses the interim values published by the Interagency Working Group on Social Cost of Greenhouse Gases (IWG) in February 2021 to represent the social cost per ton of CO_2, CH_4, and N_2O.[118] See Chapter 6.2.1 in the TSD for discussion of how these values were integrated into the CAFE Model inputs.

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[118] 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*, available at https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf.

Table 6-12 – Social Cost of GHGs (2018$ per metric ton)

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

The CAFE Model multiplies the per-ton cost values for each of the three greenhouse gases considered by the total emissions of each. Chapter 5 of the TSD describes the calculation of these total emissions, from both upstream and tailpipe sources. The CAFE Model reports the monetized values of the total greenhouse gas emissions in its output reports. All reported cost values in this chapter are in 2018$. Table 6-13 lists the total costs of GHG emissions by alternative, for model years 1981-2029, based on the 3% and 2.5% SC-GHG rates. All values in Table 6-13 are in absolute terms, monetizing the incurred costs of emissions. GHG social costs decrease for all greenhouse gases as stringency increases across the alternatives. [120]

Table 6-13 –Total Costs of GHG Emissions across Alternatives (2018$, in billions) (1981-2029 MY totals)

	No-Action Alternative (Baseline)		Alternative 1		Alternative 2		Alternative 3	
	3%	2.5%	3%	2.5%	3%	2.5%	3%	2.5%
CO_2	1,120	1,697	1,108	1,678	1,100	1,666	1,092	1,653
CH_4	43.3	58.0	42.8	57.3	42.6	57.0	42.3	56.6
N_2O	14.1	21.1	13.9	20.9	13.9	20.8	13.8	20.7

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

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

Figure 6-25 and Figure 6-26 show the social costs of GHG emissions in the no-action (baseline) scenario for calendar years 2020 – 2050, illustrating the relative magnitudes of each pollutant's monetized costs. Although CH_4 and N_2O have substantially higher social costs per ton compared to CO_2, the quantity of CO_2 emissions is much higher (see Chapter 6.6.2), accounting for the large difference between the three total social cost amounts. Comparing the two figures shows the extent to which discount rates matter for these emissions costs; using the highest discount rate (95th percentile values discounted at 3%), damage costs due to GHG emissions peak at over 200 billion dollars per year and then decline from there. In contrast, the lowest estimates (discounted at 5%) amount to little over 19 billion dollars per year at their highest point, and then decline from there. As the central values in the analysis use the 3% and 2.5% SC-GHG discount rates, subsequent graphs will use only those.

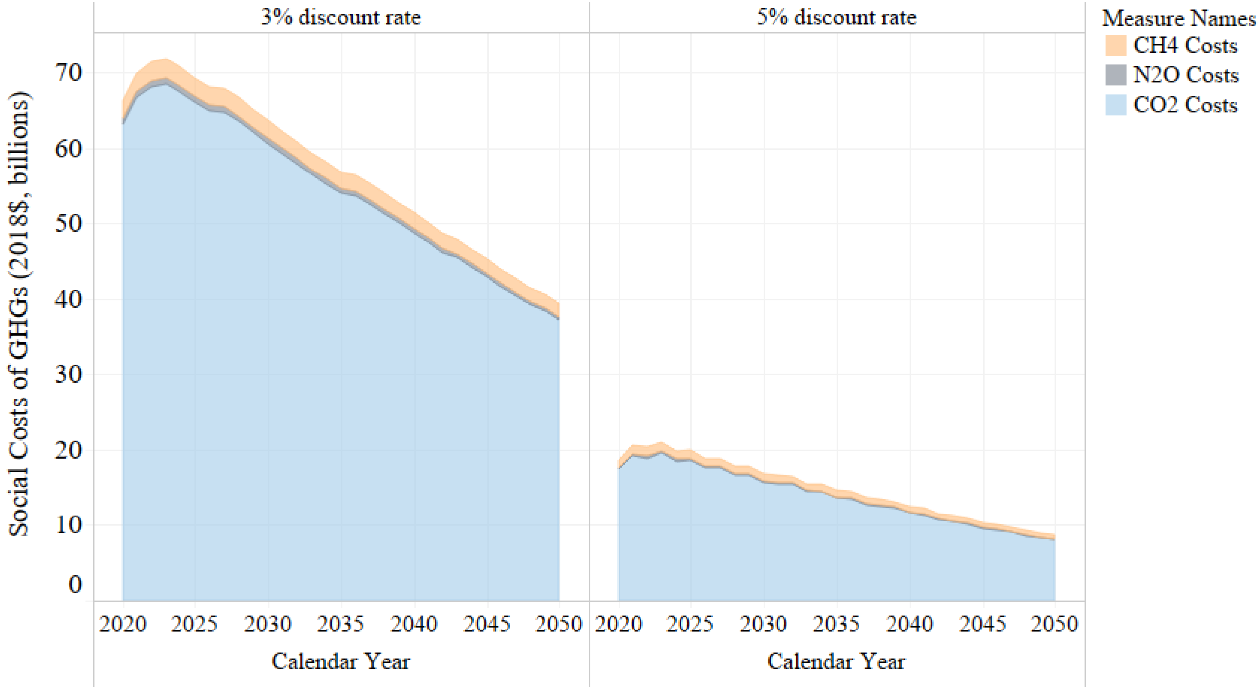

Figure 6-25 – Social Costs of CO_2, CH_4, and N_2O under the No-Action Alternative (2020-2050), 3% and 5% Percent Discount Rate (2018\$, billions)

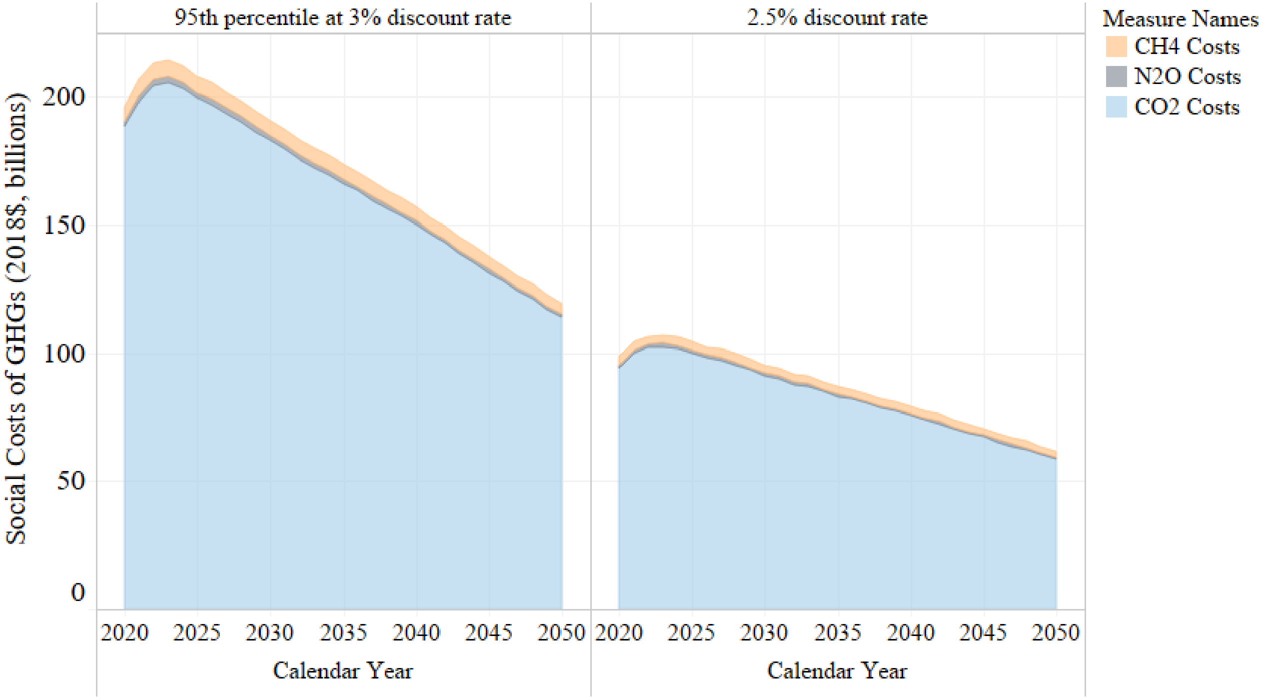

Figure 6-26 – Social Costs of CO_2, CH_4, and N_2O under the No-Action Alternative (2020-2050), 95th Percentile and 2.5% Discount Rates (2018$, billions)

Figure 6-27 and Figure 6-28 show the total costs of GHG emissions by alternative at the 3% and 2.5% discount rate, respectively, for all model years through MY 2029. These graphs serve as a visualization of the information in Table 6-13, and use the model year perspective. When viewed in absolute terms, differences between alternatives may appear relatively minor, but actually are not (note that the units are billions of dollars).

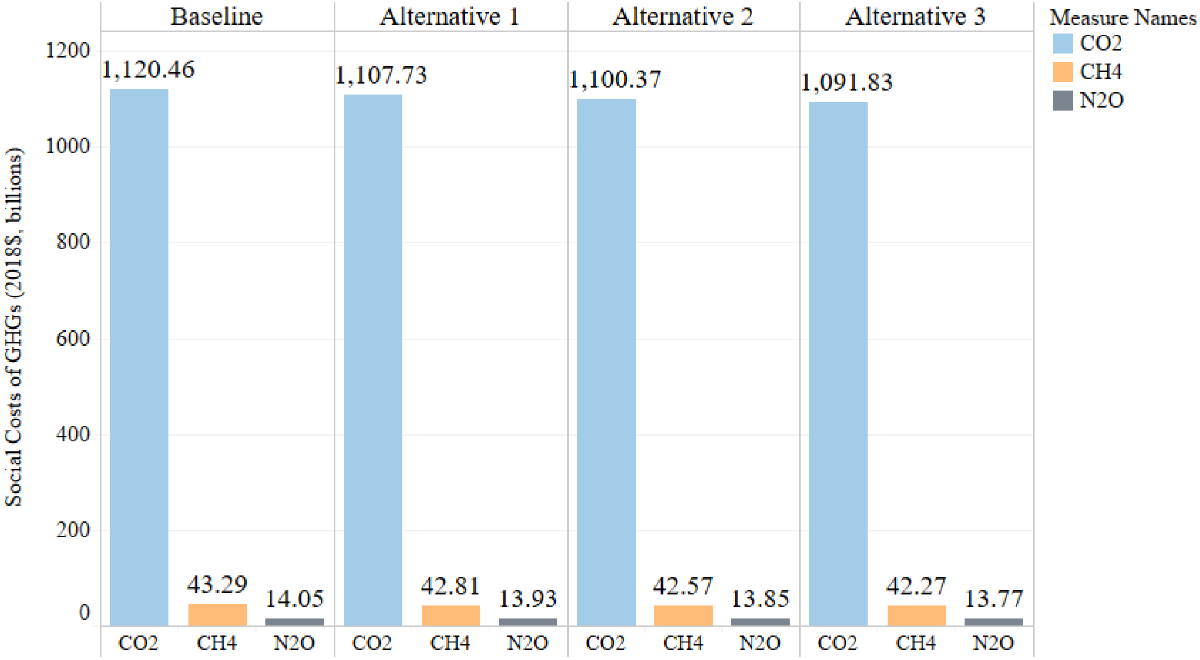

Figure 6-27 – Total Social Costs of CO_2, CH_4, and N_2O across Alternatives (3% discount rate)

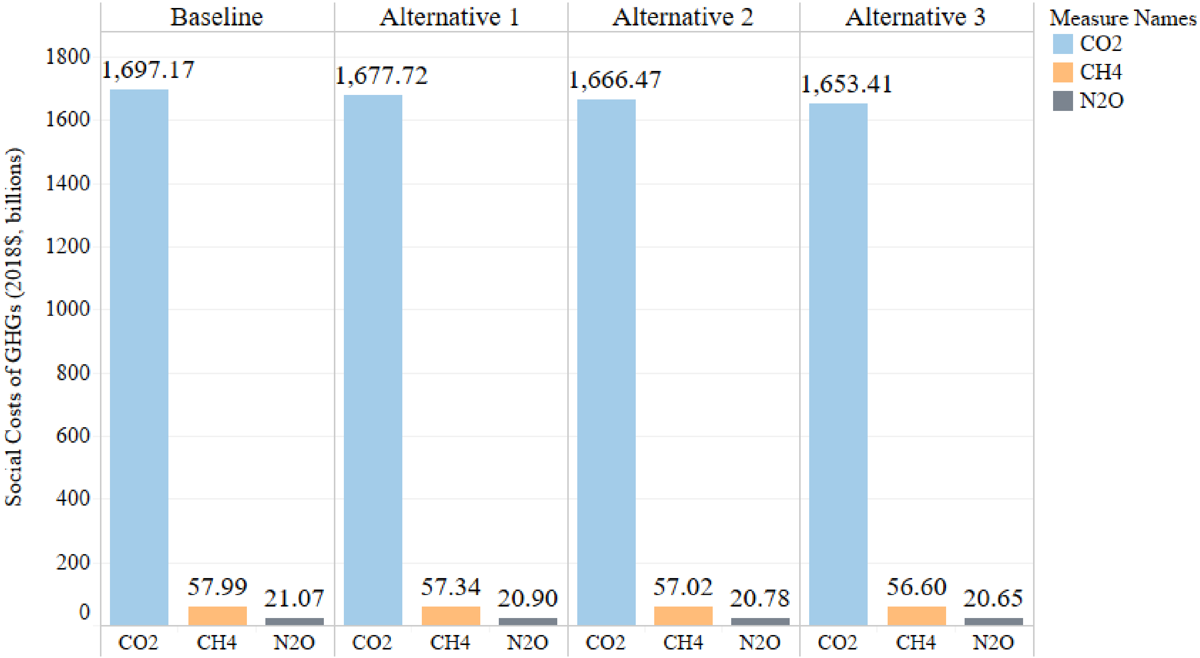

Figure 6-28 – Total Social Costs of CO_2, CH_4, and N_2O across Alternatives (2.5% discount rate)

The following figures illustrate the social costs of GHG emissions relative to the No-Action Alternative/baseline, either in terms of incurred costs or avoided costs (also referred to as social benefits). Incurred costs relative to the baseline represent the costs of GHGs in addition to the baseline total cost reported in Figure 6-27 and Figure 6-28. In other figures where social benefits are shown, positive values indicate the avoided costs of GHGs not emitted.

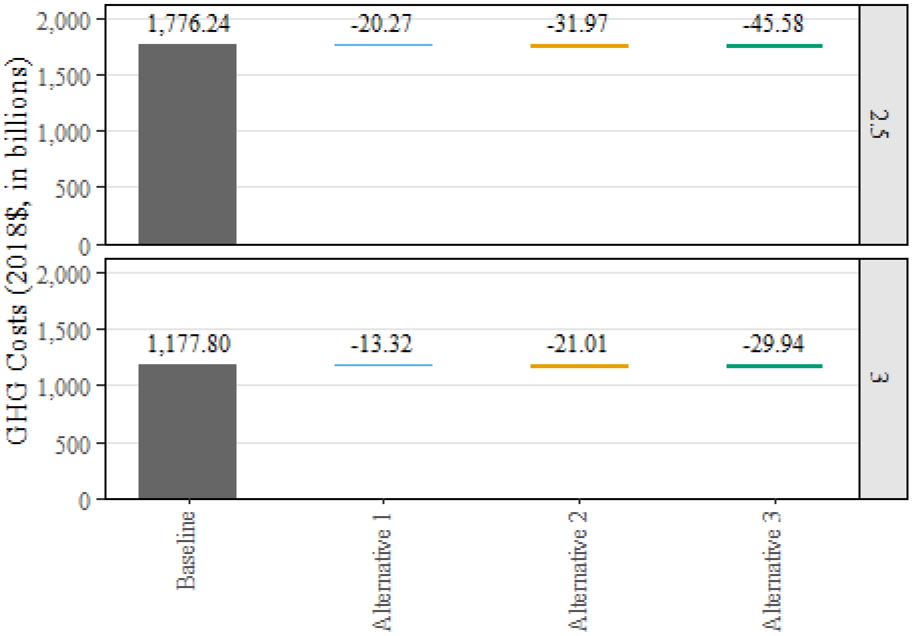

Figure 6-29 – GHG Costs Under the No-Action Alternative and Changes Relative to the No-Action Alternative (2018$, billions, discounted at 2.5% and 3%)

Figure 6-29 groups the GHG costs together, discounted at 2.5% and 3%. The GHG emission costs in the baseline are shown in absolutes, while the costs in the three alternatives are shown in terms of incremental reduced costs relative to the baseline. For instance, using the 3% discount rate, Alternative 1 reduces costs by $13.32 billion from the baseline (about 1.1% of the baseline total), while Alternative 3 reduces costs by $29.94 billion from the baseline (approximately 2.5% of the total baseline costs).

Figure 6-30 focuses on these reduced costs relative to the baseline, presenting them as benefits in positive terms (avoided costs). Unlike in the previous graphs, this figure shows the distribution of GHG benefits across calendar years, dividing the benefits into three decades: 2021-2030, 2031-2040, and 2041-2050. Through this perspective, we see that most of the monetized benefits of reducing GHG emissions occur after 2030, and the highest benefits, in every alternative, occur in the period between 2041-2050.

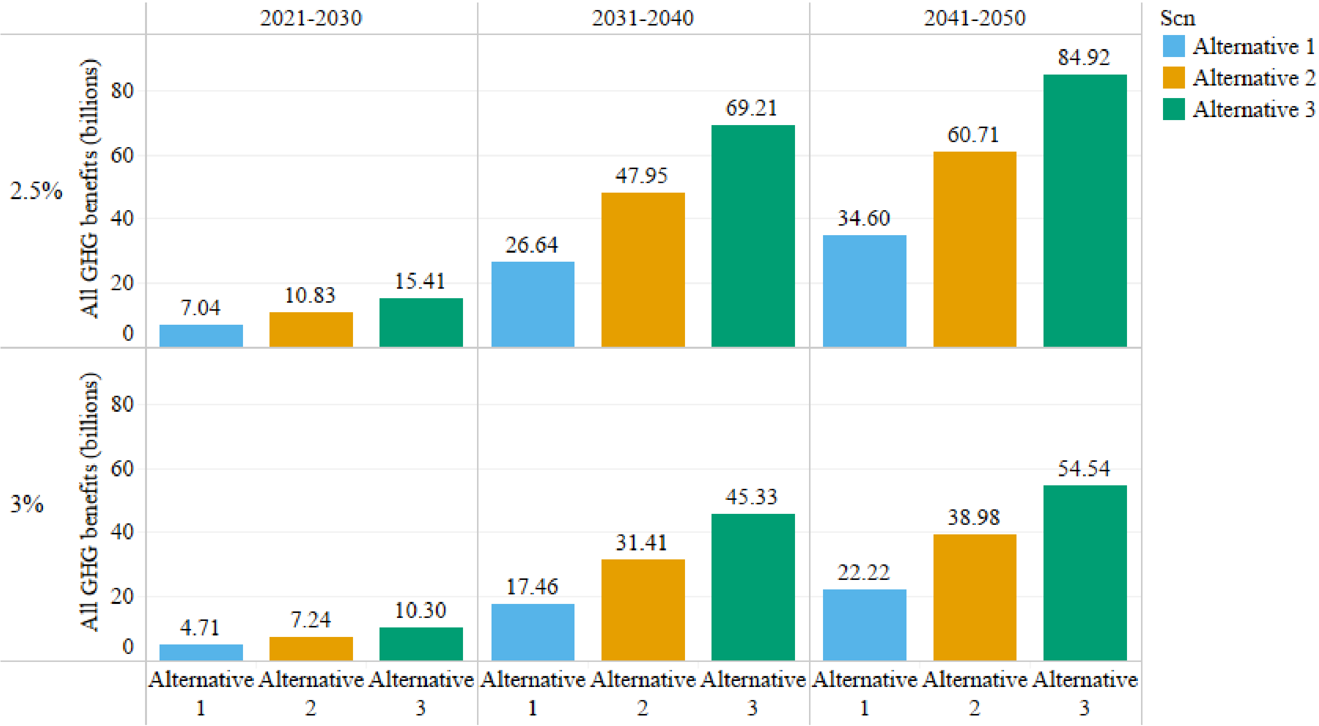

Figure 6-30 – Avoided GHG Costs Relative to the No-Action Alternative (2018$, billions, 2.5% and 3% discount rates)

6.5.2 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).[121] The model contains per-ton monetized health impact values corresponding to these health impacts (see TSD Chapter 6.2.2). The CAFE Model calculates the total criteria pollutant emissions associated with the fleet in different alternatives, based on the emissions inventory discussed in Chapter 5, and the monetized health impact values per ton are then multiplied by the total tons in the emissions inventory. The resulting total costs associated with criteria pollutant emissions can be found in the CAFE Model outputs. For further information pertaining to these criteria pollutant emissions, see also EIS Chapter 4.

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

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

Table 6-14 – Social Costs of Criteria Pollutants Under the Baseline Alternative and Percent Changes Resulting from Regulatory Alternatives, Model Year Perspective (2018$, billions)

	No-Action Alternative (Baseline)		**Alternative 1**		**Alternative 2**		**Alternative 3**	
	3%	**7%**	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
NO_x	127.6	96.2	0.1%	0.1%	0.5%	0.4%	0.7%	0.6%
SO_x	229.7	161.9	-0.5%	-0.4%	-0.2%	-0.2%	-0.2%	-0.2%
$PM_{2.5}$	383.0	276.0	-0.2%	-0.1%	-0.1%	-0.1%	-0.2%	-0.1%

Table 6-14 shows the total and incremental health costs attributable to the three criteria pollutants under each rulemaking alternative, discounted at 3% and 7%. In the baseline column, we present these costs in absolute terms, using the model year perspective (MY 1981-2029). The incremental costs (relative to the baseline) in the three alternatives are presented in terms of percent of the baseline. For instance, in Alternative 2, the decrease in SO_x costs relative to the baseline is equivalent to 0.2% of the total baseline SO_x costs. These social costs increase very slightly for NO_x and $PM_{2.5}$ in some alternatives (relative to the baseline total), due to a number of factors described below, including electrification in some alternatives causing slightly higher upstream emissions, and for downstream emissions, a decrease in sales causing older vehicles to be driven longer, and slightly more VMT due to the rebound effect. Chapter 6.6.4, which describes the changes in the pollutants themselves across alternatives, rather than the changes in costs, also includes further explanation of these effects. However, although total social costs summed across model years in this table show slight increases in NO_x and $PM_{2.5}$, it is important to underscore that the social costs decrease over calendar years in all alternatives. Furthermore, as seen in later graphs, benefits from avoided criteria pollutant costs relative to the baseline are experienced in every alternative, and they substantially outweigh any slight increases in incremental costs.

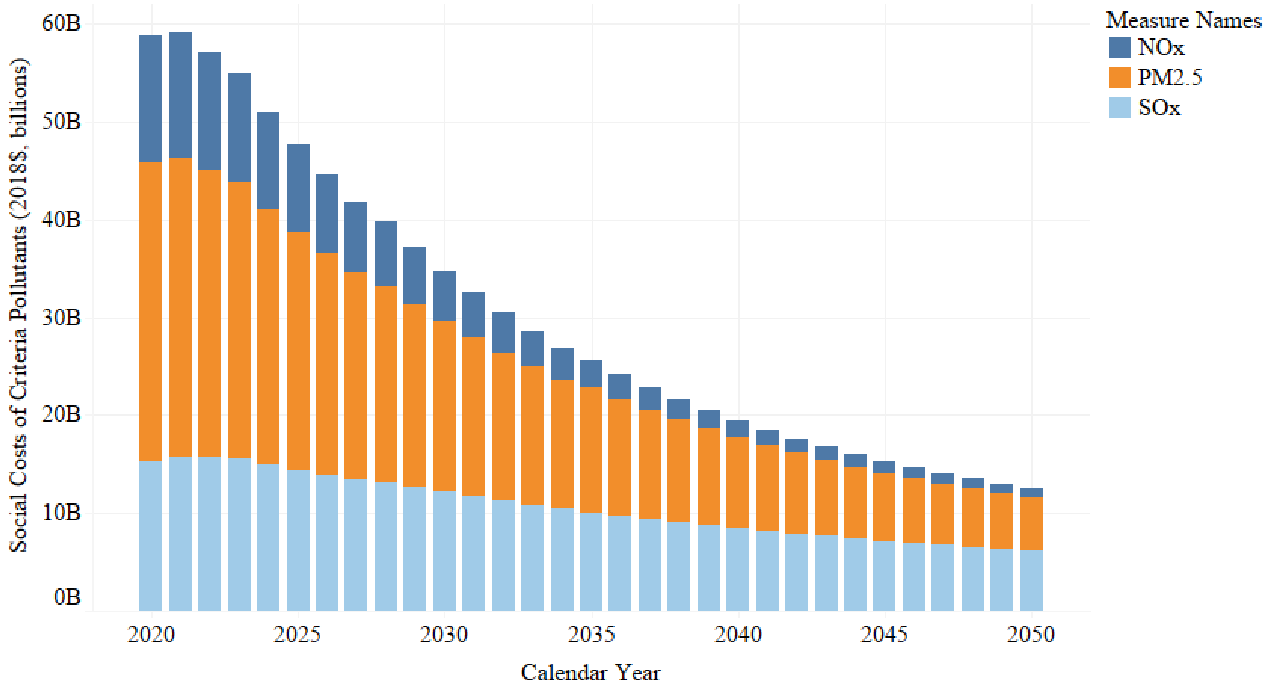

Figure 6-31 – Criteria Pollutant Health Costs under the No-Action Alternative (3% discount rate)

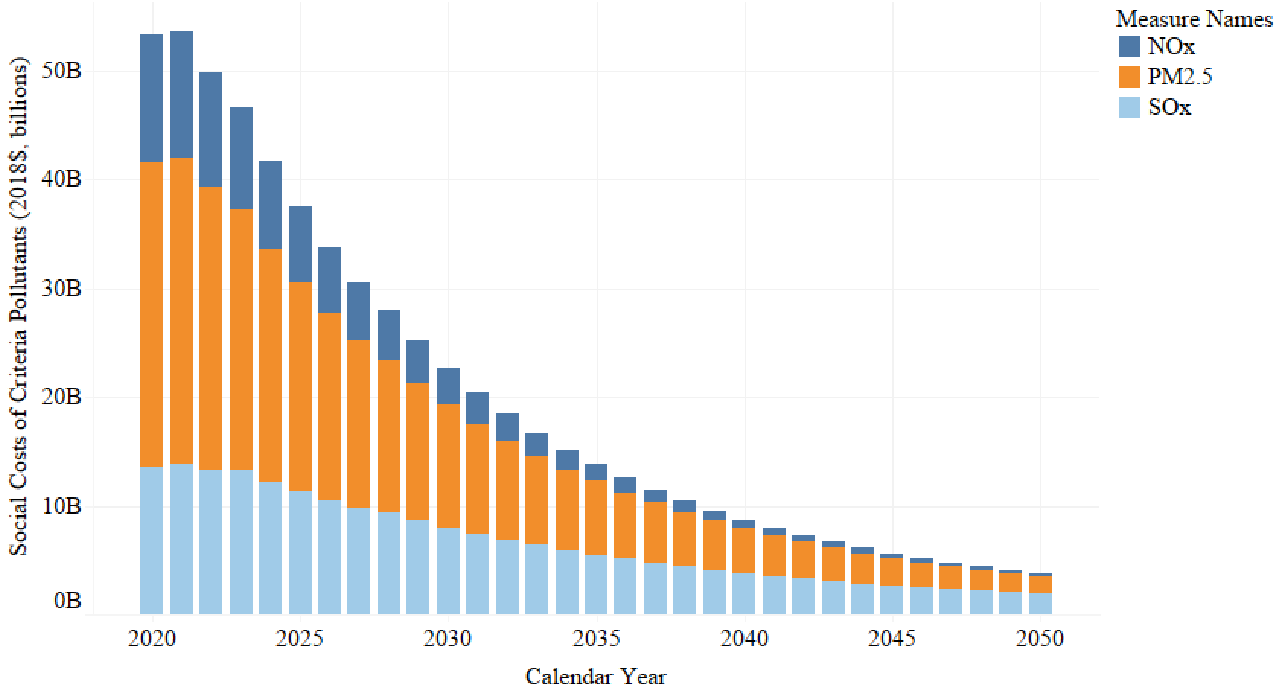

Figure 6-32 – Criteria Pollutant Health Costs under the No-Action Alternative (7% discount rate)

Figure 6-31 and Figure 6-32 (which differ only by discount rate) show how the health costs related to each criteria pollutant change over time in the baseline scenario (the no-action alternative), from calendar years 2020-2050. The social costs of criteria pollutants are a function of both the per-ton cost and the amount of each pollutant emitted. As detailed in Chapter 6.2.2 of the TSD, the per-ton costs of some criteria pollutants do increase based on the calendar year. However, as the per-ton costs do not change substantially, the changes in total costs pertain to increases and decreases in tons of emissions. The magnitude changes of each pollutant over the years come from changes in fleet mix and fuel types used. As seen in these two figures, the health costs from criteria pollutants are due largely to $PM_{2.5}$. The health cost per ton is higher for $PM_{2.5}$ than for the other pollutants, which accounts for the relatively large magnitude of its costs. This relatively high cost value does not indicate that tons of $PM_{2.5}$ emissions are the largest, only that the total health costs associated with $PM_{2.5}$ are the largest. See Chapter 6.6.4 for information regarding physical quantities of the pollutants.

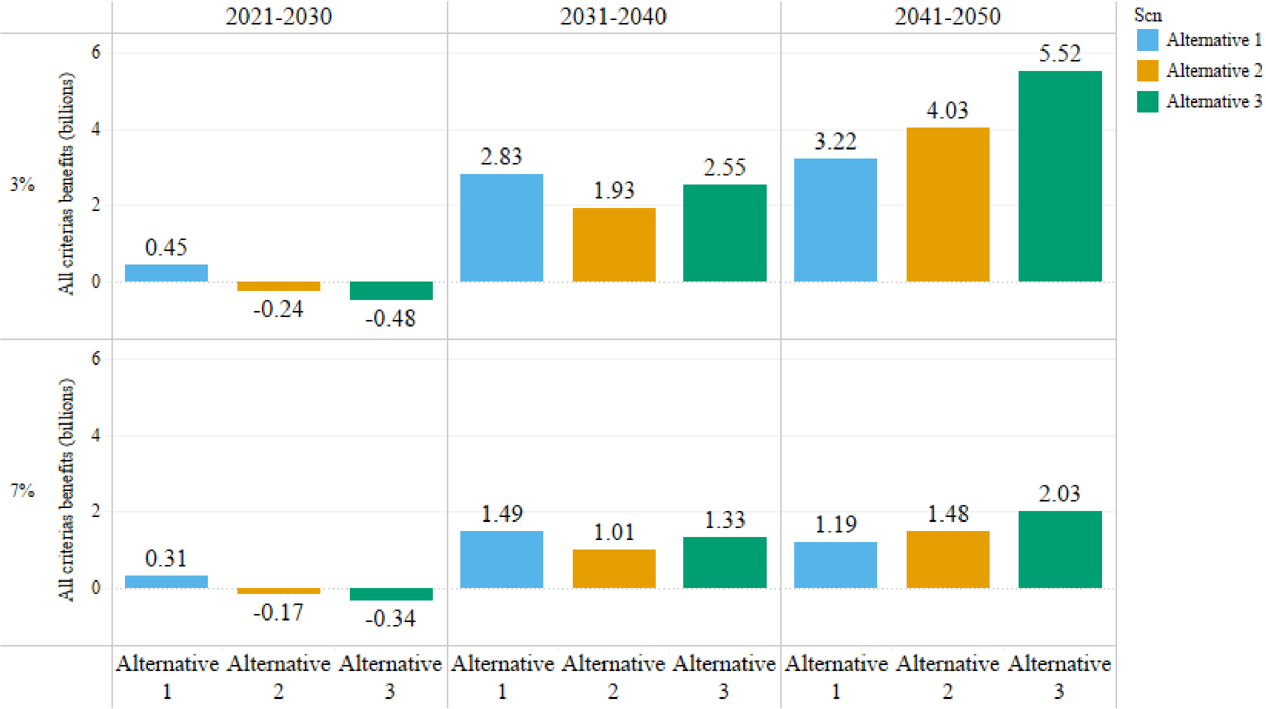

Figure 6-33 – Avoided Health Costs of Criteria Pollutants Relative to the No-Action Alternative (3% and 7% discount rates)

Figure 6-33 illustrates the differences between alternatives and across calendar year decades, in terms of avoided criteria pollutant health costs relative to the baseline. For example, using a 7% discount rate, the health costs associated with criteria pollutant emissions in Alternative 1 from 2021-2030 are 0.31 billion dollars lower than the baseline totals in that decade. We treat these differences from the baseline, the avoided costs, as positive benefits. In some cases (Alternatives 2 and 3, specifically between 2021-2030), the avoided costs are negative, indicating that the benefits are negative and that the total costs are actually slightly higher during this decade than in the baseline. Although this is the case for Alternatives 2 and 3 between calendar years 2021-2030, the overall benefits from reducing these criteria pollutants are positive. As seen in the other two decade panels in (Figure 6-11), future benefits of avoided health costs are far greater than the slight increases in health costs between 2021-2030 as a result of fleet turnover and increasing numbers of new vehicles being subject to Tier 3 requirements. For context, the slight increase in criteria pollutant health costs between 2021-2030 under Alternative 2 is equivalent only to 0.05% of the total health costs incurred over that decade. Under Alternative 3, the increase in health costs between 2021-2030 is equivalent to 0.1% of the total health costs in that decade. Alternatives 2 and 3 experience the greatest incremental benefits in the period from 2041-2050, while the largest incremental benefit under Alternative 1 falls under the second decade shown, 2031-2040.

These patterns indicate that while overall benefits of avoided criteria pollutant costs relative to the baseline are positive, the sign changes depending on calendar year, and the majority of benefits occur in later years. For reference, the benefits between 2021-2030 under Alternative 1, using a 3% discount rate, have a value equal to approximately 0.06% of the total criteria pollutant costs in the baseline. On the higher end, the benefits between 2041-2050 under Alternative 3, using a 3% discount rate, are equal in value to about 0.7% of the total criteria pollutant costs in the baseline.

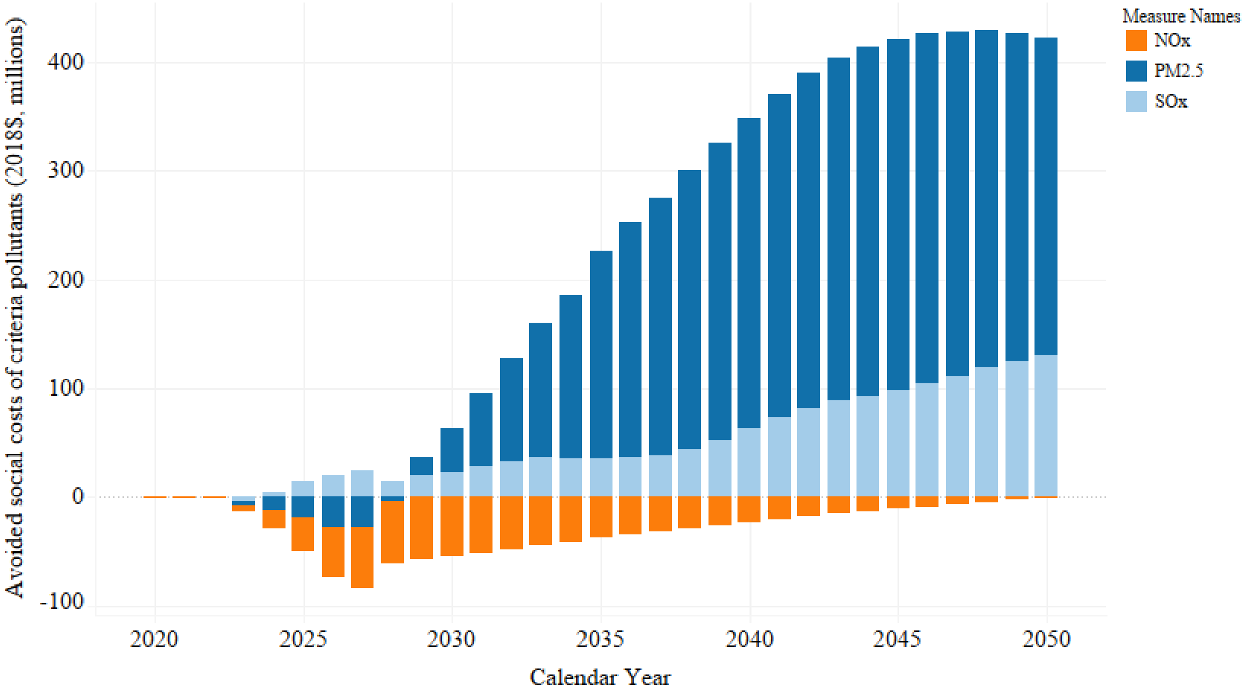

Figure 6-34 – Avoided Costs of Criteria Pollutants under Alternative 2 (3% discount rate)

Figure 6-34 provides a further example of how benefits from avoided criteria pollutant emissions can be positive or negative when viewed from a calendar year perspective (readers should remember again that costs associated with $PM_{2.5}$ appear high due to the health effects associated with $PM_{2.5}$, rather than because emissions of $PM_{2.5}$ are themselves very high). The health damages associated with NO_x emissions decrease (improve) over time across all of the alternatives as a consequence of EPA's Tier 3 program for criteria pollutant emissions. That program sets new restrictions on NO_x emissions that ramp up from 2017 – 2025, which affect total emissions across the fleet as vehicles produced in those (and later) model years become the majority of the on-road population. As the fleet turns over, across all scenarios, calendar year emissions of NO_x from automobile tailpipes plummet and the incremental effects between scenarios shrink over time. For a more detailed discussion of criteria pollutant emissions, see Chapter 6.6.

6.5.3 Social Costs of Changes to Congestion and Road Noise

Table 6-15 – Incremental Social Costs of Congestion and Noise across Alternatives (2018$, in billions)

	Alternative 1		Alternative 2		Alternative 3	
	3%	7%	3%	7%	3%	7%
Congestion	7.3	4.8	10.0	6.8	13.4	9.2
Noise	0.05	0.04	0.07	0.05	0.10	0.07

Table 6-15 reports the incremental social costs of congestion and noise relative to the baseline across alternatives using the model year totals from 1981-2029. Congestion and noise are functions of VMT, and the increases in these costs relate directly to increases in VMT (see Chapter 6.6.1) for each of the model years considered. For information regarding the calculation of congestion and noise costs in the CAFE Model, and how these relate to VMT and other inputs, see Chapter 6.2.3 in the accompanying TSD. Overall, the trend across alternatives consists of small and relatively steady increases in congestion and noise costs as regulatory stringency increases.

Figure 6-35 focuses on these differences in costs between the alternatives relative to the baseline, presenting them in terms of negative benefits. In this figure, noise and congestion costs are combined (due to the relatively small contribution of noise costs), and the calendar year perspective is used, showing how the negative benefits are distributed across decades. For example, in the top panel of the figure (corresponding to the 3% discount rate), the bar corresponding to Alternative 3 in the period from 2031-2040 represents an $18.42 billion increase in congestion and noise costs relative to the baseline totals. Most of the incremental costs (negative benefits) are incurred during the second decade, 2031-2040.

It is important to note that the incremental costs presented in Figure 6-35, even at their highest, are equal in value to a relatively small portion of the total congestion and noise costs incurred in the baseline scenario. For instance, under Alternative 3, using a 3% discount rate, the incremental costs arising from noise and congestion between 2031-2040 were equal in magnitude to about 0.05% of the total congestion and noise baseline costs. On the smaller end, the additional costs incurred from congestion and noise under Alternative 1 between 2021-2030 (using a 3% discount rate) have a value approximately equal to 0.31% of the baseline congestion and noise costs.

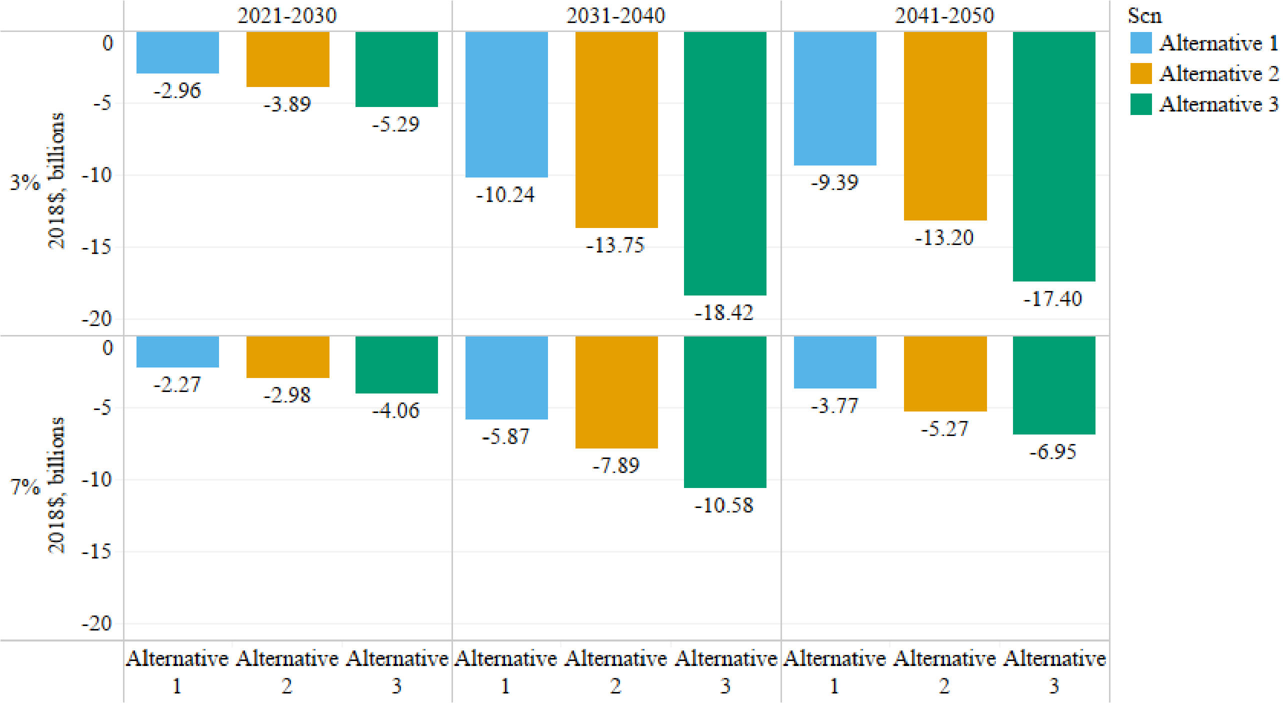

Figure 6-35 – Congestion and Noise Costs Relative to the No-Action Alternative (2018$, 3% and 7% discount)

Table 6-16 and Table 6-17 show the total and incremental social costs of congestion and noise under two sensitivity cases, one assuming a value of 10% for the rebound effect and the other assuming 20%. These tables illustrate the contrast between the rebound sensitivity cases and the central analysis, which assumes a rebound effect of 15% (see TSD Chapter 4).

Table 6-16 – Total and Incremental Social Costs of Congestion and Noise under the 10% Rebound Sensitivity Case (2018$, billions)

	Baseline		Alternative 1		Alternative 2		Alternative 3	
	3%	**7%**	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
Total Congestion Costs	5,831.1	4,443.3	5,835.9	4,446.6	5,837.8	4,448.0	5,840.0	4,449.7
Net Congestion Costs	-	-	4.9	3.2	6.7	4.7	8.9	6.4
Total Noise Costs	41.4	31.5	41.4	31.6	41.5	31.6	41.5	31.6
Net Noise Costs	-	-	0.04	0.02	0.05	0.04	0.07	0.05

Table 6-17 – Total and Incremental Social Costs of Congestion and Noise under the 20% Rebound Sensitivity Case (2018$, billions)

	Baseline		Alternative 1		Alternative 2		Alternative 3	
	3%	**7%**	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
Total Congestion Costs	5,885.6	4,484.7	5,895.7	4,491.3	5,899.3	4,493.9	5,904.1	4,497.2
Net Congestion Costs	-	-	10.1	6.6	13.8	9.2	18.5	12.5
Total Noise Costs	41.8	31.8	41.9	31.9	41.9	31.9	41.9	31.9
Net Noise Costs	-	-	0.07	0.05	0.10	0.07	0.14	0.09

6.5.4 Benefits of Increased Energy Security

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

As seen in Table 6-18, social costs of petroleum market externalities decrease (or, the benefits of increased energy security increase) steadily as alternatives become more stringent. The scope of these changes is relatively small; using the 3% discount rate, benefits are approximately equal to 1.3% (in Alternative 1), 2.3% (in Alternative 2), and 3.3% (in Alternative 3) of the total petroleum market externality costs in the baseline.

Table 6-18 – Social Costs of Petroleum Market Externalities (2018$, billions) Using the Model Year Perspective (MY 1981-2029)

	No-Action Alternative (Baseline)		**Alternative 1**		**Alternative 2**		**Alternative 3**	
	3%	**7%**	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
Petroleum Market Externalities	65.8	48.9	64.9	48.4	64.3	48.0	63.7	47.6
Difference from Baseline	-	-	0.9	0.5	1.5	0.9	2.1	1.3

Figure 6-36 shows the distribution of these avoided costs (positive benefits) across calendar year decades. The majority of benefits accrue after the first decade, and the largest share correspond to the period between 2041-2050, when the reductions in fuel consumption are largest relative to the baseline. As the figure shows, the benefits in the last decade (2041 – 2050) actually decrease relative to the preceding decade across all alternatives when discounted at 7 percent. This occurs because, even though the undiscounted benefits are increasing consistently over time, they are increasing slower than the 7 percent discount rate (but not the 3 percent discount rate, as the figure also shows).

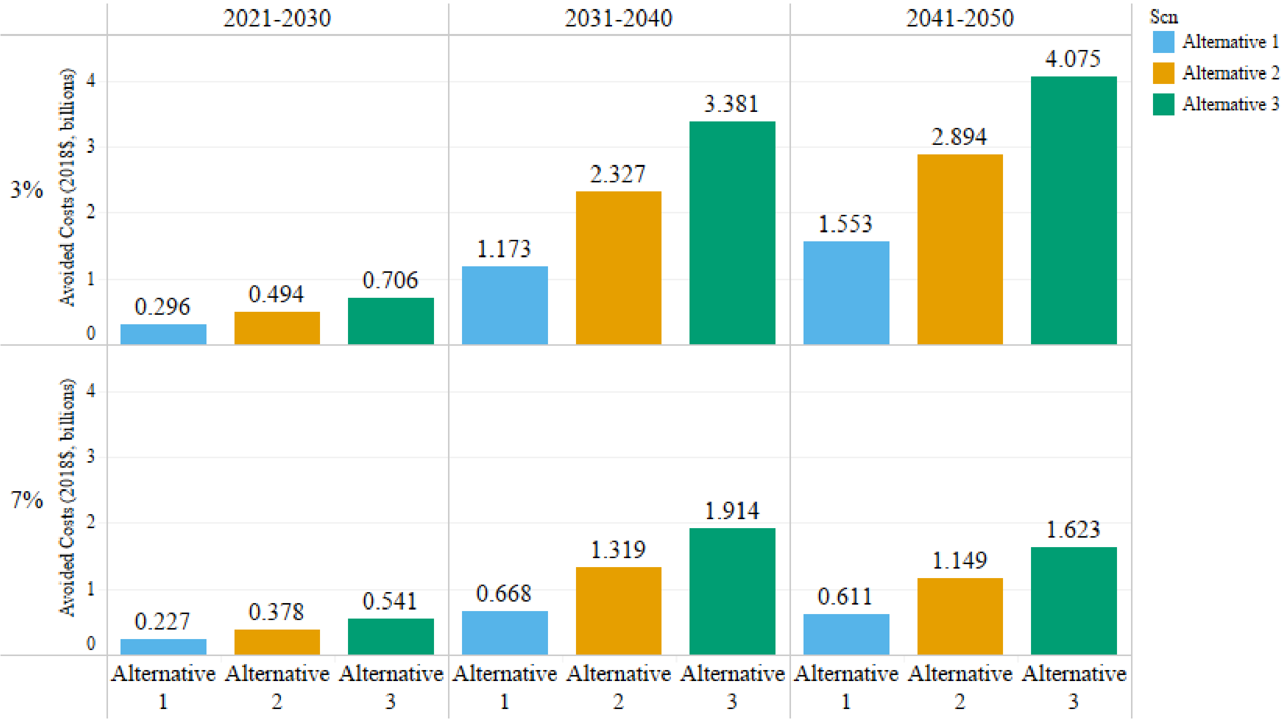

Figure 6-36 – Avoided Costs from Petroleum Market Externalities (2018$, 3% and 7% discount rates)

6.5.5 Safety Effects (Economic) of Changing Standards

Table 6-19 reports various safety costs across the different alternatives: fatality costs, non-fatal crash costs, and property damage crash costs, using the model year perspective.

Table 6-19 – Social Costs of Safety Impacts Across Alternatives (2018$, billions) Using the Model Year Perspective (MY 1981-2029)

	Alternative 1		**Alternative 2**		**Alternative 3**	
	3%	**7%**	**3%**	**7%**	**3%**	**7%**
Fatality Costs	7.8	5.2	14.5	9.9	21.1	14.7
Non-Fatal Crash Costs	4.9	3.3	8.0	5.6	11.1	7.9
Property Damage Crash Costs	1.0	0.7	1.6	1.1	2.2	1.5

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

6.5.6 Summary of Social Benefits and Costs

Table 6-20 and Table 6-21 describe the costs and benefits of increasing CAFE standards in each alternative, as well as the party to which they accrue. Manufacturers are directly regulated under the program and incur additional production costs when they apply technology to their vehicle offerings in order to improve their fuel economy. We assume that those costs are fully passed through to new car and truck buyers, in the form of higher prices. We also assume that any civil penalties – paid by manufacturers for failing to comply with their CAFE standards – are passed through to new car and truck buyers and are included in the sales price. However, those civil penalties are paid to the U.S. Treasury, where they currently fund the general business of government. As such, they are a transfer from new vehicle buyers to all U.S. citizens, who then benefit from the additional federal revenue. While they are calculated in the analysis, and do influence consumer decisions in the marketplace, they do not contribute to the calculation of net benefits (and are omitted from the tables below).

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

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

In addition to private benefits and costs, there are purely external benefits and costs that can be attributed to increases in CAFE standards. These are benefits and costs that accrue to society more generally, rather than to the specific individuals who purchase a new vehicle that was produced under more stringent CAFE standards. Of the external costs, the largest is the loss in fuel tax revenue that occurs as a result of falling fuel consumption. While drivers of new vehicles (purchased in years where CAFE stringency is increasing) save fuel costs at retail prices, the remainder of drivers experience a welfare loss. The revenue generated by fuel taxes helps to maintain roads and bridges, and improve infrastructure more generally, and that loss in fuel tax revenue is a social cost.[122] 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 impose a small additional social cost to all road users.

Among the purely external benefits created when CAFE standards are increased, the largest is the reduction in damages resulting from greenhouse gas emissions. The estimates in Table 6-20 assume a social cost of GHG emissions based on a 2.5% discount rate, and those in Table 6-21 assume social cost of GHG emissions based on a 3% discount rate. The associated benefits

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

related to reduced health damages from conventional pollutants and the benefit of improved energy security are both significantly smaller than the associated change in GHG damages across alternatives. As the tables also illustrate, the overwhelming majority of both costs and benefits are private costs and benefits that accrue to buyers of new cars and trucks, rather than external welfare changes that affect society more generally. This has been consistently true in CAFE rulemakings.

The choice of discount rate also affects the resulting benefits and costs. As the tables show, net social benefits are positive for Alternative 1 and 2 at a 3% discount rate, but only for Alternative 1 when applying a 7% discount rate to benefits and costs. Alternative 3 has negative net benefits under both discount rates. As the discussion at the start of Chapter 6.4 describes, the benefits of the regulatory alternatives, but especially Alternative 3, are concentrated in later years where a higher discount rate has a greater contracting effect. Totals in the following tables may not sum perfectly due to rounding.

Table 6-20 – Incremental Benefits and Costs Over the Lifetimes of Total Fleet Produced Through 2029 (2018$ Billions), 3% Percent Discount Rate, by Alternative

Alternative:	**1**	**2**	**3**
Private Costs			
Technology Costs to Increase Fuel Economy	34.3	67.6	100.1
Increased Maintenance and Repair Costs	0.0	0.0	0.0
Sacrifice in Other Vehicle Attributes	0.0	0.0	0.0
Consumer Surplus Loss from Reduced New Vehicle Sales	0.1	0.6	1.3
Safety Costs Internalized by Drivers	6.2	8.2	11.2
Subtotal - Private Costs	40.6	76.4	112.6
Social Costs			
Congestion and Noise Costs from Rebound-Effect Driving	7.3	10.1	13.5
Safety Costs Not Internalized by Drivers	7.5	15.8	23.2
Loss in Fuel Tax Revenue for the Highway Trust Fund	11.0	18.9	27.0
Subtotal - Social Costs	25.8	44.8	63.7
Total Social Costs	66.4	121.2	176.3
Private Benefits			
Reduced Fuel Costs	47.9	73.0	103.8
Benefits from Additional Driving	12.3	15.3	20.8
Less Frequent Refueling	-0.5	-0.8	0.3
Subtotal - Private Benefits	59.7	87.5	124.9
External Benefits			
Reduction in Petroleum Market Externality	0.9	1.5	2.1
Reduced Climate Damages	20.3	32.0	45.6
Reduced Health Damages	1.7	0.4	0.3
Subtotal - External Benefits	22.9	33.9	48.0
Total Social Benefits	82.6	121.4	172.9
Net Social Benefits	16.1	0.3	-3.4

Table 6-21 – Incremental Benefits and Costs Over the Lifetimes of Total Fleet Produced Through 2029 (2018$ Billions), 7% Percent Discount Rate, by Alternative

Alternative:	**1**	**2**	**3**
Private Costs			
Technology Costs to Increase Fuel Economy	28.1	55.0	81.4
Increased Maintenance and Repair Costs	0.0	0.0	0.0
Sacrifice in Other Vehicle Attributes	0.0	0.0	0.0
Consumer Surplus Loss from Reduced New Vehicle Sales	0.1	0.5	1.1
Safety Costs Internalized by Drivers	3.7	4.9	6.8
Subtotal - Private Costs	31.9	60.4	89.3
Social Costs			
Congestion and Noise Costs from Rebound-Effect Driving	4.8	6.8	9.3
Safety Costs Not Internalized by Drivers	5.5	11.6	17.3
Loss in Fuel Tax Revenue	7.0	11.9	17.0
Subtotal - Social Costs	17.3	30.3	43.6
Total Social Costs	34.6	60.6	87.2
Private Benefits			
Reduced Fuel Costs	29.7	44.9	63.7
Benefits from Additional Driving	7.5	9.3	12.7
Less Frequent Refueling	-0.4	-0.6	0.0
Subtotal - Private Benefits	36.8	53.6	76.4
External Benefits			
Reduction in Petroleum Market Externality	0.5	0.9	1.3
Reduced Climate Damages	13.3	21.0	29.9
Reduced Health Damages	0.9	0.1	-0.1
Subtotal - External Benefits	14.8	22.0	31.2
Total Social Benefits	51.6	75.6	107.6
Net Social Benefits	2.3	-15.1	-25.2

6.5.6.1 Social Benefits and Costs under Sensitivity Cases

Various sensitivity cases impact total social costs and benefits, such as differing rebound effect assumptions, fuel prices, and high and low SC-GHG values. The following tables present social costs, benefits, and net benefits under these sensitivity cases. For detailed information regarding the construction of each sensitivity case, see Chapter 7.

Table 6-22 shows the social benefits, costs, and net benefits for two different rebound assumption cases (10% and 20%). The central analysis assumes a rebound effect of 15%. To compare the sensitivity case values with the central analysis's cost and benefit values, see Table 6-20 and Table 6-21. Using the 3% discount rate when rebound = 0.10, all three alternatives have positive net benefits, but positive net benefits occur only in Alternative 1 when using the

7% discount rate. In the case when rebound = 0.20, net benefits are positive only under Alternative 1, for both discount rates, while net benefits are negative for the other two alternatives, regardless of discount rate. Totals in the following tables may not sum perfectly due to rounding.

Table 6-22 – Social Benefits, Costs, and Net Benefits under Different Rebound Cases

	Alternative 1		**Alternative 2**		**Alternative 3**	
Discount rate	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
Rebound = 10%						
Benefits	81.0	57.8	119.0	85.4	169.4	121.4
Costs	62.2	46.6	115.3	87.2	168.4	127.9
Net Benefits	18.8	11.2	3.7	-1.8	1.0	-6.5
Rebound = 20%						
Benefits	84.4	59.4	124.3	88.0	176.9	125.3
Costs	71.5	52.3	127.8	94.9	185.5	138.6
Net Benefits	13.0	7.0	-3.5	-6.9	-8.6	-13.2

The following three tables present the values resulting from sensitivity cases using different fuel price assumptions (Global Insight fuel prices, EIA's AEO low fuel price case, and EIA's AEO high fuel price case).

Table 6-23 shows the social costs, benefits, and net benefits corresponding to the sensitivity case that uses Global Insights fuel prices. In comparison to the net benefits for the central case (see Table 6-20 and Table 6-21) which show positive net benefits under the 3% discount rate under Alternatives 1 and 2, the net benefits under this sensitivity case are positive only under Alternative 1.

As shown in Table 6-24, the net benefits under the AEO low fuel price sensitivity case are positive only in Alternative 1, and are negative in the other two alternatives, under both discount rates. In the AEO high fuel price sensitivity case, shown in Table 6-25, net benefits have a higher magnitude than those in the central case, and are positive across all three scenarios and both discount rates.

Table 6-23 – Social Costs, Benefits, and Net Benefits under the Global Insights Fuel Prices Case

	Alternative 1		**Alternative 2**		**Alternative 3**	
Discount rate	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
Benefits	74.1	54.1	106.3	78.6	151.7	112.1
Costs	67.9	49.9	125.3	92.6	184.5	136.8
Net Benefits	6.2	4.2	-19.0	-14.0	-32.9	-24.7

Table 6-24 – Social Costs, Benefits, and Net Benefits under the AEO Low Fuel Price Case

	Alternative 1		Alternative 2		Alternative 3	
Discount rate	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
Benefits	74.7	54.9	103.4	77.6	139.0	104.7
Costs	70.9	51.4	135.4	99.4	196.2	144.5
Net Benefits	3.7	3.5	-32.0	-21.8	-57.1	-39.8

Table 6-25 – Social Costs, Benefits, and Net Benefits under the AEO High Fuel Price Case

	Alternative 1		Alternative 2		Alternative 3	
Discount rate	**3%**	**7%**	**3%**	**7%**	**3%**	**7%**
Benefits	86.0	58.6	151.3	103.6	225.4	154.3
Costs	50.0	36.6	103.7	78.5	151.7	116.0
Net Benefits	35.9	22.0	47.6	25.1	73.7	38.3

NHTSA presents a sensitivity analysis in Table 6-26 and Table 6-27where both distant future and nearer-term GHG impacts are discounted using the 3% rate combined with all other costs and benefits discounted at 3%.

Table 6-26– Comparison of Results Using a 3% Discount Rate for All Impacts except GHGs with Impacts Using either 2.5% or 3% for Climate-Related Benefits, Model Years 1981 through 2029

	Totals	
	3%/2.5% SC-GHG Discount Rate	**3%/3% SC-GHG Discount Rate**
Costs	121.1	121.1
Benefits	121.4	110.5
Net Benefits	0.3	-10.6

Table 6-27 – Comparison of Results Using a 3% Discount Rate for All Impacts except GHGs with Impacts Using either 2.5% or 3% for Climate-Related Benefits, Calendar Years 2021 through 2050

	Totals	
	3%/2.5% SC-GHG Discount Rate	**3%/3% SC-GHG Discount Rate**
Costs	333.6	333.6
Benefits	433.6	391.7
Net Benefits	100	58.1

Table 6-26 presents the social costs, benefits, and net benefits for two sensitivity cases that use different SC-GHG values, those estimated from the 95th percentile at 3%, and those estimated using a 5% SC-GHG discount rate. These provide bounding estimates for total benefits since they represent the lowest and highest benefits resulting from alternative combinations of discount rates used to construct the SC-GHG values and those used to discount other benefits and costs.[123] The SC-GHG values calculated using the 95th percentile are matched to the 3% discount rate for all other social costs and benefits, while the SC-GHG values corresponding to the 5% SC-GHG discount rate are matched to the 7% discount rate for other costs and benefits. For a detailed explanation of these discount rates, see TSD Chapter 6.2.1.

Under the high SC-GHG case, net benefits are positive and of higher magnitudes than seen in the central analysis (see Table 6-20 and Table 6-21), across all three alternatives. Under the low SC-GHG case, net benefits are negative under all three alternatives.

Table 6-28 – Social Costs, Benefits, and Net Benefits under High and Low SC-GHG Cases

	Alternative 1		**Alternative 2**		**Alternative 3**	
Discount Rate	**95th pct. SC-GHG (other costs 3%)**	**5% SC-GHG (other costs 7%)**	**95th pct. SC-GHG (other costs 3%)**	**5% SC-GHG (other costs 7%)**	**95th pct. SC-GHG (other costs 3%)**	**5% SC-GHG (other costs 7%)**
Benefits	102.6	41.7	153.0	60.0	217.9	85.3
Costs	66.5	49.3	121.1	90.7	176.3	132.8
Net Benefits	36.1	-7.6	31.9	-30.7	41.6	-47.5

6.6 Physical and Environmental Effects

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

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[123] Costs and other benefits are discounted following guidance from OMB Circular A-4. Climate benefits are discounted following the "Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide: Interim Estimates under Executive Order 13990."

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. As can be seen from Table 6-27 and Figure 6-37, the differences in the on-road fleet and VMT between alternatives are marginal; however, the differences in the amount of aggregate fuel consumed and CO_2 emitted are more pronounced in the latter two decades.

Table 6-29 – Cumulative Impacts for All Alternatives

	Alternative 0	**Alternative 1**	**Alternative 2**	**Alternative 3**
On-Road Fleet (Million Units)				
2021 - 2030	2,546	2,543	2,541	2,538
2031 - 2040	2,678	2,665	2,650	2,636
2041 - 2050	2,715	2,704	2,690	2,677
Vehicle Miles Traveled (Billion Miles)				
2021 - 2030	30,491	30,519	30,528	30,542
2031 - 2040	33,164	33,290	33,333	33,392
2041 - 2050	33,220	33,374	33,437	33,508
Fuel Consumption (Billion Gallons/GGE)				
2021 - 2030	1,223	1,214	1,209	1,203
2031 - 2040	1,132	1,098	1,069	1,040
2041 - 2050	1,020	969	930	894
CO_2 Emissions (mmT)				
2021 - 2030	13,489	13,394	13,342	13,280
2031 - 2040	12,519	12,128	11,815	11,502
2041 - 2050	11,279	10,711	10,285	9,891

Figure 6-37 – Cumulative Impacts for All Alternatives

The sections that follow provide additional detail of the aforementioned effects, while comparing the outcomes of this proposal between the action and the no-action alternatives.

6.6.1 Changes to On-Road Fleet and Vehicle Miles Traveled

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

Figure 6-38 presents the size of the on-road fleet through 2050 under the no-action alternative. The vertical bars in the figure denote the annual progression of the passenger car and light truck fleets independently, while the evolution of the combined fleet is depicted by the gray line. As demonstrated by Figure 6-38, the overall fleet continues to grow at a steady pace (until around 2043), with the passenger car and light truck shares being roughly the same. During the middle set of years (between 2025 and 2040), the on-road truck fleet undergoes faster growth, overtaking the passenger car vehicles by a small margin; however, the car fleet eventually catches up in the latter years.

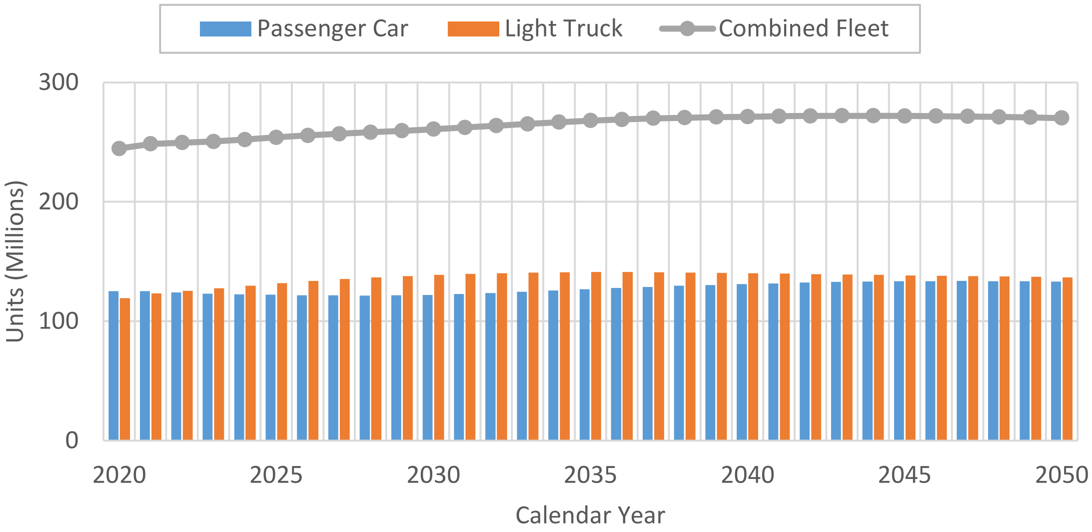

Figure 6-38 – Total On-Road Fleet in the Baseline Scenario

At the onset of analysis for this rulemaking (in MY 2020), the production of light trucks (7.66m units) exceeds that of passenger cars (5.93m units) by about 30%. Throughout analysis of the no-action alternative, however, as both fleets get progressively more efficient (albeit by less than under the action alternatives), the volume of trucks sold generally declines in response to higher fuel prices. Meanwhile, passenger cars see a sharp rise early on, followed by a plateauing in the amount of units produced and sold in the mid to out years. The initial surplus of truck sales leads to an eventual shift of the on-road fleet from cars to trucks in the middle set of years, as aging vehicles are retired in favor of newer models. However, the subsequent decrease in the production of new light truck models, coupled with the gains realized by the passenger car fleet, results in the on-road fleet gradually shifting some of the volume back to passenger cars. The outcome of this behavior is visualized by Figure 6-38.

Along with the annual growth experienced by the on-road fleet in the no-action alternative, the total amount of vehicle miles traveled also increases steadily year over year, as illustrated in Figure 6-39. Around calendar year 2040, however, the total fleet-wide VMT peaks, and begins a marginal annual descend. The VMT for both passenger car and light truck fleets follows a similar pattern of growth, which was observed for the on-road fleet. The share of miles traveled by the car and truck fleets is roughly the same throughout the years, with trucks showing a stronger presence on the road in the mid years, while passenger cars regain ground in the latter ones.

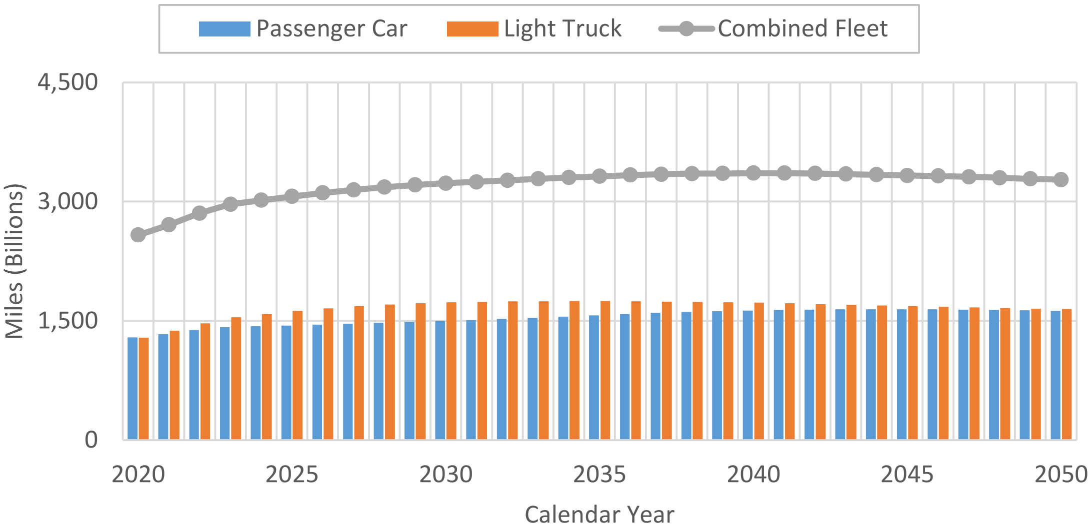

Figure 6-39 – Total VMT in the Baseline Scenario

With the increases in stringency that the action alternatives represent, the number of new vehicles produced and sold during future model years declines slightly as compared to the no-action alternative. As with the no-action alternative, this reduction translates to the cumulative decrease of the on-road population of the combined fleet in each calendar year, as can be seen in Figure 6-40. This figure presents the incremental differences, as compared to the baseline scenario (the no-action alternative), for each action alternative evaluated as part of this rulemaking. From this figure, higher CAFE standards, as defined for Alternative 3, lead to a greater reduction of the volume of the on-road fleet as compared to the alternatives with smaller increases of the standards.

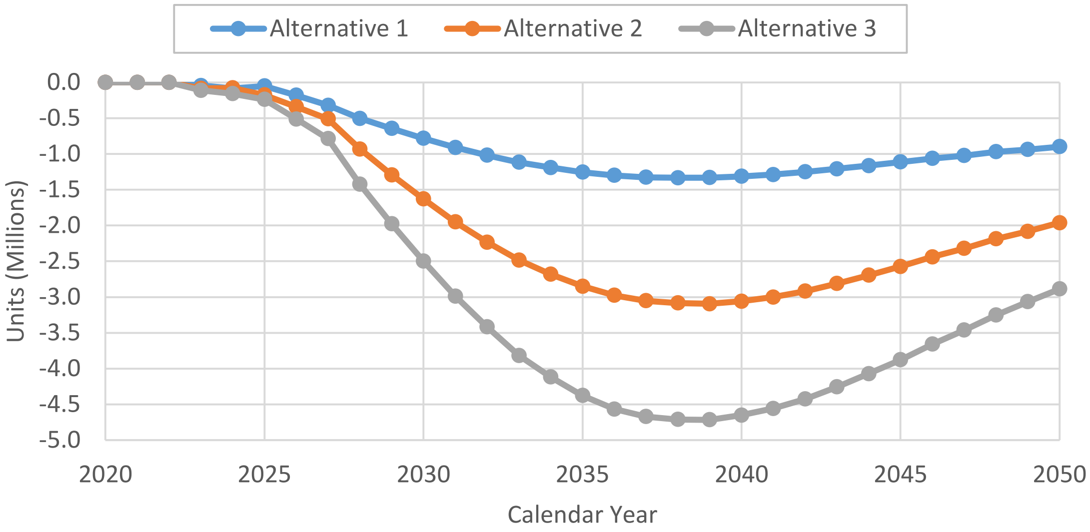

Figure 6-40 – Changes in On-Road Fleet over Baseline (Combined Fleet)

When considering the on-road population of the individual fleets, however, more stringent standards slightly decrease the volume of the passenger car fleet, while also slightly increasing the amount of light trucks on the road, as compared to the no-action alternative. Incremental improvements from fuel consumption-improving technologies typically have a greater impact on vehicles that begin with lower fuel economy ratings, as they are able to achieve a greater reduction in the consumption of fuel, than what would have been possible by their higher rated counterparts. Thus, the volume of light trucks is more likely to be impacted by pushing the CAFE standards beyond the baseline level, since the decreases in the cost of travel for the truck fleet are marginally better than for the car fleet. Figure 6-41 and Figure 6-42 show the incremental on-road fleet differences for each alternative over the baseline scenario.

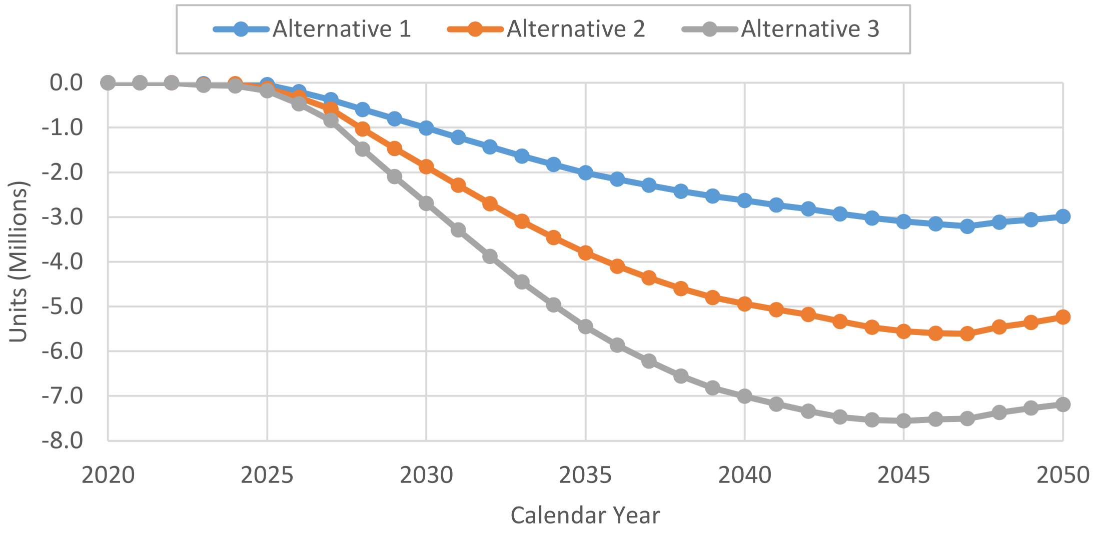

Figure 6-41 – Changes in On-Road Fleet over Baseline (Passenger Car Fleet)

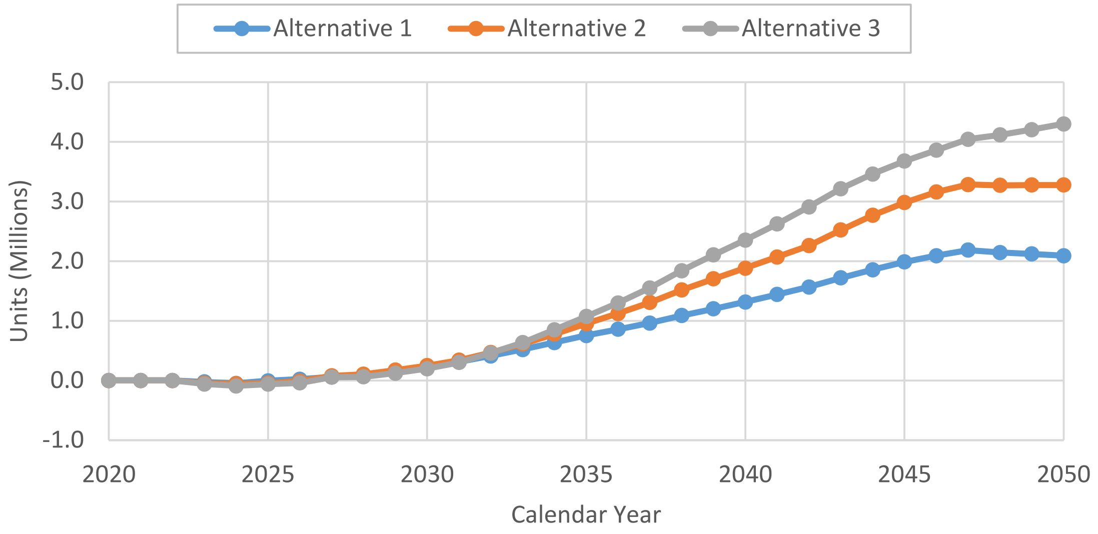

Figure 6-42 – Changes in On-Road Fleet over Baseline (Light Truck Fleet)

While the volume of the on-road fleet decreases slightly as a consequence of the new CAFE standards defined by the action alternatives, the amount of total miles traveled by the entire fleet grows slightly when compared to the no-action alternative. The VMT increases, which are attributable to the fuel economy rebound effect, result in an overall greater demand for travel, as the average cost-per-mile reduces. Figure 6-43 illustrates the incremental differences for each calendar year between the action alternatives and the baseline scenario.

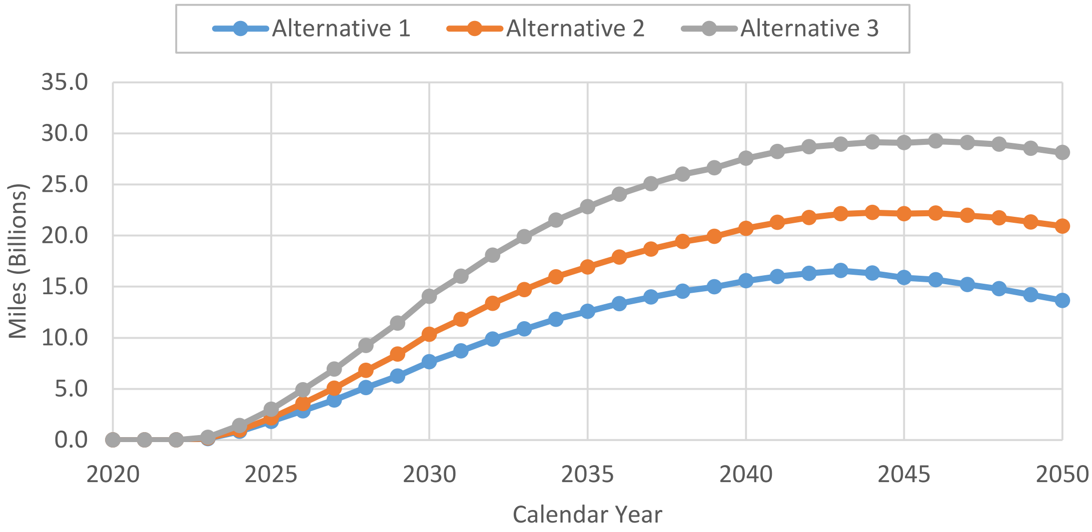

Figure 6-43 – Changes in VMT over Baseline (Combined Fleet)

Although the rebound effect increases VMT for the entire fleet, the decline of the passenger car population in the action alternatives is not enough to offset the greater travel demand ascribed to each individual vehicle. Hence, the car fleet sees a marginal reduction in the total amount of miles traveled against the no-action alternative, as shown in Figure 6-44. In contrast, the higher volume of light trucks as compared to the baseline, along with their increases in fuel economy, result in the truck fleet contributing a greater portion of total on-road miles, as presented by Figure 6-45.

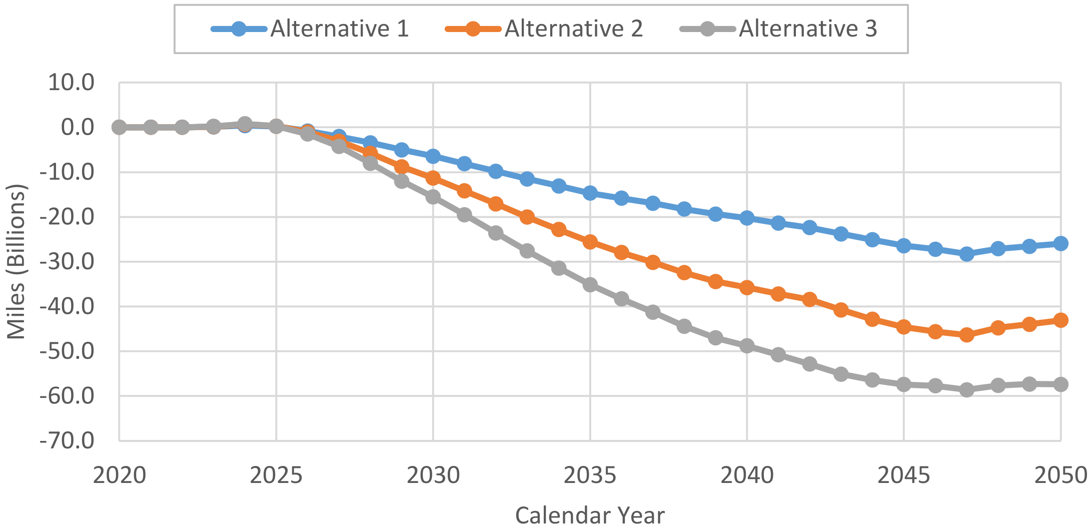

Figure 6-44 – Changes in VMT over Baseline (Passenger Car Fleet)

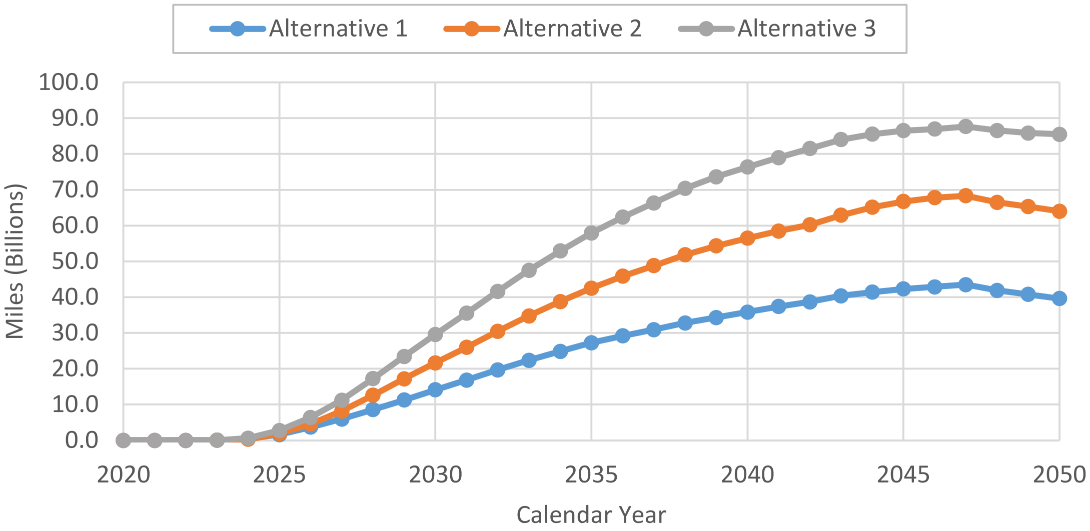

Figure 6-45 – Changes in VMT over Baseline (Light Truck Fleet)

6.6.2 Changes to Fuel Consumption and Emissions of Greenhouse Gases

Increases in CAFE standards reduce the total amount of fuel consumed, as more fuel-efficient vehicles enter the market, displacing the older and less efficient models. With the aging fleet gradually turning over with each subsequent calendar year, the benefits of higher standards enforced during earlier model years become even more apparent, as the annual fuel consumption of the U.S. passenger vehicle fleet declines further. Moreover, with the rise of alternative fuel vehicles, specifically PHEVs and BEVs, the use of gasoline within the light-duty fleet is slowly supplanted by electricity. Figure 6-46 presents the consumption of various fuel types in each calendar year for the no-action alternative. In Figure 6-46, the consumption of gasoline, E85, and diesel are denominated in gallons of the native fuel (e.g., gallons of E85), while electricity and hydrogen are specified as gasoline gallon equivalent (GGE).

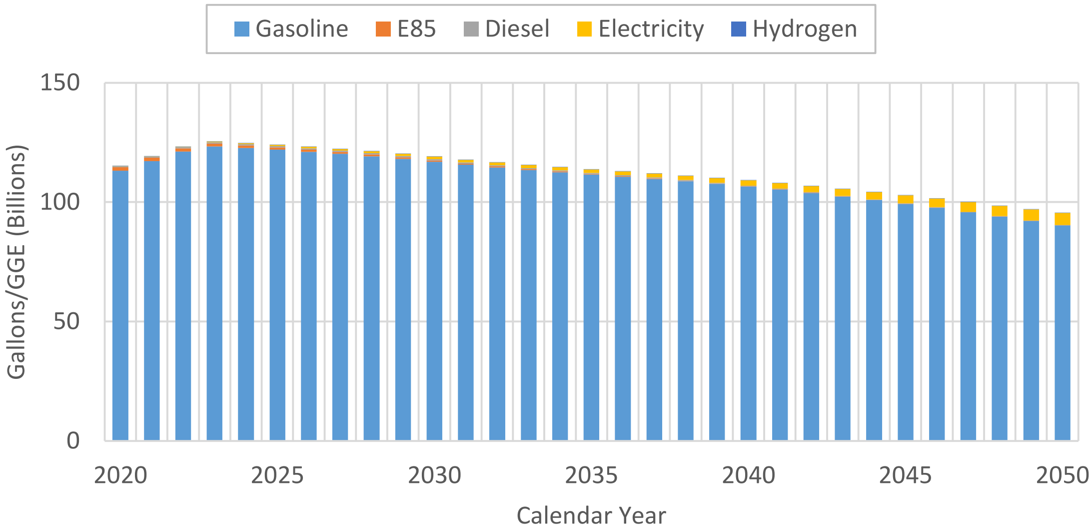

Figure 6-46 – Fuel Consumption in the Baseline Scenario

As illustrated by Figure 6-46, gasoline remains the predominant source of fuel into the future under the no-action alternative. Meanwhile, the collective sum of all the other fuel types used by the on-road fleet is only a fraction of the total energy consumed during each calendar year.[124] Hence, most of fuel-related savings are attainable through the reduction of gasoline use. However, as shown in Figure 6-47, electricity has the strongest annual growth among the non-gasoline fuels. Over the same timeframe, the use of E85 and diesel steadily declines.

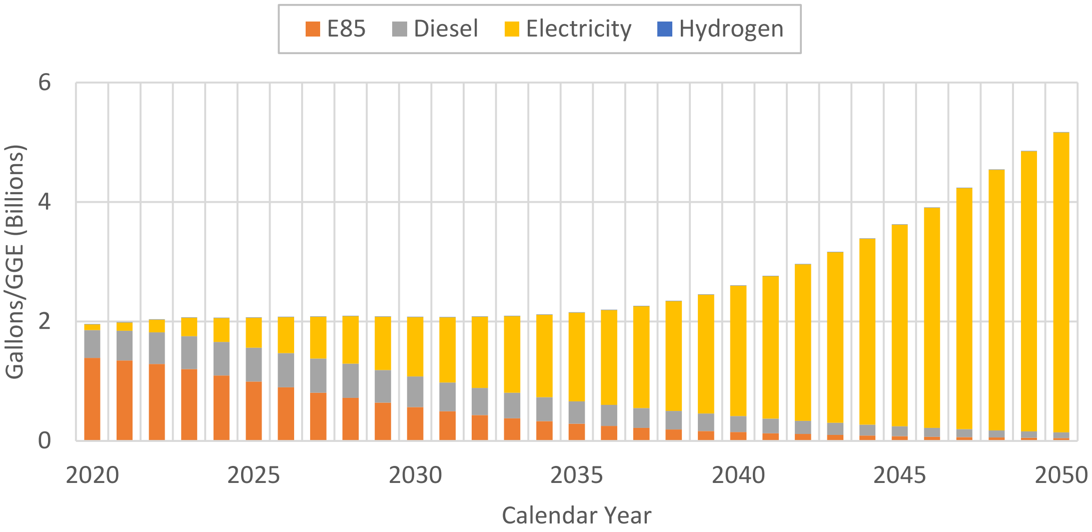

Figure 6-47 – Consumption of Non-Gasoline Fuels in the Baseline Scenario

Since consumption of fuel by the fleet directly releases carbon dioxide, reducing overall energy consumption also reduces emissions of CO_2. Equally, emissions attributed to the other greenhouse gases (GHG) – methane (CH_4) and nitrous oxide (N_2O) – see an annual decline as well. Figure 6-48 displays the amount of annual GHG emissions generated by the light-duty fleet under the standards defined by the no-action alternative. In the figure, the emissions of CO_2, CH_4, and N_2O are combined and presented using a cumulative total. The amount of CO_2 is measured using million metric tons (mmT),[125] while emissions coming from CH_4 and N_2O are scaled by the global warming potential (GWP) multipliers of 25 and 298 respectively,[126] and are denominated using mmT of CO_2 equivalent emissions. However, CO_2 remains the predominant contributor of greenhouse gases, making up approximately 86% of total GHG upstream emissions and 99.5% of GHG tailpipe emissions.[127] As shown in Figure 6-48, the upstream emissions, which are attributed to the production and distribution of various types of fuel, stay at a mostly constant level throughout the years, with only a mild amount of fluctuation. The

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[124] By CY 2050, the total amount of non-gasoline fuel consumed by the on-road fleet reaches 5.4% in the no-action alternative.

[125] Or kilo-kilo-Megagrams, as they are more commonly referred to in some circles.

[126] GWP multipliers here are derived from the 4th IPCC Report; NHTSA is aware that the 5th IPCC report changes these values slightly, but tentatively concludes that the difference is not meaningful for purposes of Figure 6-12. NHTSA calculates emissions of CH_4 and N_2O directly in terms of tons emitted for benefits purposes.

[127] Depending on calendar year being considered, the CO_2 share of GHG upstream emissions varies by about 1.5%, while the share of tailpipe emissions varies by about 0.2%.

downstream emissions, which occur during vehicle operation, see a declining trend similar to what was observed for the overall annual consumption of fuel.

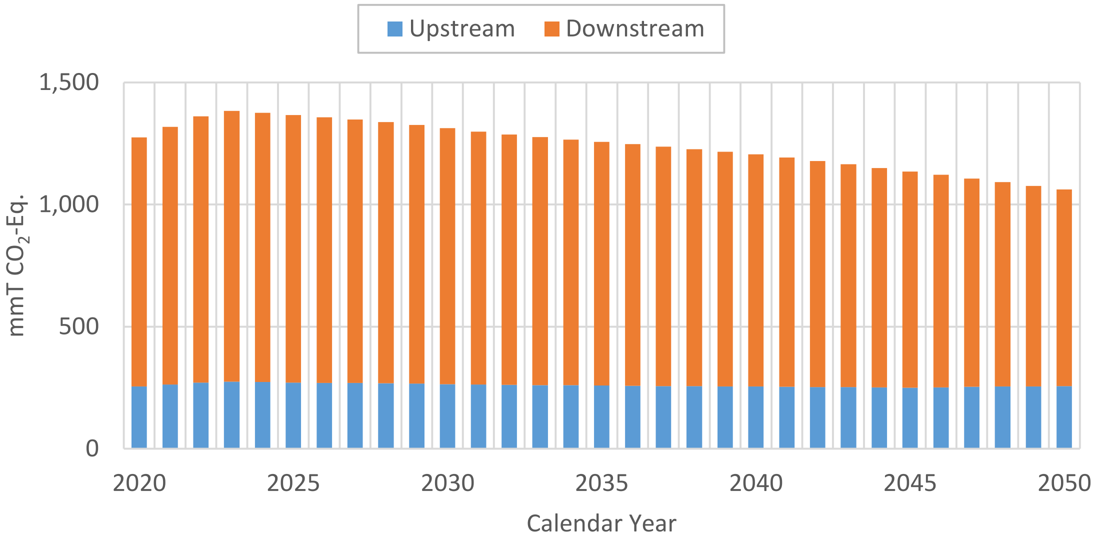

Figure 6-48 – Emissions of GHG in the Baseline Scenario

Fleet-wide fuel consumption and GHG emissions continue to decline further under the action alternatives in response to higher CAFE standards. Figure 6-49 presents the incremental differences to overall energy consumption, as compared to the baseline scenario, for each action alternative. As shown in the figure, the outcome of the progressively increasing stringency defined by each action alternative is greater reductions in the amount of fuel consumed by the on-road light duty fleet.

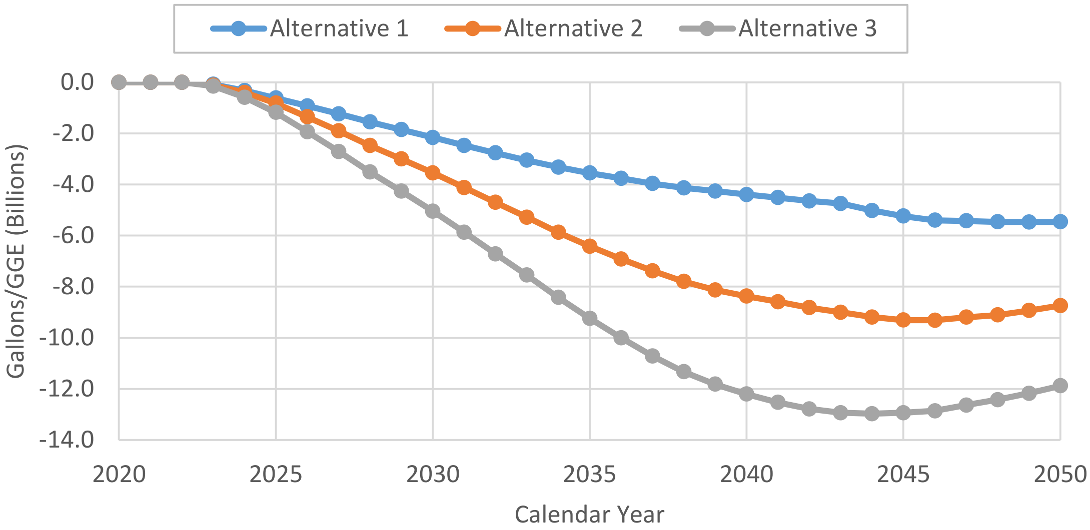

Figure 6-49 – Changes in Fuel Consumption over Baseline

As was the case under the no-action alternative, gasoline remains the dominant source of fuel for the light-duty fleet in all calendar years, and for all action alternatives. However, with more stringent standards, gasoline consumption falls by larger margins, while the annual use of electricity increases further. Figure 6-50 separates and presents the incremental changes of gasoline and electricity use, as those had the largest observable difference over the baseline. The differences observed between the action and the no-action alternatives for all other fuels were inconsequential, and are hence omitted from the figure.

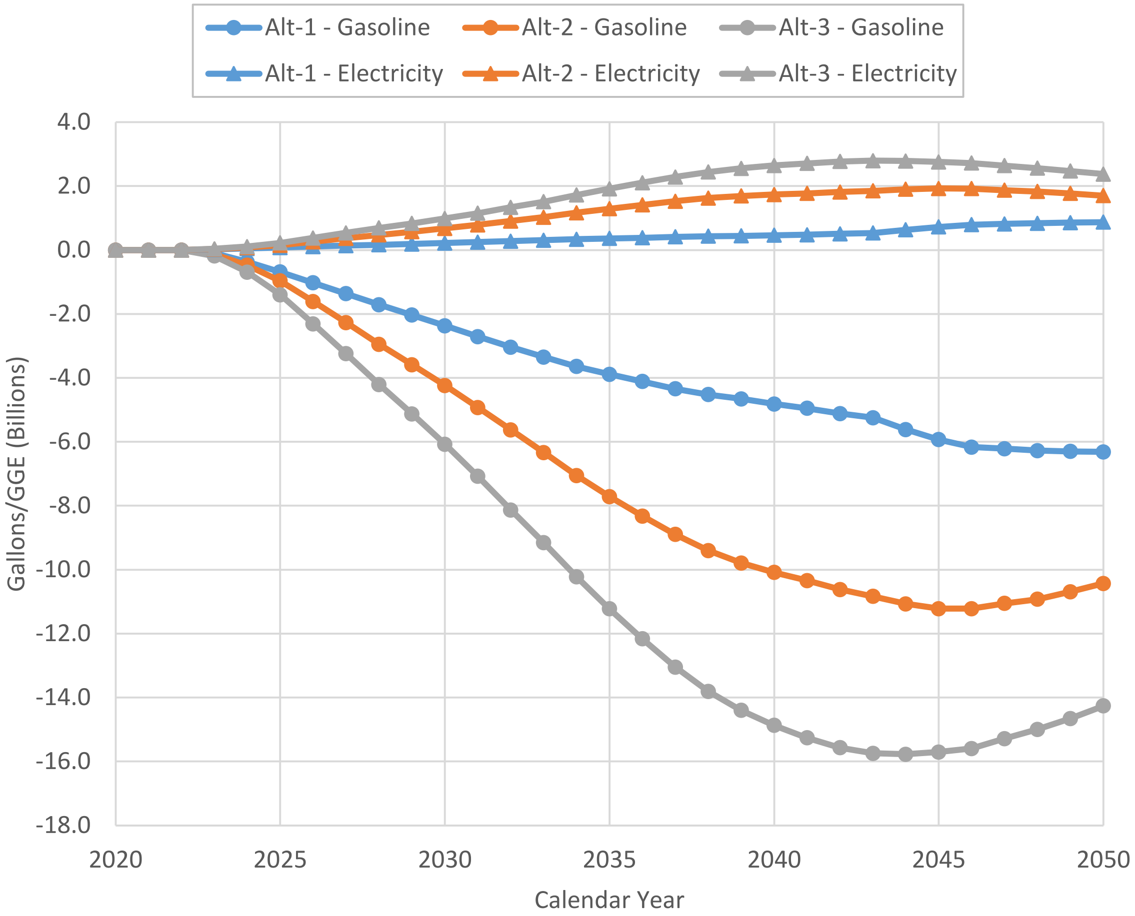

Figure 6-50 – Changes in Gasoline and Electricity Consumption over Baseline by Fuel Type

Along with the reduction of fuel use, the GHG emissions generated by the on-road fleet also decline in each action alternative. As shown in Figure 6-51, the incremental emissions of greenhouse gases decrease at a greater rate as the standards defined by the action alternatives increase in stringency.

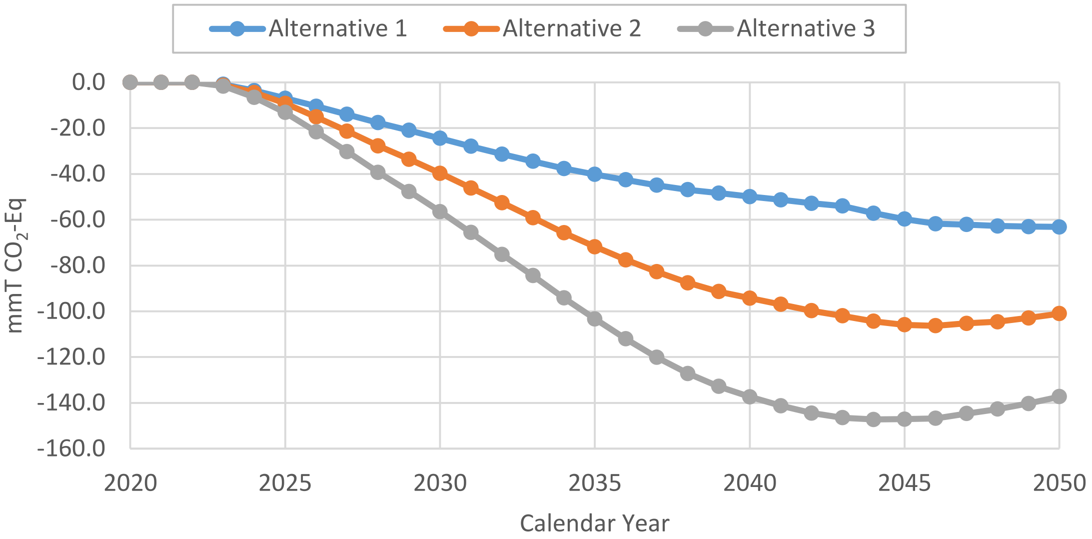

Figure 6-51 – Changes in Total GHG Emissions Compared to Baseline

Figure 6-52 presents the incremental upstream emissions of GHG as compared to the no-action alternative. As shown in the figure, the differences between action alternatives are minor. However, it is worth noting that Alternative 1 (the least stringent option) shows a greater reduction of GHG upstream emissions during the mid-years as compared to the other two, although it relinquishes its lead during the last few years.

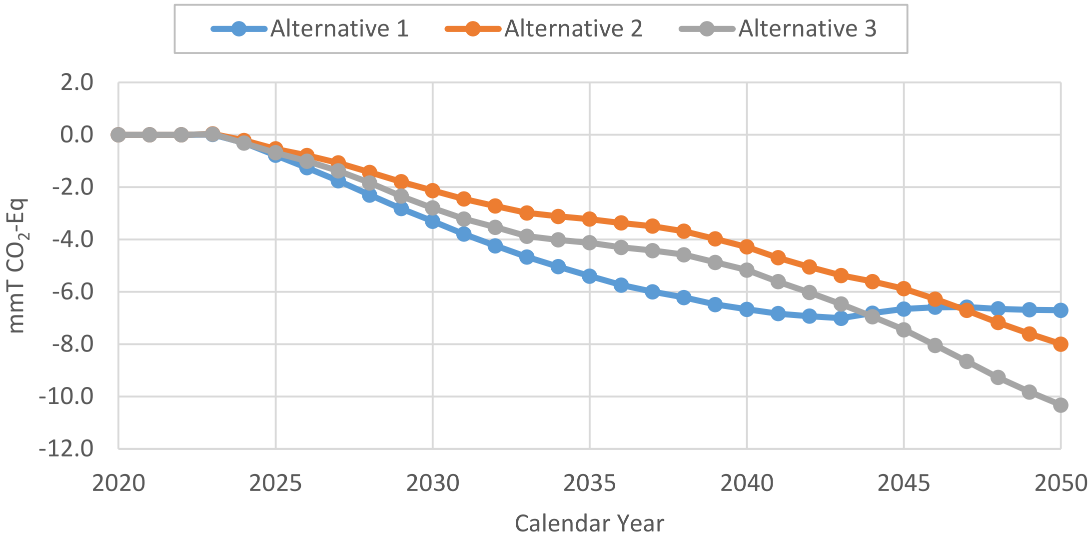

Figure 6-52 – Changes in Upstream GHG Emissions Compared to Baseline

The behavior depicted by the preceding figure can be attributed to the lower presence of electricity-consuming vehicles (PHEVs and BEVs) in Alternative 1 than the other action alternatives. According to GREET, the amount of greenhouse gases, in particular CO_2, emitted during electricity generation is currently significantly higher on average than emissions that occur due to production and distribution of gasoline.[128] As was noted by Figure 6-50 earlier, electricity consumption increased with more stringent alternatives. Accordingly, upstream emissions of GHG arising from the use of electricity increased as well.

Figure 6-53 displays the incremental GHG upstream emissions for gasoline and electricity for each action alternative. As with fuel consumption, the other fuel types do not differ meaningfully here, and are therefore omitted. As shown in the figure, the increases in electricity emissions are comparatively more significant than decreases in gasoline emissions for Alternatives 2 and 3 during the middle years. However, the downward trend in electricity emissions appearing in the last few years for Alternatives 2 and 3 are simply the effect of the baseline catching up with its own electricity use (see Figure 6-47) and diminishing the incremental impacts from these two alternatives. Conversely, the annual rise in consumption of electricity for Alternative 1 follows closer in line with the baseline, therefore forgoing the downward trend seen for the other two alternatives.

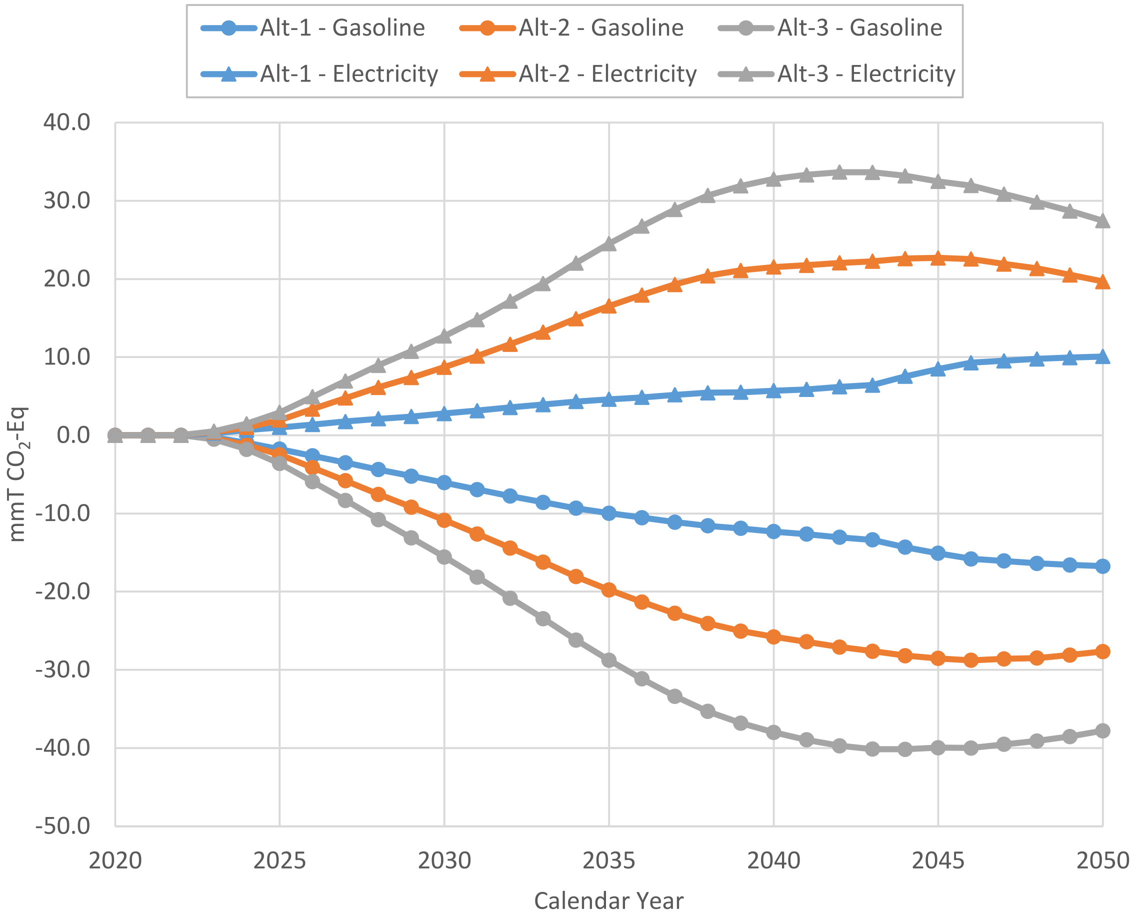

Figure 6-53 – Changes in Upstream Gasoline and Electricity GHG Emissions over Baseline

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

The incremental differences in downstream GHG emissions between the action alternatives and the baseline may be more intuitive, as demonstrated by Figure 6-54. The highest CAFE standards, defined by Alternative 3, lead to the greatest reduction of downstream emissions of GHG occurring during vehicle operation.

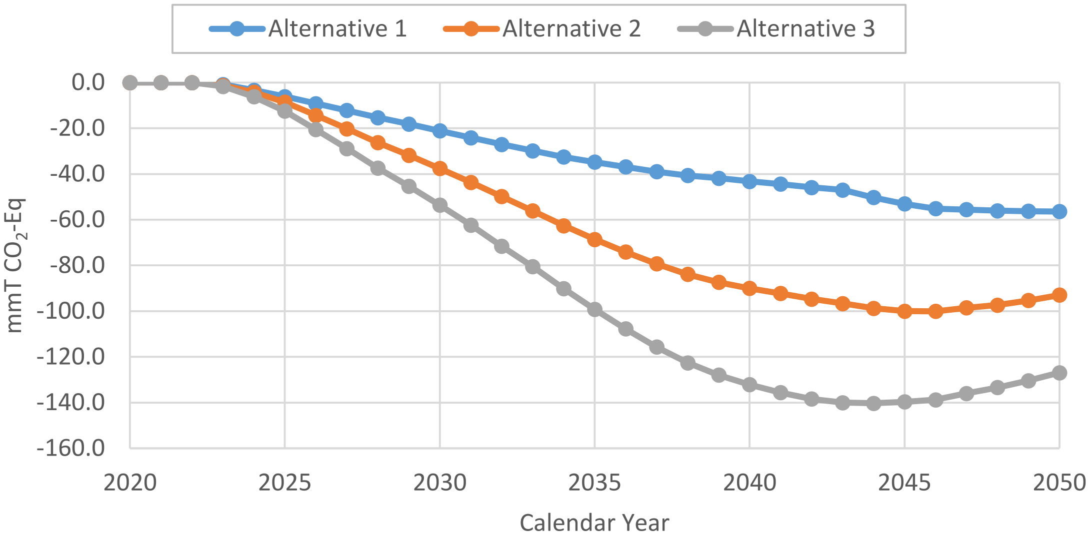

Figure 6-54 – Changes in Downstream GHG Emissions over Baseline

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

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

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

Figure 6-55 shows a comparison of fuel consumption between sensitivity cases for the no-action alternative. The overall consumption from all fuel types is presented in the larger chart at the top, while the left and right portions at the bottom provide separate views of gasoline and electricity consumption, respectively. For all sensitivity cases, gasoline still remains the dominant source of fuel, following a steady annual decline, while electricity use rapidly increases year after year.

The *high fuel price* case shows the fastest annual reduction in fuel consumption, while the *low fuel price* case is the slowest. These differences can be attributed to the degree of voluntary over-compliance that the CAFE Model employees during analysis. Under the *high fuel price* case, the fuel savings resulting from technology application increase, leading to a greater selection of cost-effective technologies[129] and to additional over-compliance. For the *low fuel price* case, however, the potential for fuel savings diminishes, which, in turn, reduces the amount of voluntary over-compliance. Readers may also note that under the *high fuel price* case, electricity use rises significantly when compared to the central analysis. Once again, this can be attributed to much higher fuel savings, resulting in PHEVs and BEVs becoming more attractive options.

As shown in Figure 6-55, the *faster battery cost learning* case results in the greater reduction to overall annual fuel consumption, as compared to the central case, while also having significantly greater adoption of electric-powered vehicles. Meanwhile, the *slower battery cost learning* case falls just below the central analysis for overall fuel use, but also shows a noticeably larger reduction to the amount of electricity consumed. These results can be explained by the cumulative impacts of battery cost learning beginning to amplify and influence PHEV and BEV technology utilization starting around CY 2035, as the two cases are shown diverging from the central analysis during that timeframe.

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

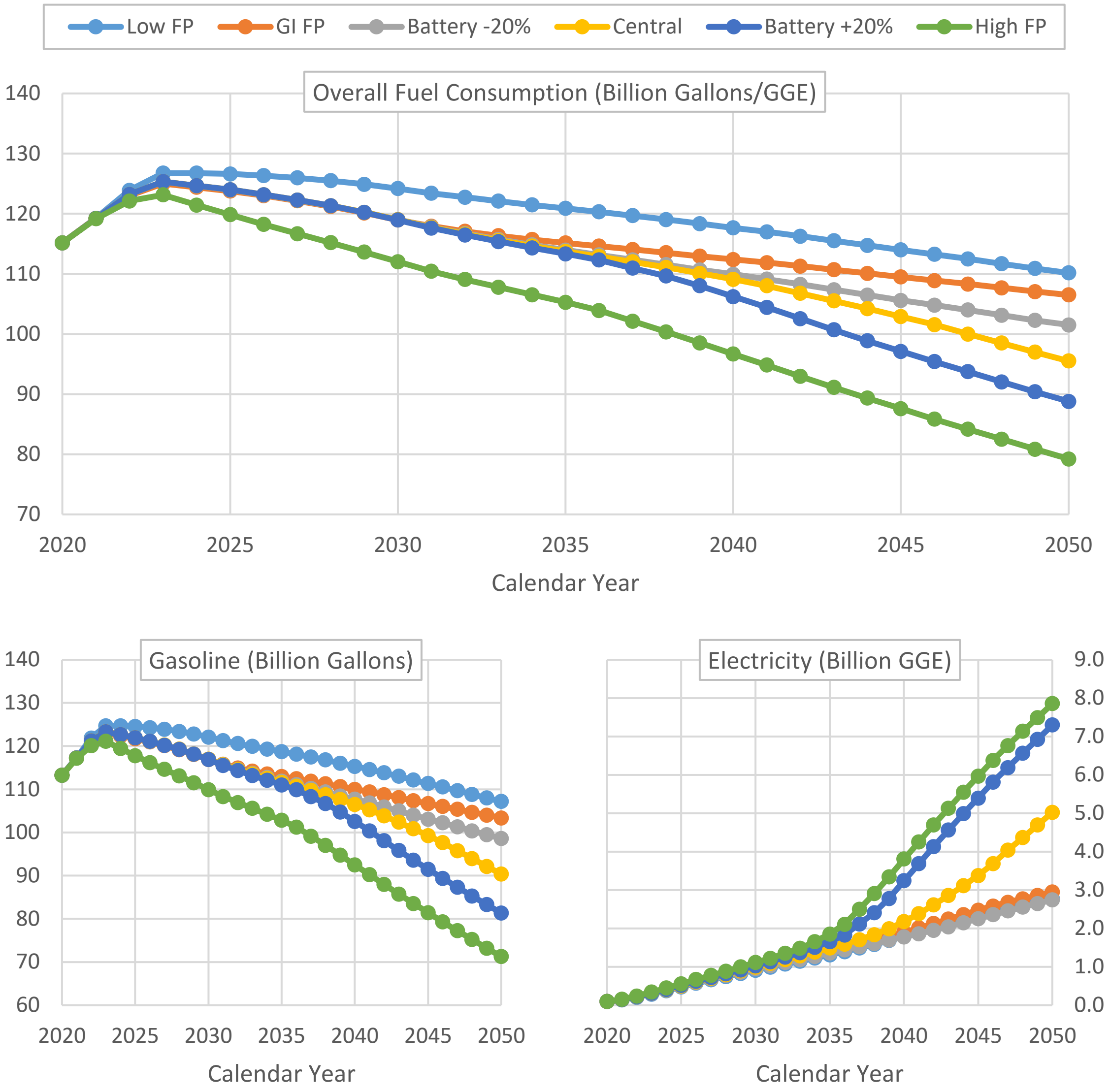

Figure 6-55 – Comparison of Fuel Consumption Across Sensitivity Cases in the Baseline Scenario

As noted earlier, fuel consumed by the vehicles during vehicle operation emits GHGs. Hence, as demonstrated in Figure 6-56, the overall and downstream GHG emissions for all sensitivity cases under the no-action alternative show the same patterns and annual trends that were observed for the total fuel consumption. For the upstream GHG emissions (bottom-left chart in Figure 6-56), however, the two cases with alternative battery cost learning rates have swapped the relative positions with respect to the central case. As stated previously, according to GREET, upstream GHG emissions from electricity generation are higher than from production and distribution of gasoline. Hence, the significantly greater electricity consumption under the *faster battery cost learning* case results in an increase of upstream emissions when compared to the central analysis. For the *slower battery cost learning* case, however, the reduction in electricity use has the opposite effect, decreasing the upstream emissions with respect to the central case. Even though the *high fuel price* case also shows a surge in the use of electricity, the significant reduction in gasoline consumption for that sensitivity case contributes to the lowest *net* amount of upstream emissions.

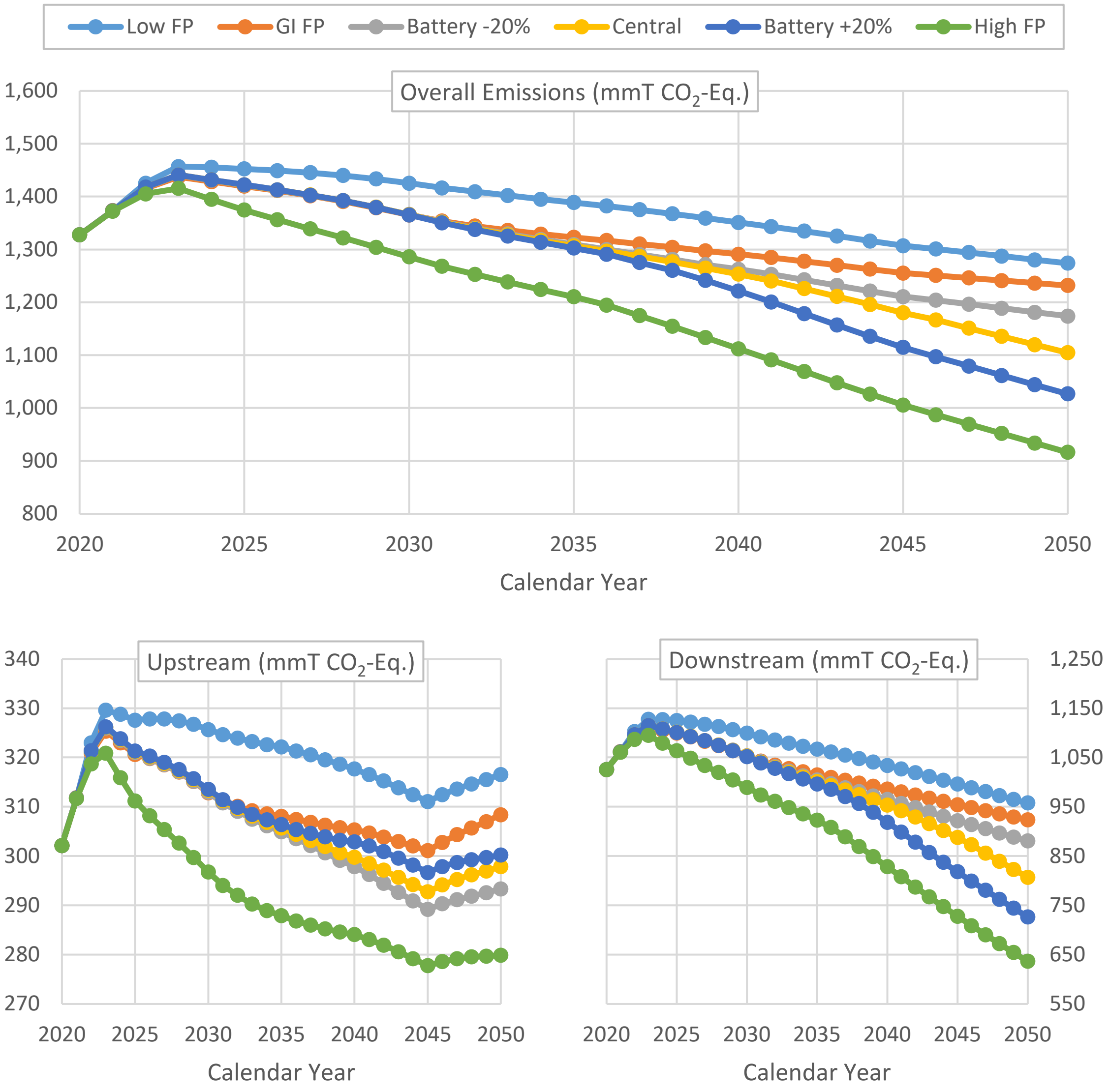

Figure 6-56 – Comparison of GHG Emissions Across Sensitivity Cases in the Baseline Scenario

For the rest of the action alternatives, when considering the values on an absolute basis, the patterns of behavior and relative ordering of sensitivity cases were identical to the no-action alternative, although with lower overall fuel consumption and GHG emissions. Figure 6-57 and Figure 6-58 present the comparison of cumulative impacts to fuel consumption and GHG emissions over the next three decades for all sensitivity cases and action alternatives.

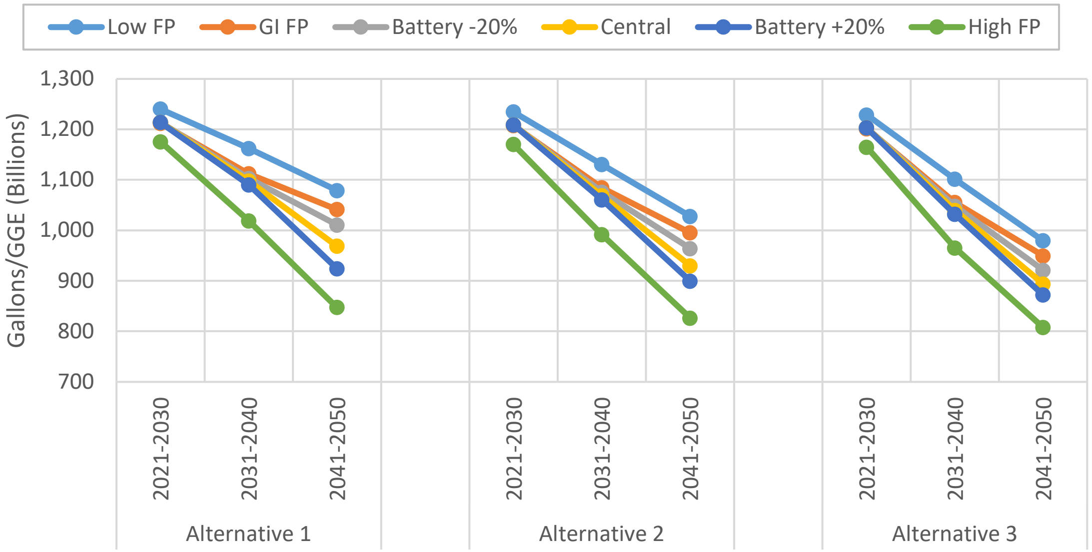

Figure 6-57 – Comparison of Fuel Consumption Across Sensitivity Cases in the Action Alternatives

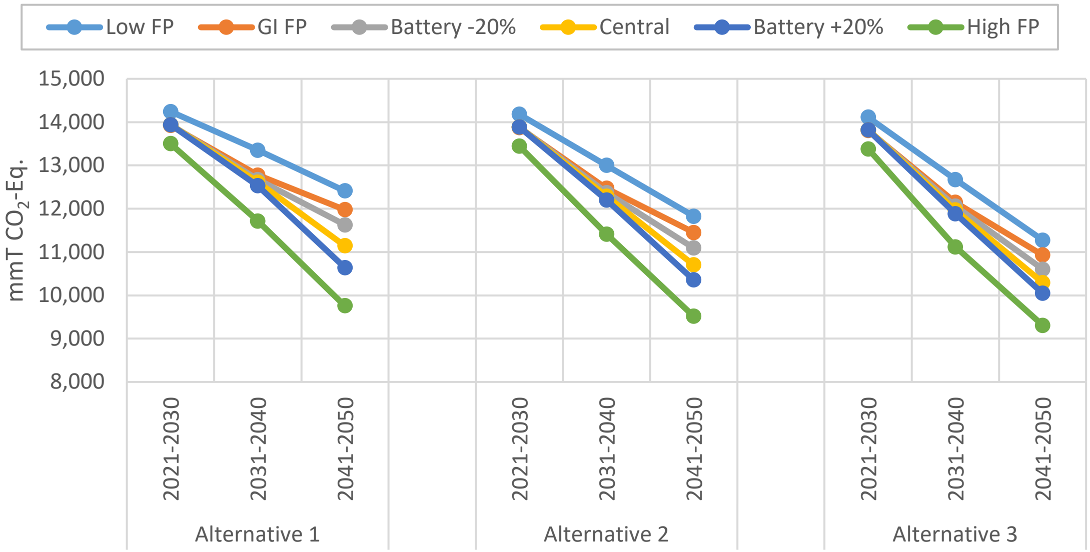

Figure 6-58 – Comparison of GHG Emissions Across Sensitivity Cases in the Action Alternatives

However, when considering the incremental changes in fuel consumption and GHG emissions compared to the no-action alternative, the relative ordering of sensitivity cases reverses as illustrated by Figure 6-59 and Figure 6-60. Here, the *high fuel price* case is shown as having the lowest incremental reduction of fuel consumption and GHG emissions when compared to the baseline scenario, while the *low fuel price* case shows the greatest reduction of these values. Under the *high fuel price* case, as the baseline scenario absorbs additional cost-effective technologies due to voluntary over-compliance, the potential for improvements in the action alternatives (with respect to the baseline) reduces. Hence, the incremental changes to fuel consumption and GHG emissions reduce as well. Conversely, for the *low fuel price* case, as the degree of voluntary over-compliance in the baseline scenario declines, the potential for improvements in the action alternatives increases. Thus, the incremental changes go up in each alternative in the *low fuel price* case.

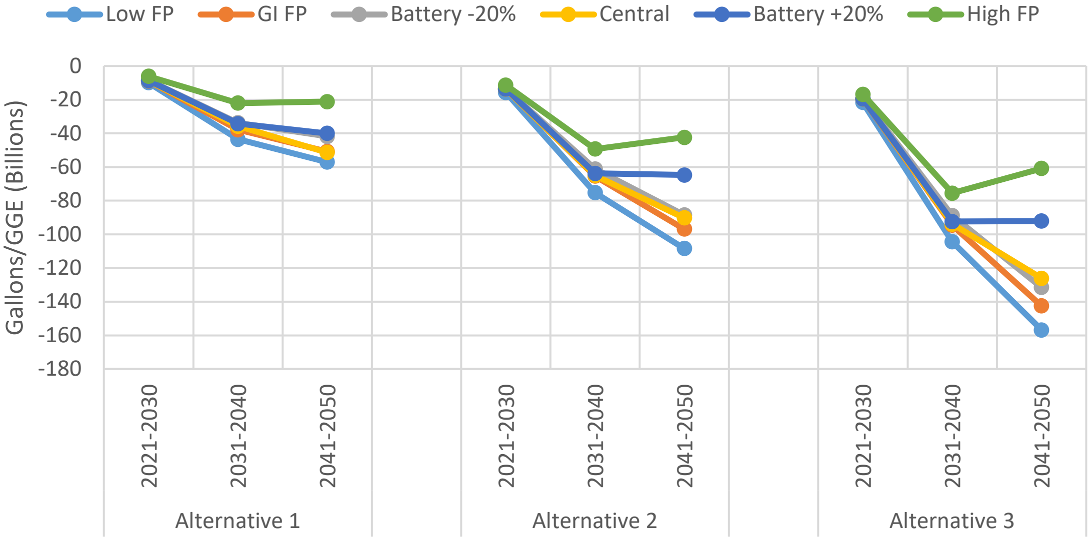

Figure 6-59 – Comparison of Changes in Fuel Consumption Across Sensitivity Cases

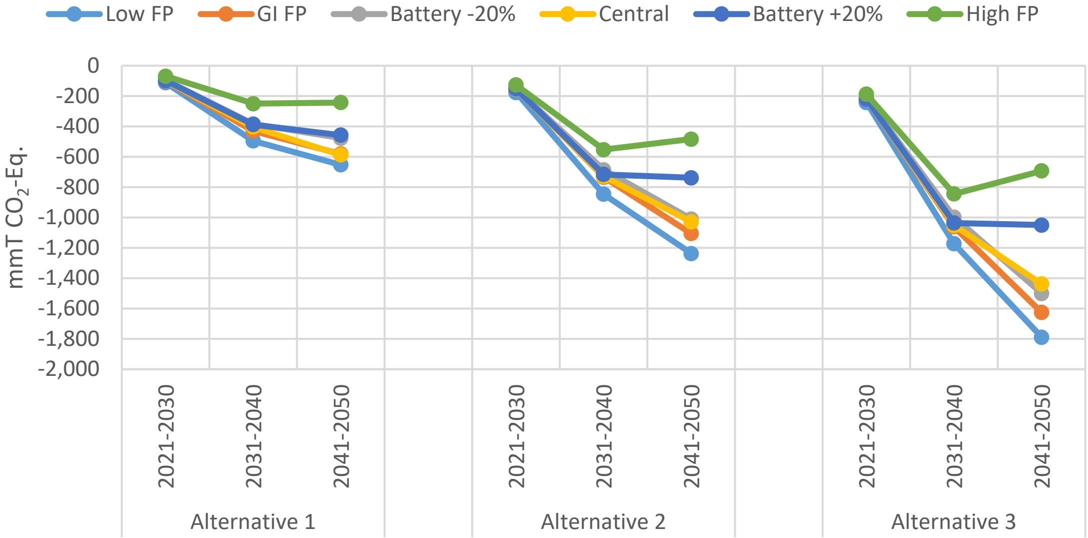

Figure 6-60 – Comparison of Changes in GHG Emissions Across Sensitivity Cases

6.6.3 Changes to Emission of Criteria Air Pollutants

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

Figure 6-61 and Figure 6-62 present annual upstream and downstream emissions of NO_X and $PM_{2.5}$ respectively, which are attributed to the light-duty fleet under the standards defined by the no-action alternative. As the older vehicles are retired and replaced by models with stricter emissions standards, a rapid decline of NO_X and $PM_{2.5}$ downstream emissions can be seen from both figures. However, the relative impacts on upstream emissions for both pollutants are significantly less pronounced, showing small growth until CY 2023, followed by gradual and marginal decline thereafter. The initial upsurge in upstream emissions correlates with the higher demand for fuel that was presented in Figure 6-46. Likewise, the subsequent decline also follows the overall annual reduction to fuel consumption. Although the no-action alternative sees a larger shift to electric-powered vehicles in the latter years, the additional upstream emissions from electricity do not outweigh the larger cumulative savings from improved gasoline models. As such, the upstream emissions of NO_X and $PM_{2.5}$ show an inconsequential incline in the last few years.

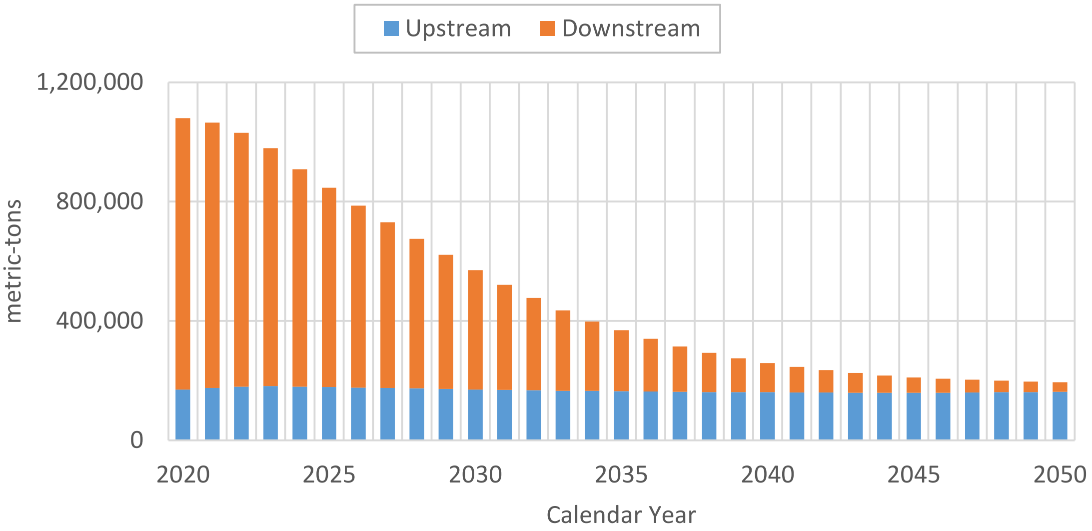

Figure 6-61 – Emissions of NO_X in the Baseline Scenario

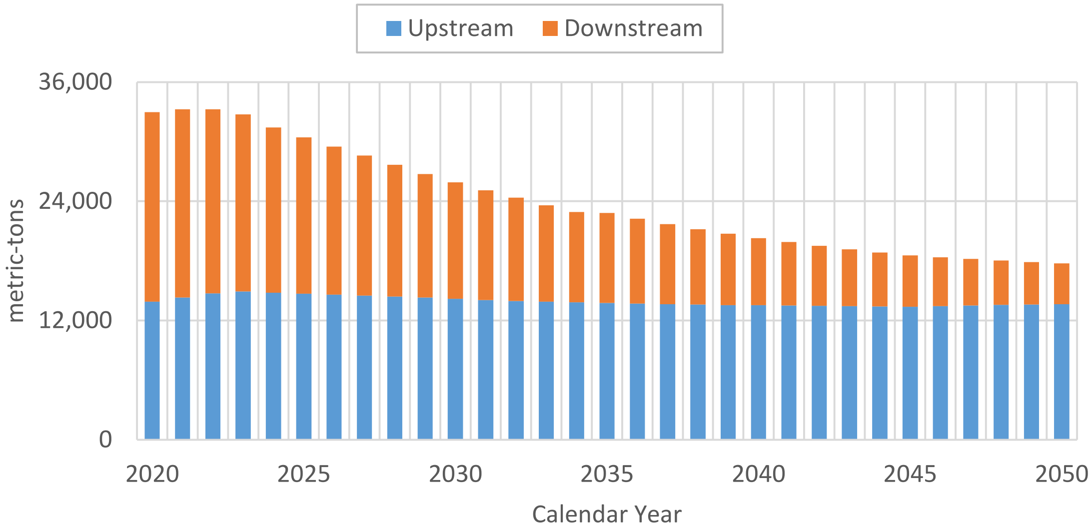

Figure 6-62 – Emissions of $PM_{2.5}$ in the Baseline Scenario

Figure 6-63 shows the annual SO_X emissions for the on-road fleet under the no-action alternative. Contrary to the previous two pollutants, downstream emissions of SO_X are measured based on the consumption of fuel, rather than on a per-mile basis dictated by the vehicle emissions standards. Hence, SO_X emissions are influenced directly by changes to the amount of fuel consumed, rather than the total miles traveled by the light duty fleet. As can be seen from Figure 6-63, the downstream component provides a marginal contribution to the overall SO_X emissions, and generally undergoes a downward trend as fuel consumption decreases. The inner plot in the bottom-right corner of Figure 6-63 presents a magnified view of downstream SO_X emissions for clarity. The upstream SO_X emissions see a similar pattern as was observed for NO_X and $PM_{2.5}$ pollutants. Here, emissions peak in CY 2023 due to increasing fuel consumption, then steadily decline over the next 20 years, before ultimately increasing once again after CY 2045 due to greater presence of electric vehicles in the fleet.

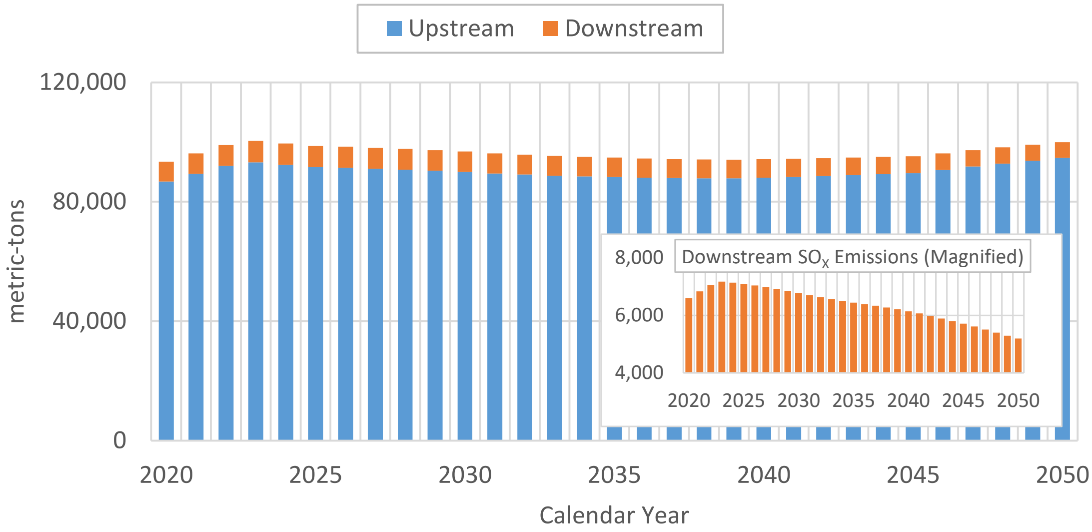

Figure 6-63 – Emissions of SO_X in the Baseline Scenario

As demonstrated in the next several figures, increases in CAFE standards generally lead to surges in overall emissions of criteria air pollutants under the two most stringent alternatives, when compared to the baseline (no-action alternative). Under the least stringent alternative, however, the incremental emissions typically decrease versus the baseline. The upstream portion sees a similar pattern as the total emissions, albeit with minor differences observed for the SO_X pollutant. Meanwhile, the downstream $PM_{2.5}$ and SO_X emissions in the action alternatives generally decline over the baseline, while emissions of NO_X see a large upward swing in the first half of the analyzed years, before receding below the baseline levels in the second half.

Figure 6-64 shows the incremental changes to NO_X emissions in the action alternatives verses the baseline scenario. The larger chart at the top presents the overall emissions of NO_X, while the left and right portions at the bottom provide deconstructed views of upstream and downstream components, respectively. As previously noted, the higher standards of the more stringent alternatives (2 and 3) increase upstream NO_X emissions versus the baseline in almost all years. Similar to the behavior of GHG pollutants discussed in Chapter 6.6.2, the rising upstream NO_X emissions can be attributed to the higher penetration of electricity-consuming vehicles (PHEVs and BEVs) in the light-duty fleet under Alternatives 2 and 3 than in the baseline. As the utilization of electricity increases in the baseline as well, the incremental differences of upstream NO_X emissions begin to subside, leading to an eventual net reduction in Alternatives 2 and 3 in the last few years. The declining trend in upstream NO_X emissions under Alternative 1 can be characterized by the overall reduction in fuel consumed versus the no-action alternative. The increase in the last several years, however, occurs due to Alternative 1 adopting electric-powered vehicles at a faster rate than the baseline.

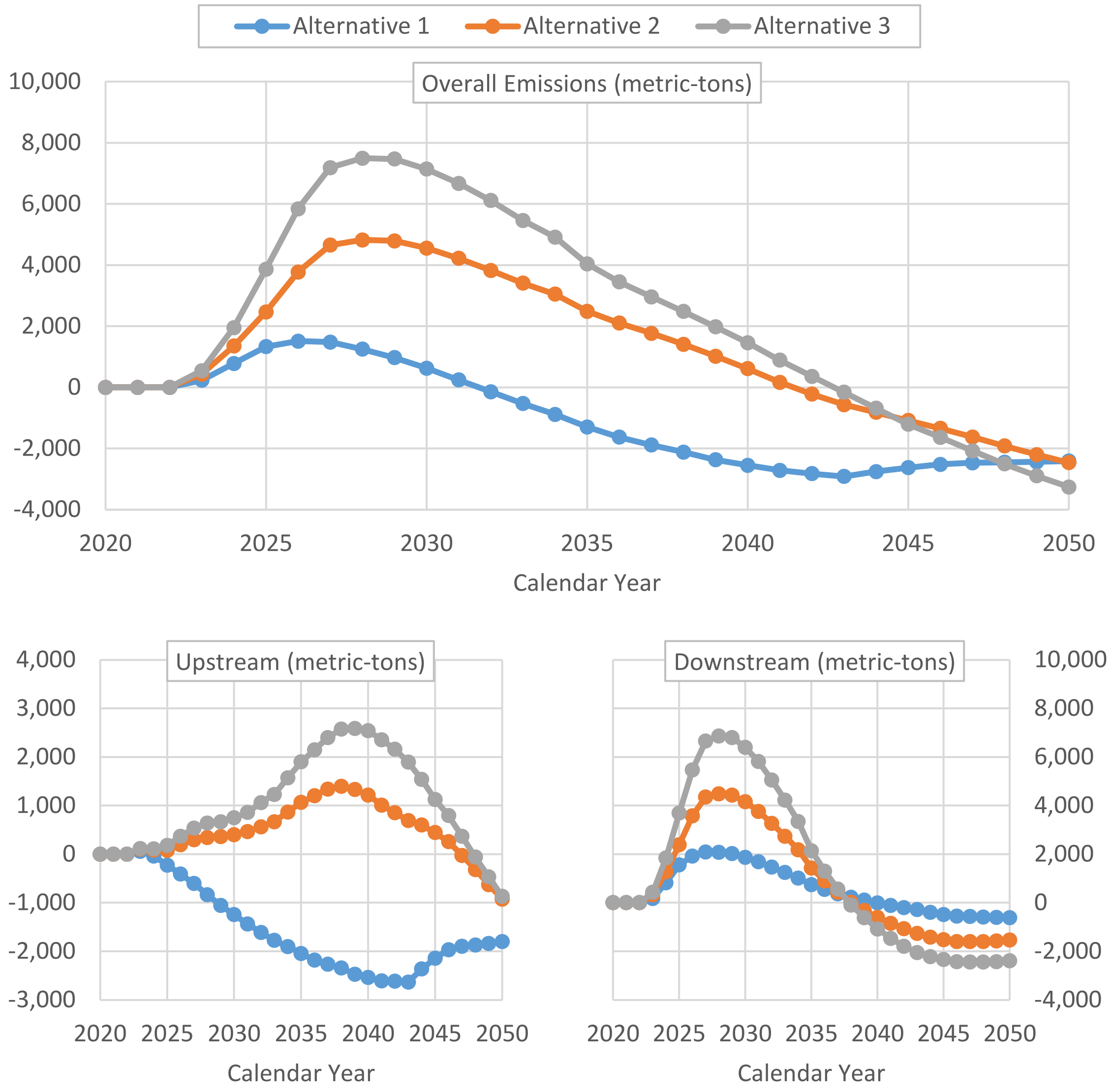

Figure 6-64 – Changes in NOX Emissions over Baseline

The downstream emissions in Figure 6-64 show an increase in the earlier years under all action alternatives as compared to the baseline, before leading to a net decrease in the later years. In response to the higher standards proposed by the action alternatives, the CAFE Model simulates a reduction of the 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,[130] the net downstream NOX emissions rise while the on-road fleet gradually turns over. As the older models are replaced in the later years, the NOX emissions begin to fall, eventually declining to below baseline levels.

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

Figure 6-65 presents the incremental changes to $PM_{2.5}$ emissions in the action alternatives as compared to the baseline scenario. The upstream and downstream emissions trends for $PM_{2.5}$ criteria air pollutant are similar to that of NO_X, while also having the same underlying root causes for the observed behavior. However, since the magnitude and the model-year differences of per-mile emissions of $PM_{2.5}$ are not as significant as they were for NO_X, the negative impacts on downstream $PM_{2.5}$ emissions in the action alternatives are less prominent.

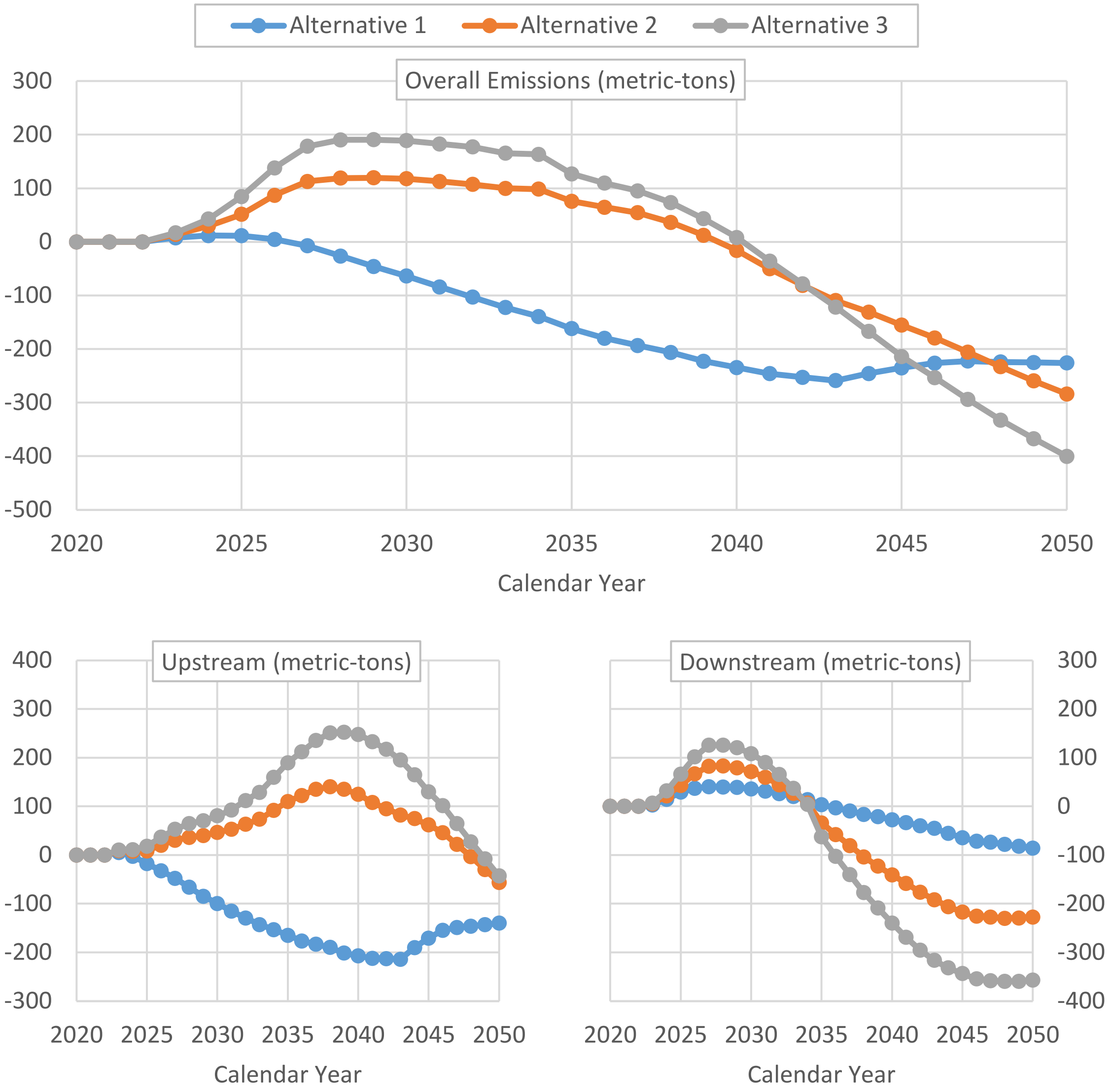

Figure 6-65 – Changes in $PM_{2.5}$ Emissions over Baseline

Figure 6-66 illustrates the incremental emission changes for SO_X for the action alternatives versus the baseline. As was noted earlier, the SO_X downstream emissions are measured based on the total consumption of fuel, rather than on per-mile basis. Thus, the reduction in fuel use in the action alternatives reduces the downstream emissions as compared to the no-action alternative. The SO_X upstream emissions show a similar pattern as for NO_X and $PM_{2.5}$. Unlike for those two pollutants, however, upstream emissions of SOx are higher than the baseline in all action alternatives and all calendar years (with the exception of a few calendar years in Alternative 1).

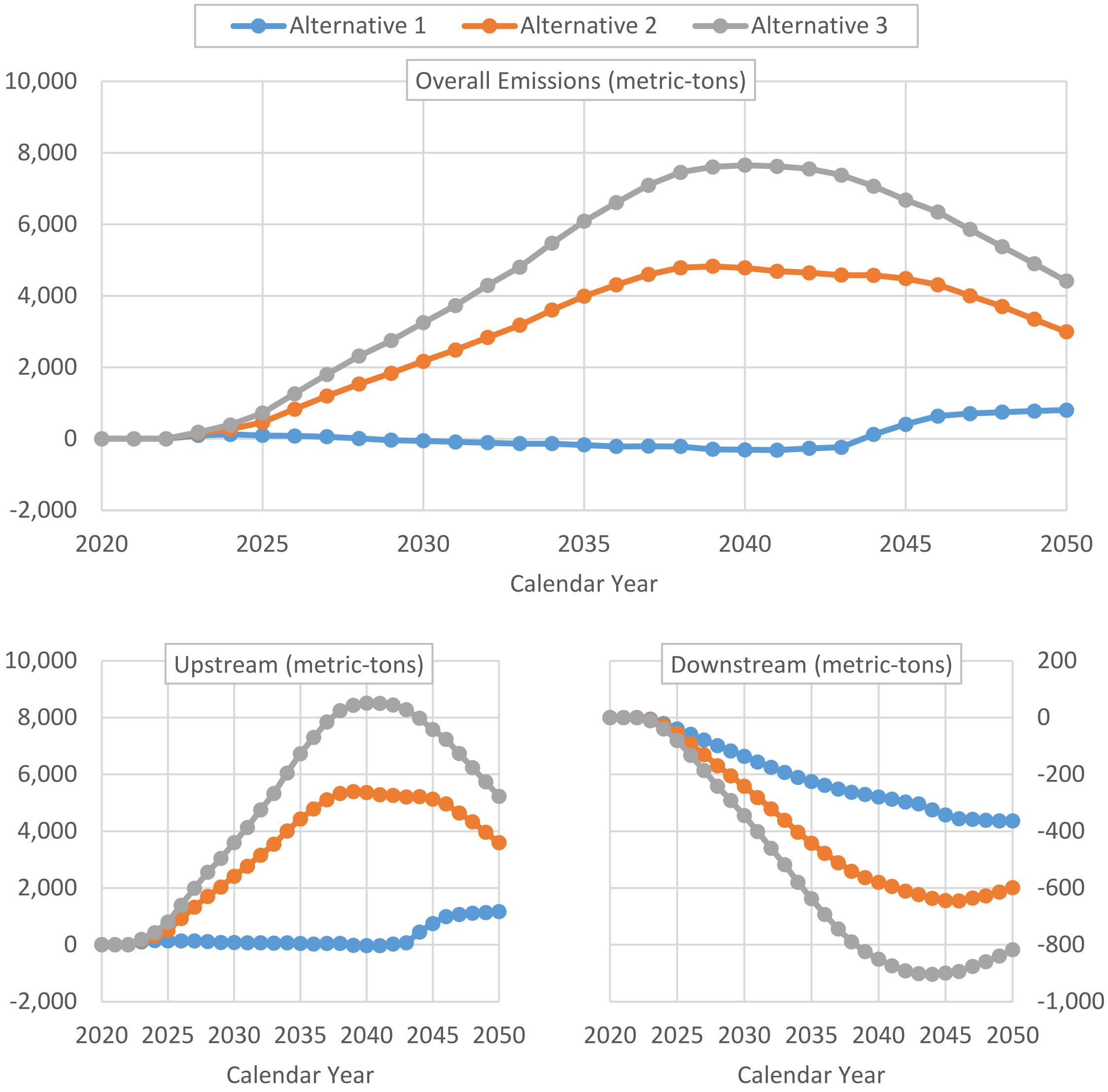

Figure 6-66 – Changes in SOx Emissions over Baseline

As demonstrated in this section, the emissions of NOx, SOx, and $PM_{2.5}$ generally increase under the two most stringent action alternatives as compared to the baseline scenario. Though these results may appear counterintuitive, they are a direct consequence of the input assumptions used for this analysis, as well as the uncertainty surrounding these assumptions. When estimating the upstream emissions, the CAFE Model relies on the upstream emission rates provided by the GREET 2020 Model for the various supported fuel types. These input emission rates may change over time (and between rulemakings) depending on the version of the GREET Model used and the internal assumptions a particular GREET version uses regarding the production and distribution of various petroleum-based feedstocks.

In addition to the upstream emission rates obtained from GREET, the CAFE Model also relies on the various fuel import assumptions, which apply certain weighting to the GREET values, thus introducing additional uncertainty. These fuel import assumptions define what portion of total emissions, which arise from the various stages of fuel production and distribution, are assumed to occur domestically. When considering gasoline and diesel fuels, this analysis assumes that only 5 percent of the total emissions related to crude oil extraction and transportation to refining facilities occur within the United States. Furthermore, 50 percent of the total emissions generated during the petroleum refining process occur domestically. Lastly, emissions occurring during transportation, storage, and distribution of refined gasoline and diesel (Fuel TS&D) are assumed to occur in the U.S. in their entirety. Hence, the cumulative upstream emissions attributed to the various stages of gasoline or diesel production and distribution depend on the fuel import assumptions that are specified as inputs to the CAFE Model. Conversely, all of the upstream emissions resulting from generation and distribution of electricity are assumed to occur domestically.

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

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

The magnitude of adverse health incidents caused by exposure to criteria air pollutants reduces as the consumption of gasoline by the light-duty fleet drops between calendar years and more stringent alternatives. Figure 6-67 presents the proportions of each of the various emission health impacts, which were considered during this rulemaking, occurring during calendar year 2020. The pie chart on the left provides a subset of the health impacts where the count of incidents numbers in the tens of thousands and beyond, while the pie chart on the right includes the remainder of the health outcomes with incident counts fewer than ten thousand. For both charts, the emission health impacts with relatively small amounts (shown as a green slice in the left pie and a dark red slice in the right pie) were pooled together and presented in a stacked column.

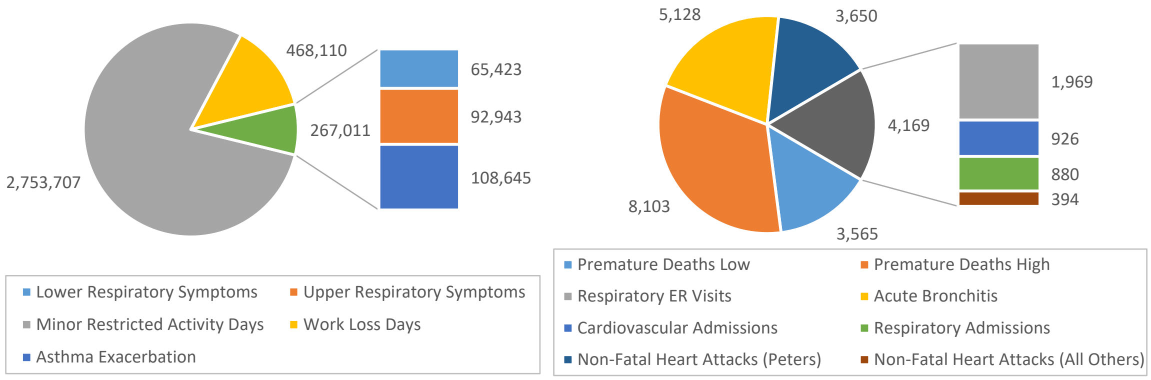

Figure 6-67 – Emission Health Impacts in CY 2020

As demonstrated by Figure 6-67, the "Minor Restricted Activity Days" category significantly outweighs the cumulative total of all the other health-related incidents. Conversely, the respiratory and cardiovascular hospital admissions categories are least significantly affected by exposure to emissions from criteria air pollutants. Throughout the analysis of all alternatives, the proportions of each category remained mostly the same during each calendar year, although moderately declining with each subsequent year.

The emission health impacts attributed to the no-action alternative for the remainder of the calendar years are presented as cumulative impacts over the next three decades in Figure 6-68 and Figure 6-69. Once again, the figures were split into subsets of high incident counts (above ten thousand) and low incident counts (below ten thousand) to aid with interpretation. As revealed by both figures, the health-related outcomes in every single category follow a significant downward trend between the decades in response to significantly declining overall emission of NO_X and $PM_{2.5}$ pollutants (discussed in Chapter 6.6.2.1).

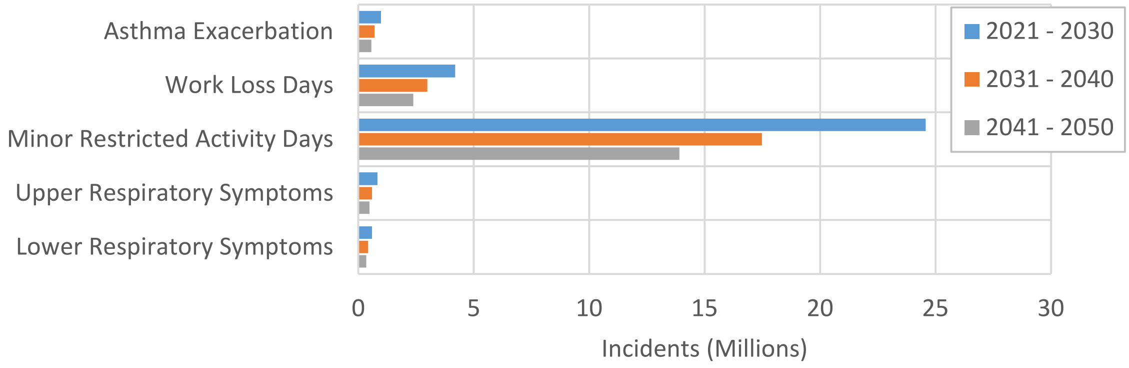

Figure 6-68 – Cumulative Emission Health Impacts in the Baseline Scenario (1)

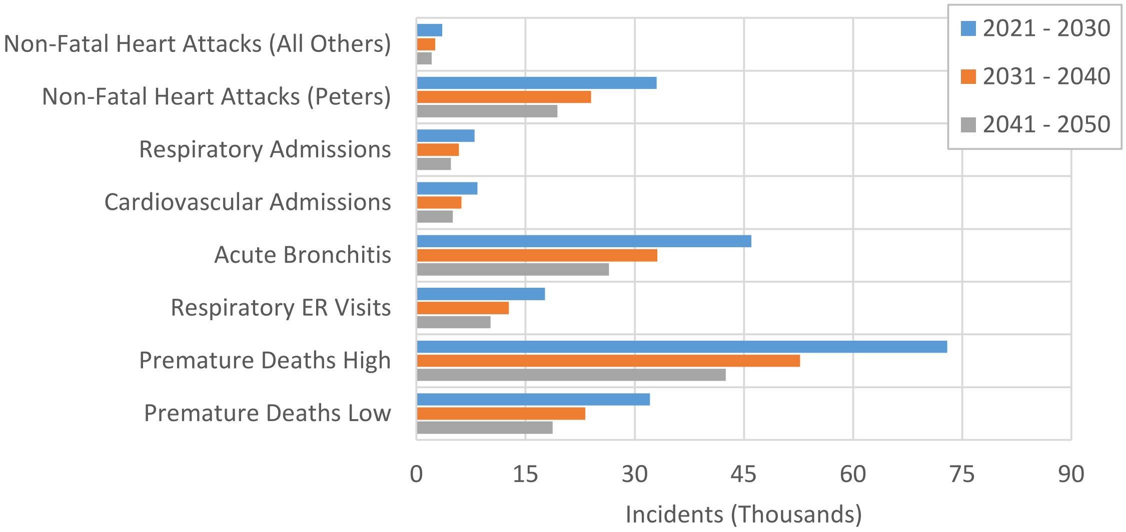

Figure 6-69 – Cumulative Emission Health Impacts in the Baseline Scenario (2)

With increasing CAFE standards under the action alternatives, health-related incidents are further decreased in response to an even greater reduction of fuel consumed. Although the net emissions of criteria air pollutants increase in some action alternatives, the reduction in the consumption of gasoline, and the subsequent reduction exposure to upstream and downstream emissions attributed to gasoline fuel use, lead to an eventual decline in adverse health outcomes. Figure 6-70 and Figure 6-71 illustrate the incremental changes in emission health impacts for each alternative over the baseline scenario for the next three decades. With the most stringent CAFE standards, Alternative 3 sees the greatest reduction in the number of incidents among all alternatives evaluated during the last two decades. During the first decade (2021 – 2030), however, the least stringent Alternative 1 shows the largest cumulative decline in emission related incidents for each category. This occurs as the first decade sees a significant increase in tailpipe emissions in Alternatives 2 and 3 as compared to Alternative 1 and the baseline.

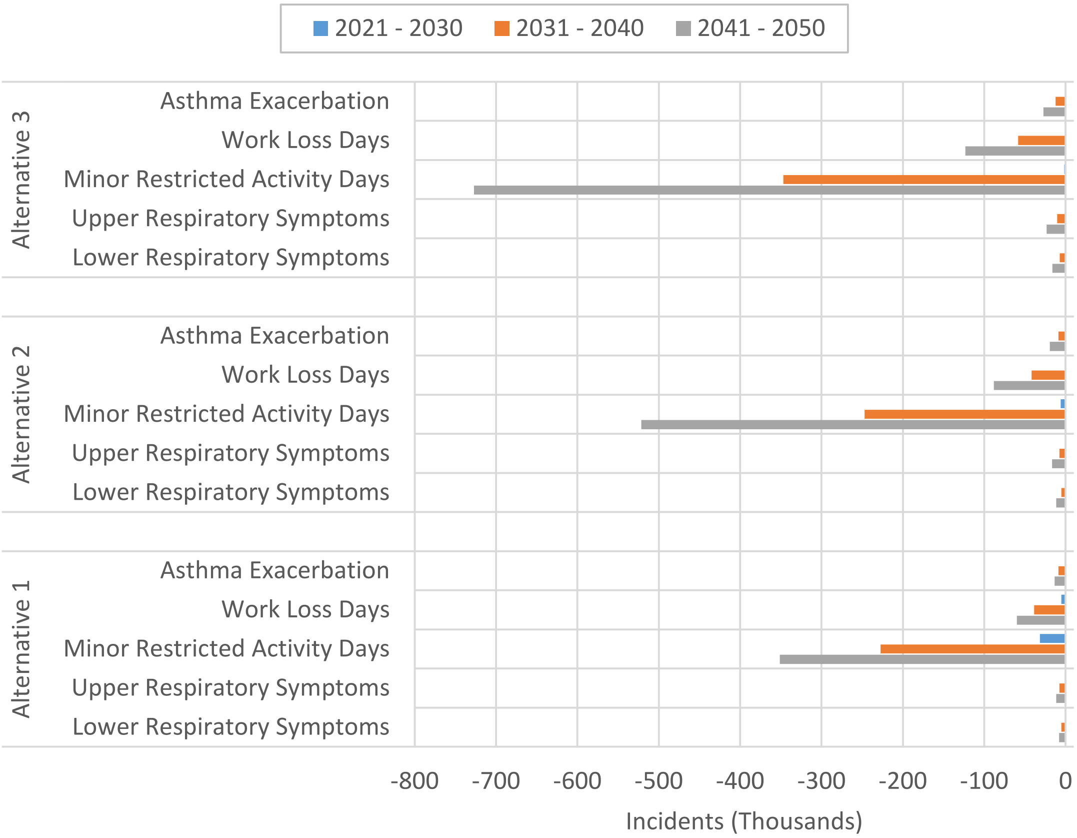

Figure 6-70 – Changes in Cumulative Emission Health Impacts over Baseline (1)

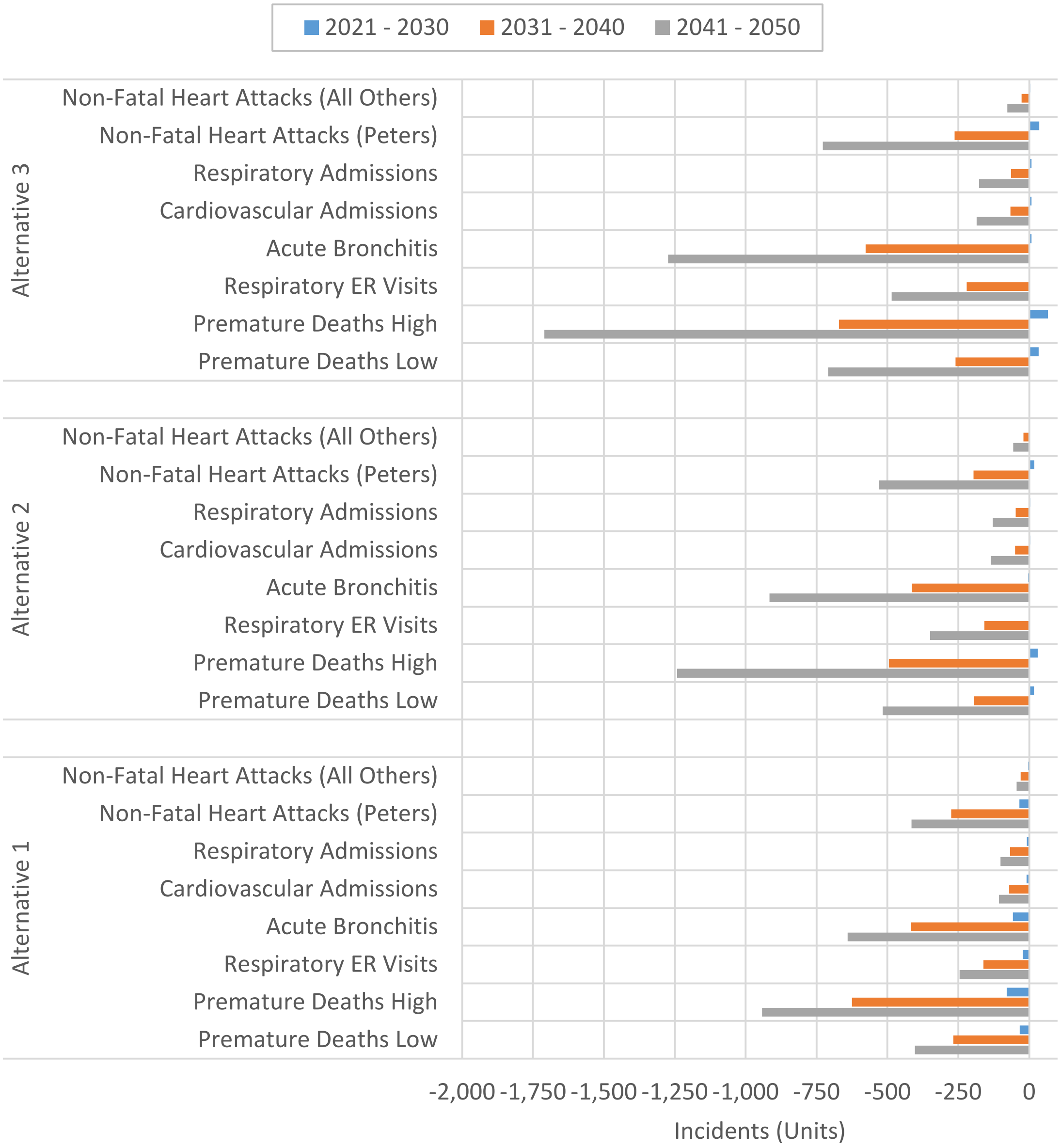

Figure 6-71 – Changes in Cumulative Emission Health Impacts over Baseline (2)

7. Expanded Sensitivity Analysis

7.1 Description of Sensitivity Cases

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

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

Some assumptions, however, may be more uncertain than others. Whether and, if so, how the market for automotive fuel economy varies with regulatory provisions, and how consumers value the expected fuel savings from fuel economy improvements, are among the important sources of uncertainty in our analyses (as discussed in Chapter 4.3.1). Like all prior versions since 2012, the current version of the CAFE Model treats the market's apparent valuation of fuel economy as being the same across regulatory alternatives included in a given execution of the model (e.g., any given case included in the today's sensitivity analysis). NHTSA is considering how uncertainty of this nature can be incorporated into the model as a possible area for future research and development.

Results of NHTSA's sensitivity analysis are summarized below, and detailed model inputs and outputs are available on the agency's website.[131] These are reported as incremental values for the proposal relative to the baseline No-Action alternative. They compare to the measures presented in the central analysis, above, using the reference case assumptions. The reference case values are also reported in the tables for easier comparison. It is important to note that the values of both the No-Action alternative and the preferred alternative change for each sensitivity case; the incremental changes are not due solely to a change in the absolute outcomes of the preferred alternative, but also due to changes in the absolute outcomes in the No-Action case. This can sometimes lead to counterintuitive incremental impacts of changing some of the reference assumptions. We discuss these as they arise.

Table 7-1 lists and briefly describes the cases included in the sensitivity analysis.

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[131] https://www.nhtsa.gov/corporate-average-fuel-economy/compliance-and-effects-modeling-system.

Table 7-1 – Cases Included in Sensitivity Analysis

Sensitivity Case	Description
Reference case (RC)	Reference case, including 2.5% SC-GHG discount rate.
RC w/ 3% social DR, 3% SC-GHG DR	Reference case with 3% SC-GHG discount rate.
RC w/ 7% social DR, 3% SC-GHG DR	Reference case with 3% SC-GHG discount rate. (For 7% social discount rate.)
RC w/ 7% social DR, 5% SC-GHG DR	Reference case with 5% SC-GHG discount rate.
RC w/ 3% social DR, 95th percentile SC-GHG, 3% DR	Reference case with 95th percentile SC-GHG values using 3% discount rate.
Domestic SC-GHG at 3% social DR, 3% SC-GHG DR[132]	Social cost of carbon values at 2020 Final Rule levels
One-year redesign cadence	Vehicles redesigned every year
MR5/6 skip (>100k)	MR5 and MR6 skipped for platforms with 100k or more units
MR5/6 skip (>2k)	MR5 and MR6 skipped for platforms with 2k or more units
No MR5/6 skip	No MR5 or MR6 application applied without SKIP restriction
2020 Final Rule MR5/6 costs	Cost values for MR5 and MR6 at levels from 2020 Final Rule
No HCR skip	HCR engine applicable for all OEMs and technology classes
Flat AC/OC	No additional AC or OC credit accumulation after MY 2021 levels.
Adjusted MDPCS stringency	Minimum domestic passenger car standard reduced as described in Section VI of the preamble.
60-month payback period	60-month payback period
Battery direct costs (-20%)	Battery direct manufacturing cost decreased by 20%, reference battery learning cost
Battery direct costs (+20%)	Battery direct manufacturing cost increased by 20%, reference battery learning cost
Battery learning costs (-20%)	Battery learning cost decreased by 20%, reference direct manufacturing cost
Battery learning costs (+20%)	Battery learning cost increased by 20%, reference direct manufacturing cost
Rebound (10%)	Ten percent rebound effect
Rebound (20%)	Twenty percent rebound effect
Mass-size-safety (low)	The lower bound of the 95% CI for all model coefficients

Sensitivity Case	Description
Mass-size-safety (high)	The upper bound of the 95% CI for all model coefficients
Crash avoidance (low effectiveness)	Lower-bound estimate of effectiveness of 6 current crash avoidance technologies at avoiding fatal, injury, and property damage
Crash avoidance (high effectiveness)	Upper-bound estimate of effectiveness of 6 current crash avoidance technologies at avoiding fatal, injury, and property damage
Sales-scrappage response (-20%)	Sales-scrappage elasticity decreased by 20%
Sales-scrappage response (+20%)	Sales-scrappage elasticity increased by 20%
Low GDP	Low economic growth (AEO2021)
High GDP	High economic growth (AEO2021)
Oil price (EIA low)	Input oil price series based on EIA low forecast
Oil price (Global Insight)	Input oil price series based on Global Insight forecast
Oil price (EIA high)	Input oil price series based on EIA high forecast

7.2 Summary of Sensitivity Results

7.2.1 Effect of Assumptions on Primary Cost and Benefit Measures

A number of the input parameters for the CAFE Model lend themselves to a comparison of program effects for input values both above and below those of the central case. A selection of these scenarios is presented in Figure 7-1. Note first that the net social benefit estimate in the reference case is very close to break-even, and perturbations of input parameters in all paired sensitivity cases produce results of differing signs. The two cases with the largest deviation from the net benefit level of the reference case are cases that vary oil prices, and cases that vary direct battery costs. This is consistent with the discussion of Chapter 6.3, where these two scenarios had a large influence on technology application, costs, and the value of fuel savings.

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[132] According to OMB's Circular A-4 (2003), an "analysis should focus on benefits and costs that accrue to citizens and residents of the United States", and international effects should be reported separately. To correctly assess the total climate damages to U.S. citizens and residents, an analysis must account for impacts that occur within U.S. borders, climate impacts occurring outside U.S. borders that directly and indirectly affect the welfare of U.S. citizens and residents, and spillover effects from climate action elsewhere. The SC-CO_2 estimates (and likewise the SC-CH4 and SC-N2O estimates) used in regulatory analysis under revoked E.O. 13783, including in the RIA for this proposed rule, are an approximation of the climate damages occurring within U.S. borders only (e.g., \$7/mtCO_2 (2016 dollars) and \$9/mtCO_2 using a 3% discount rate for emissions occurring in 2021 and 2040, respectively). However, as discussed at length in the IWG's February 2021 TSD, estimates focusing on the climate impacts occurring solely within U.S. borders are likely to underestimate benefits of GHG mitigation accruing to U.S. citizens and residents, and are also subject to a considerable degree of uncertainty due to the manner in which they are derived.

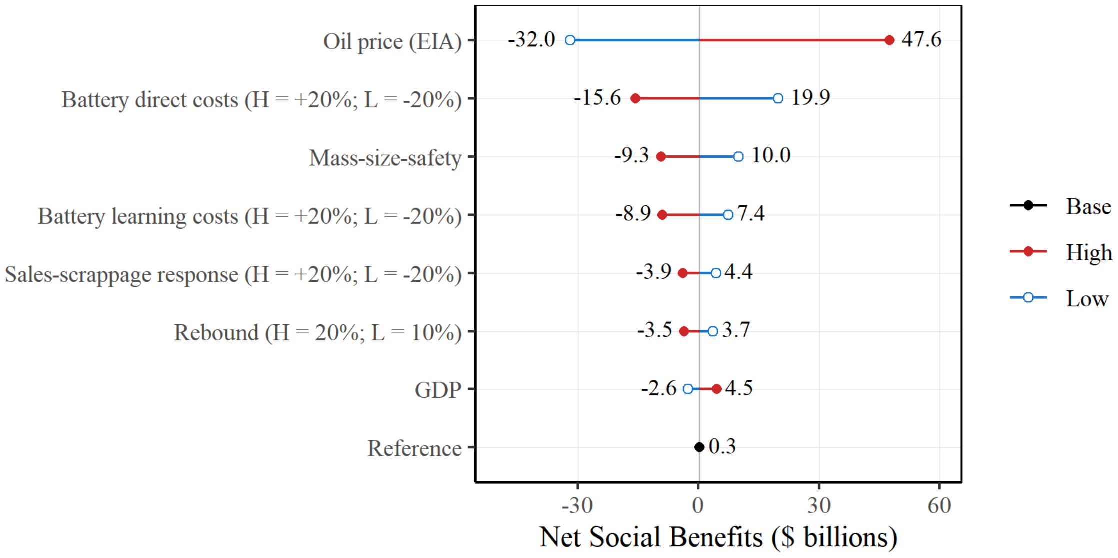

Figure 7-1 – Relative Magnitude of Sensitivity Effect on Net Benefits

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

The remaining sub-sections offer additional context to this scenario analysis, focusing on the scenarios that lead to greater differences in aggregate social costs and benefits over the central case. Table 7-2 presents the full suite of sensitivity case results and summarizes key output measures including fuel consumption and associated emissions, consumer costs and benefits, and aggregate social benefits, costs, and net benefits.

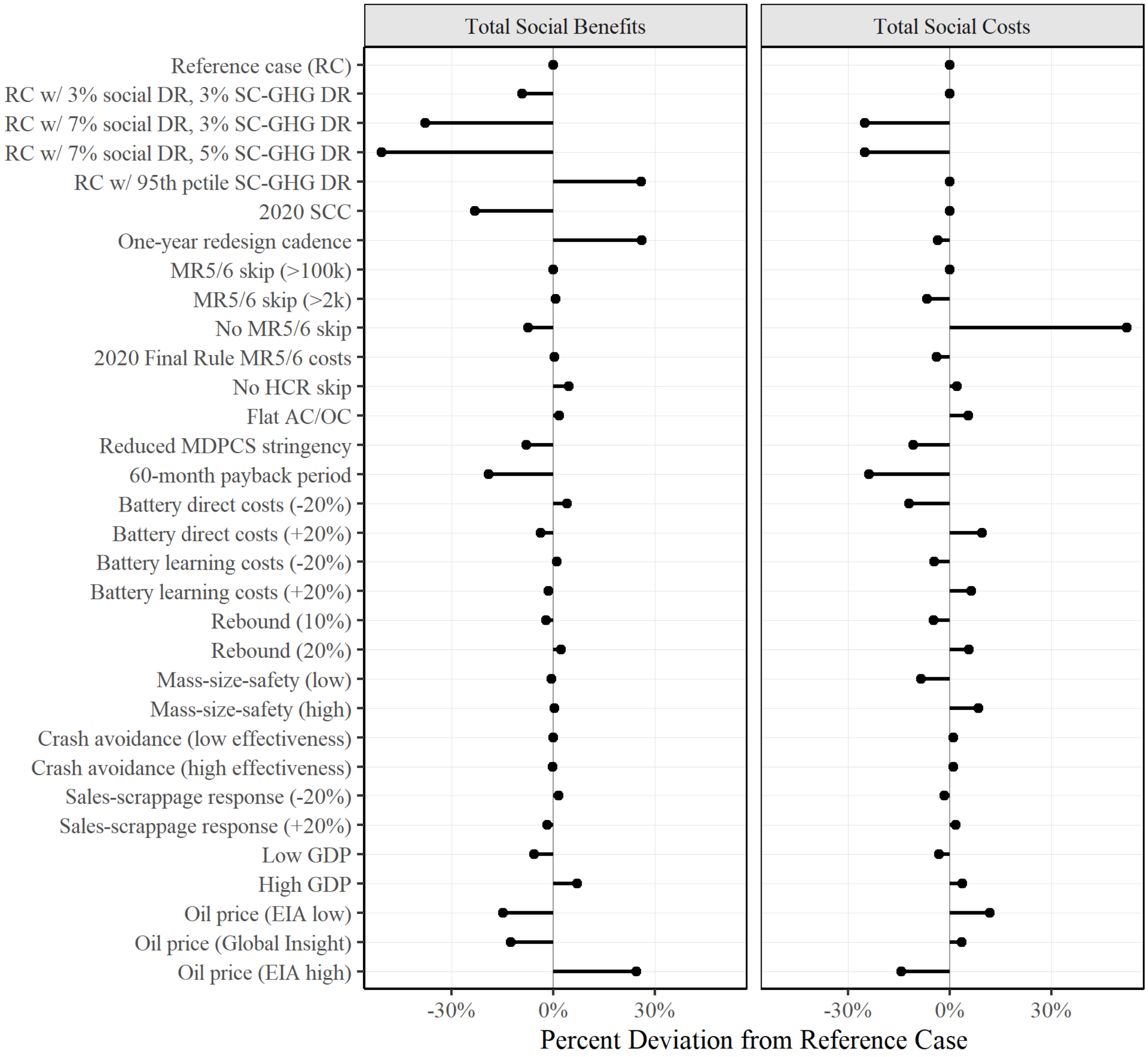

Figure 7-2 – Relative Deviation in Total Social Costs and Total Social Benefits from Reference Case

Table 7-2 – Summary of Sensitivity Results

Sensitivity Case	Gasoline Consump. †	Electricity Consump. †	CO_2 Emissions †	Average Vehicle Purchase Costs‡	Average Lifetime Fuel Savings‡	Social Benefits†		Social Costs†		Net Benefits †
	(b. gal.)	(TWh)	(mmt)	($/vehicle)	($/vehicle)	($b)	% diff. from RC	($b)	% diff. from RC	($b)
Reference case (RC)	-51	273	-467	1,310	-1,186	121.4	-	121.1	-	0.3
RC w/ 3% social DR, 3% SC-GHG DR	-51	273	-467	1,310	-1,186	110.5	-9%	121.1	0%	-10.6
RC w/ 7% social DR, 3% SC-GHG DR	-51	273	-467	1,310	-1,186	75.6	-38%	90.7	-25%	-15.1
RC w/ 7% social DR, 5% SC-GHG DR	-51	273	-467	1,310	-1,186	60.0	-51%	90.7	-25%	-30.7
RC w/ 95th percentile SC-GHG DR	-51	273	-467	1,310	-1,186	153.0	26%	121.1	0%	31.9
Domestic SC-GHG at 3% social DR, 3% SC-GHG DR	-51	273	-467	1,310	-1,186	93.5	-23%	121.1	0%	-27.6
One-year redesign cadence	-48	62	-509	1,154	-1,556	153.2	26%	116.8	-4%	36.4
MR5/6 skip (>100k)	-51	273	-467	1,310	-1,186	121.4	0%	121.1	0%	0.3
MR5/6 skip (>2k)	-51	274	-470	1,221	-1,206	122.4	1%	113.0	-7%	9.4
No MR5/6 skip	-49	268	-440	2,226	-1,025	112.6	-7%	184.2	52%	-71.6
2020 Final Rule MR5/6 costs	-51	273	-468	1,255	-1,197	121.9	0%	116.4	-4%	5.5
No HCR skip	-50	231	-476	1,326	-1,231	127.0	5%	123.6	2%	3.4
Flat AC/OC	-51	267	-470	1,383	-1,187	123.6	2%	127.8	6%	-4.1
Reduced MDPCS stringency	-48	273	-434	1,129	-1,074	111.9	-8%	108.1	-11%	3.8
60-month payback period	-39	160	-377	998	-906	98.4	-19%	92.1	-24%	6.2
Battery direct costs (-20%)	-50	236	-464	1,151	-1,256	126.5	4%	106.6	-12%	19.9

Sensitivity Case	Gasoline Consump. †	Electricity Consump. †	CO_2 Emissions †	Average Vehicle Purchase Costs‡	Average Lifetime Fuel Savings‡	Social Benefits†		Social Costs†		Net Benefits †
	(b. gal.)	(TWh)	(mmt)	($/vehicle)	($/vehicle)	($b)	% diff. from RC	($b)	% diff. from RC	($b)
Battery direct costs (+20%)	-49	258	-448	1,435	-1,159	117.0	-4%	132.6	10%	-15.6
Battery learning costs (-20%)	-51	268	-470	1,260	-1,183	122.9	1%	115.5	-5%	7.4
Battery learning costs (+20%)	-50	269	-455	1,374	-1,188	119.7	-1%	128.7	6%	-8.9
Rebound (10%)	-52	272	-476	1,310	-1,220	119.0	-2%	115.3	-5%	3.7
Rebound (20%)	-50	274	-457	1,310	-1,146	124.3	2%	127.8	6%	-3.5
Mass-size-safety (low)	-51	273	-467	1,310	-1,186	120.9	0%	110.9	-8%	10.0
Mass-size-safety (high)	-51	273	-467	1,310	-1,186	121.9	0%	131.2	8%	-9.3
Crash avoidance (low effectiveness)	-51	273	-467	1,310	-1,186	121.6	0%	122.4	1%	-0.8
Crash avoidance (high effectiveness)	-51	273	-467	1,310	-1,186	121.3	0%	122.3	1%	-1.0
Sales-scrappage response (-20%)	-52	276	-473	1,311	-1,224	123.5	2%	119.1	-2%	4.4
Sales-scrappage response (+20%)	-51	272	-462	1,311	-1,148	119.4	-2%	123.3	2%	-3.9
Low GDP	-50	263	-456	1,320	-1,198	114.6	-6%	117.2	-3%	-2.6
High GDP	-53	282	-479	1,287	-1,206	130.0	7%	125.5	4%	4.5
Oil price (EIA low)	-57	292	-527	1,406	-945	103.4	-15%	135.4	12%	-32.0
Oil price (Global Insight)	-50	274	-458	1,315	-982	106.3	-12%	125.3	4%	-19.0
Oil price (EIA high)	-44	240	-398	1,148	-1,501	151.3	25%	103.7	-14%	47.6

Sensitivity Case	**Gasoline Consump. †**	**Electricity Consump. †**	**CO_2 Emissions †**	**Average Vehicle Purchase Costs‡**	**Average Lifetime Fuel Savings‡**	**Social Benefits†**		**Social Costs†**		**Net Benefits †**
	(b. gal.)	**(TWh)**	**(mmt)**	**($/vehicle)**	**($/vehicle)**	**($b)**	**% diff. from RC**	**($b)**	**% diff. from RC**	**($b)**

Unless otherwise noted, results assume a 3 percent social discount rate and a 2.5 percent SC-GHG discount rate. Reference case is presented in the first row for context. Metrics vary by column, as shown.

†Sum over vehicles’ expected lifetimes, MY 1981-2029.

‡ MY 2029 vehicles. Undiscounted values.

7.2.2 Effect of Technology-Related Parameters

The largest components of estimated program costs and benefits include reduced fuel costs that result from improved fuel economy and increased technology and other regulatory costs required to meet proposed fuel efficiency standards. Unsurprisingly, input parameters that alter these cost and benefits categories have the potential to change bottom-line results. Many of these sensitivity cases were discussed in the context of program effects on manufacturers (Chapter 6.3) and on consumers (Chapter 6.4). In the broader context of total social costs and benefits, the assumed payback period over which new car buyers value fuel economy improvements, battery cost metrics, and global oil price forecast assumptions are significant drivers of overall net social benefits.

7.2.2.1 Mass Reduction

Assumptions about specific technology pathways can produce fluctuations in social net benefit totals as well. For example, high-level (and high cost) mass reduction technologies, if applied too broadly, could theoretically strain existing supply networks for carbon fiber. To address this, the central case restricts MR5 and MR6 application to platforms with fewer than 40 thousand units. The sensitivity cases “MR5/6 skip (>100k),” “MR5/6 skip (>2k),” and “No MR5/6 skip” vary this limit. The first two cases replace the limit with 100,000 units and 2,000 units, respectively. The third removes the constraint entirely. Expanding the limit has no measurable effect on overall program costs or benefits. Contracting the limit to platforms with 2,000 units produces minimal change to social benefits but decreases estimated social costs by 7 percent. This corresponds to a drop in average per-vehicle purchase cost. Eliminating the constraint on high-level mass reduction technology nearly doubles average per vehicle costs and increases social costs by over 50 percent. While this demonstrates the role high-priced, advanced technologies may play, the likelihood such a case would play out in practice is exceedingly small, in part because these cases are being run with “standard setting” constraints, under which the model is limited in how it may apply (relatively cheaper) electrification, and thus chooses more expensive mass reduction to increase compliance fuel economy when given the opportunity to use MR. In the real world, and even under the “unconstrained” runs discussed in the accompanying SEIS, electrification is likely to be a more viable option for significantly increasing fuel economy than high-level mass reduction, at least in the near- to mid-term.

7.2.2.2 Redesign Schedules

As discussed in Chapter 2.2.1.7 of the TSD, vehicle manufacturers establish redesign cadences for their vehicles considering the availability of capital and other resources, competitive position in certain market segments, the sales volume for each of the manufacturer’s vehicle models, and the influence of regulatory requirements. As discussed in the preamble and elsewhere in this PRIA, 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, or a manufacturer’s capital availability, among other factors. To test an extreme case of redesign flexibility, one sensitivity allowed for annual vehicle redesigns. In this setting, the pool of available vehicle and technology combinations appears significantly greater for each manufacturer. This increases the likelihood of more optimal technology solutions being selected by the CAFE Model in each model year. This, in turn, could lead to a more optimal overall solution, producing higher overall consumer and social benefits, while at the same time lowering technology costs (if there were no costs associated with a redesign cadence this rapid, which the agency does not believe is likely). As presented in the table of sensitivity results, social benefits increase by approximately 26 percent over the reference case while costs decline by 4 percent. While this demonstrates the value of nimble manufacturer response to fuel efficiency requirements, it is an unrealistic representation of manufacturers' ability to modify their vehicle portfolios. This case does not account for the costs of stranded capital from such high frequency, nor scaling up of the facilities and development and design teams required to implement annual redesign schedules across the portfolio. These costs would likely be significant, and the CAFE Model does not estimate or incorporate these into overall program cost estimates.

7.2.2.3 Payback Period

New vehicle buyers have a variety of preferences for vehicle attributes (e.g., seating capacity, interior volume, drive type, performance, and fuel efficiency, among many others). The current analysis characterizes buyers' preference for fuel economy improvements by the number of years required to offset the initial technology investment with avoided fuel costs – the payback period. Like the 2012, 2016, and 2020 versions of the CAFE Model, the current version applies the same payback period across all regulatory alternatives. While the central analysis uses a 30-month payback period to quantify the average preference for fuel economy improvements in the new vehicle market, the sensitivity cases include an alternative with a payback period twice this length. With a longer payback period, more-costly, but effective, technologies and technologies that offer smaller marginal fuel efficiency improvements become more attractive options. Technologies with higher costs, but also higher effectiveness, can appear more attractive (to both manufacturers and consumers) if the period over which fuel savings is valued is longer. More effective technologies will likely have higher monthly savings but, with shorter assumed payback periods, there still may not be enough months to accumulate sufficient fuel savings to offset the higher initial cost.

This holds in the presented sensitivity results: average vehicle costs, lifetime fuel savings, social benefits, and social costs (relative to the baseline) all decrease when compared to reference case levels. Though social benefits and social costs are both smaller than the reference case, their ratio adjusts such that net benefits relative to the baseline increase. An important limitation of this case's implementation in the CAFE Model: the current sales and scrappage modules do not respond to changes in the payback period assumption. This means that, while the technology application assumes buyers are willing to pay for any technology that pays back in the first 60 months of avoided fuel costs, the sales and scrappage modules would both still treat too large a portion of those technology costs as true price increases. In the reference case, those assumptions are harmonized, but they are not (yet) flexible enough to accommodate alternative assumptions like the 60-month payback described here. CAFE Model development will continue in order to improve this flexibility.

7.2.2.4 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 new vehicles are produced and in subsequent years when vehicles are used. In the central analysis, the rising price of fuel over time creates fuel savings (in dollars) above and beyond the anticipated savings at the time of purchase. Under the high fuel price case, this phenomenon is more pronounced.

Figure 7-3 presents the fuel price time series for the reference case and sensitivity cases alongside historical fuel price levels in 2020 dollars. The historical trend highlights the amount of price variability in past years. While future trends in prices are uncertain, this sensitivity analysis relies on three price projections: high- and low-price projections from AEO 2021 that rely on EIA assumptions about future oil price trajectories, and a price forecast from Global Insight. Details of these price projections are available in Chapter 4.1.2 of the accompanying TSD. In broad terms, the high, low, and reference price projections represent high, low, and moderate growth trends in fuel prices. The Global Insight forecast follows the reference case assumptions of moderate growth until approximately 2030 before declining to 2050 levels slightly below $2.50 per gallon in real terms.

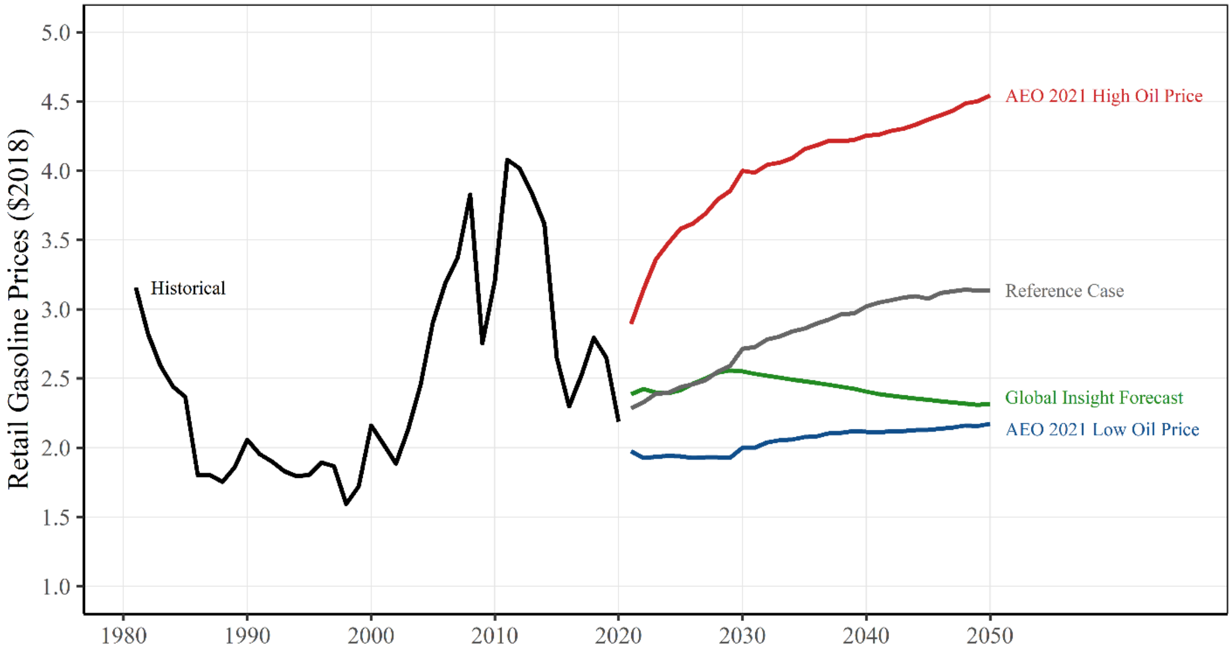

Figure 7-3 – Fuel Price Sensitivity Cases

In the case of increasing fuel prices—especially the rapid increase in the high oil price scenario—consumers foreseeably demand more fuel economy in the new vehicle market because each gallon of fuel saved during the 30-month payback period is worth more. As a result, more fuel-saving technology is applied in the baseline, and the number of gallons saved under the proposed alternative (as compared to the baseline) is muted – though each gallon saved is worth more than in the reference case. The opposite is true in the low oil price case. This can be seen in the average vehicle cost results of Table 7-2 , where the difference in costs between the No-Action Alternative and Alternative 2 are smaller in the high oil price case than in the reference case (and vice versa for low oil prices). Average fuel savings are correspondingly higher. Lower costs and greater avoided fuel expenditure produce significantly higher total social benefits and lower total social costs. Together, the high oil price case results in net benefits of approximately $48 billion relative to the No-Action Alternative. Effects in the low oil price case are also large, in the opposite direction. In a low gasoline price setting, the stringencies of Alternative 2 are binding for more manufacturers compared to what would be happening in the baseline and require technology application with smaller fuel savings returns (on a dollar basis). This translates to a decrease in overall social benefits and a corresponding increase in costs. Net benefits decline by more than $30 billion relative to the baseline. The Global Insights forecast leads to costs similar to those of the reference case. This result is unsurprising as the forecast follows the reference case price series closely during the time at which most fuel-saving technology is applied. Social benefits decline, however, as subsequent use of vehicles occurs during a time of declining gas prices. On net, this reduces net benefits by close to $20 billion.

The results of these oil price sensitivities lead to a wide range of potential net benefit outcomes from the preferred alternative. This is the product of two important factors. First, the price of fuel is one of the most significant determinants of the value of avoided fuel consumption. Large differences in this metric plays a key role in influencing total social benefits. Second, the value of these fuel savings is a direct input into the effective cost metric used to determine technology application. Alongside technology costs, it is a primary factor in determining total social costs. Further, the price series used in this sensitivity analysis (especially the EIA high and low oil price forecasts) represent extremes of potential future price points, with prices ranging from just over $2 per gallon to $4.50 per gallon in 2018 dollars. In evaluating the sensitivity of the model to these oil price cases, it is important to note as well that the cases are not symmetrical. There is a greater difference between the reference case and the high case, than the reference and low case. However, there is also no period in the historical series that represents *sustained* real prices as high as the high oil case beyond 2035.

7.2.2.5 Battery Costs

Sensitivity results in Table 7-2 include cases for two determinants of electrification technology costs: direct costs of batteries and battery learning costs. The scenario analysis includes versions of the model with costs and learning rates separately increased and decreased by 20 percent from their reference case levels. Figure 7-4 includes indexed cost values for battery cost trajectories under all four scenarios along with the reference case. As discussed in TSD Chapter 3.3.5.1.4, we compared our projected battery pack costs to the projected pack costs from other sources to assess the learning rate applied in the central analysis. The survey of other sources' projected pack costs showed that most projected costs fell within +/- 20% of our costs. Therefore, we determined that limiting sensitivity cases to examining the impacts of increasing and decreasing the direct cost of batteries and battery learning costs by 20 percent from their reference case levels was reasonable. The measure presented in the figure is BEV300 battery cost indexed to the 2020 reference case cost. The curves in the graph illustrate the differences in the two battery cost categories over time. Battery direct costs are a fixed ratio of the reference cost values. Learning cost scenarios gradually deviate from the reference level. This is especially important to note when coupled with the timing of most electrification technology application. Model runs with greater levels of electrification earlier will see a smaller effect from accelerated learning cost changes.

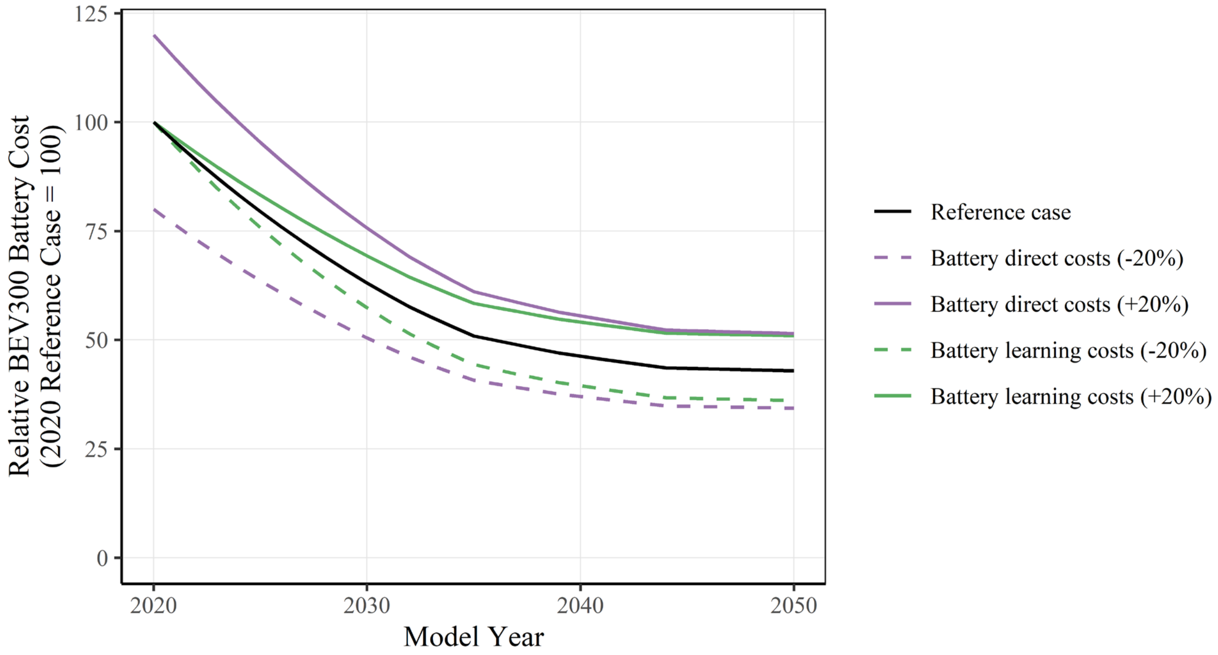

Figure 7-4 – Battery Cost Sensitivity Cases

Lower battery direct costs have the largest effect on electrification technology application, especially the role of BEVs and PHEVs. When comparing the extreme cases, which is 20 percent higher and lower direct manufacturing costs for battery packs relative to reference case, the electrification technology adoption is within 1.5 percent of the central case. However, in the case of BEV300, lower battery direct costs have marginally more effect on electrification technology adoption by 2030 and later years. This is expected, as manufacturers will likely choose broader application of BEVs and reduce the number of PHEVs and SHEVs offered. Across all battery cost scenarios, social benefits do not deviate from the reference case by large amounts. This aligns with the modest differences in PHEV and BEV penetration technology penetration rates discussed in Chapter 6.3.4. These scenarios do alter costs to apply electrification technology and therefore produce notable changes in total social costs. The scenario with direct battery cost reductions of 20 percent reduces social costs by 12 percent compared to that of the reference case, while battery costs 20 percent higher than reference case levels increase social costs by 10 percent. This results in net benefit levels at approximately $20 billion and -$16 billion, respectively. Though smaller in magnitude, adjustments to battery learning rate assumptions are also of note, with 20 percent faster learning producing net benefits of $7 billion and 20 percent slower learning at approximately - $9 billion.

7.2.3 Effect of Consumer and Social Parameters

NHTSA recognizes the uncertainties present in many of the consumer and social parameters used in the CAFE rulemaking analysis. This section discusses the sensitivity of the model results to various consumer and social parameters including the rebound effect, mass-size safety, sales and scrappage, crash avoidance, and social costs of greenhouse gases (SC-GHG) estimates. The TSD accompanying this RIA contains detailed information concerning the construction of these parameters.

7.2.3.1 Social Costs of Greenhouse Gases

Different sensitivity cases were created to incorporate each of the social cost of greenhouse gas (SC-GHG) values published by the Interagency Working Group on Social Cost of Greenhouse Gases (IWG). These social cost values (of carbon dioxide, methane, and nitrous oxide) differ only by the rate used to discount each stream of future climate damage cost estimates. NHTSA uses discount rates of 3% and 2.5% in the main analysis for presentational purposes (see Chapter 6.2.1 in the TSD) but uses the other IWG SC-GHG estimates (those discounted at 5%, and the 95th percentile estimates discounted at 3%) as sensitivity cases. The case using the SC-GHG values that reflect the 5% discount rate (while discounting and including all other benefits at a 7% discount rate) reduces total benefits by more than half and results in significantly lower net benefits (-30.7 compared to 0.3), as well as a 51% decrease in total benefits, one of the largest changes across all of the sensitivity cases. The sensitivity case that employs the 95th percentile SC-GHG estimates developed using the 3% discount rate (which discounts including all other benefits at 3% discount rate) case similarly increases total social benefits by 26% and thus yields substantially different net benefits (31.9 compared to 0.3) and positively increases total social benefits by 26%. Note that the 5% and 95th percentile SC-GHG cases discount costs and include other benefits at different discount rates (7% vs. 3%), which contributes significantly to drives some of these differences.

NHTSA also presents a sensitivity case showing costs and benefits under a scenario using the now-rescinded interim domestic only SC-GHG values at a 3% discount rate. These values, unlike the current values recommended by the IWG, represent an estimate of the domestic-only costs of GHGs.[133] In this sensitivity case, net benefits fall far below those in the main analysis, to -27.6 (see Table 7-2). The benefits decrease by -23%, a relatively large difference compared to other sensitivity cases. Overall, net benefits differ significantly depending on the SC-GHG estimates used in the analysis.

7.2.3.2 Rebound Effect

The CAFE Model results are less sensitive to some parameters than others. As seen in Table 7-2, changing the rebound effect in either direction has a minor impact on net benefits. The reference case (main analysis) uses a rebound effect of 15%, and the two sensitivity cases used assume 10% rebound and 20% rebound. Assuming a rebound effect of 10% results in slightly lower costs and benefits (relative to the reference case), and an increase in net benefits, while assuming a rebound effect of 20% leads to higher cost and benefit values and negative net benefits. In both cases, benefits change by a magnitude of 2%, while costs decrease by 5% in the

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[133] According to OMB's Circular A-4 (2003), an "analysis should focus on benefits and costs that accrue to citizens and residents of the United States", and international effects should be reported separately. To correctly assess the total climate damages to U.S. citizens and residents, an analysis must account for impacts that occur within U.S. borders, climate impacts occurring outside U.S. borders that directly and indirectly affect the welfare of U.S. citizens and residents, and spillover effects from climate action elsewhere. The SC-CO_2 estimates used in regulatory analysis under revoked E.O. 13783, including in the RIA for this proposed rule are an approximation of the climate damages occurring within U.S. borders only. However, as discussed at length in the IWG's February 2021 TSD, estimates of climate impacts occurring solely within U.S. borders are likely to underestimate benefits of CO_2 mitigation accruing to U.S. citizens and residents, and are also subject to a considerable degree of uncertainty due to the manner in which they are derived.

10% rebound case and increase by 6% in the 20% rebound case – relatively low changes compared to other sensitivity cases discussed in this chapter.

7.2.3.3 Sales and Scrappage Response

Sensitivity cases with adjusted sales and scrappage responses also cause relatively small changes in net benefits. As shown in Table 7-2, we include two cases with different sales-scrappage responses: "sales-scrappage response (+20%)", where the magnitude of the response to effective price changes (net of fuel savings) is increased by 20 percent, and "sales-scrappage response (-20%), a similar 20 percent decrease in magnitude. In "Sales-scrappage response (+20%)", social benefits decrease, and social costs increase, leading to a decrease in net benefits (-3.9 compared to 0.3). In the case called "Sales-scrappage response (-20%), total benefits increase, total costs decrease, and net benefits increase to 4.4. In both cases, total benefits and total costs change by a magnitude of 2%, showing the relatively small effect of changes in the sales-scrappage response.

7.2.3.4 Mass-Size Safety and Crash Avoidance

The two mass-size safety sensitivity cases cause social costs to change by a magnitude of 8%, with negative net benefits under the high mass-size safety case (-9.3) and positive benefits under the low mass-size safety case (10.0).

The crash avoidance effectiveness values are the least responsive out of all of the consumer and social parameters, as the two crash avoidance sensitivity cases show 1% change in magnitude of social costs relative to the reference case. In both the low effectiveness and high effectiveness cases, net benefits decrease, to -0.8 (low effectiveness case) and -1.0 (high effectiveness case).

7.2.4 Effect of Macroeconomic Growth

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 vehicle market, the rate at which the on-road fleet turns over, and the total demand for travel in light-duty vehicles. In this analysis, the reference case assumptions match those in AEO 2021 as closely as possible.[134] EIA publishes a number of "side cases" with every Annual Energy Outlook, two of which usually describe different growth paths for the U.S. economy. The "Low GDP" and "High GDP" sensitivity cases in Table 7-2 refer to our implementation of those two growth cases in the CAFE Model. In addition to the macroeconomic assumptions listed above, all of which are replaced with comparable assumptions from the two EIA side cases, each of these growth cases produces internally consistent sets of fuel prices – and those are incorporated into the sensitivity cases as well.

The lingering consequences of the COVD pandemic have only increased the level of uncertainty that would typically be present in any projection of macroeconomic conditions that spans a period as long as the one covered by this analysis. However, as Table 7-2 illustrates, the

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[134] The AEO does not publish a consumer confidence series, which comes from the Global Insight Macroeconomic Forecasting model.

deviations from the reference case estimate of net benefits are relatively small. While it's true that the lower growth case produces negative net benefits, and the higher growth case further increases (positive) net benefits, the reference case is sufficiently close to the threshold that this occurs in most sensitivity cases. This result should provide some measure of confidence that the estimated net benefits in the reference case are only somewhat sensitive to alternative growth assumptions about the U.S. economy.