Regulatory Impact Analysis:

Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards

United States
Environmental Protection
Agency

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

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EPA-420-R-12-016
August 2012

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Executive Summary

The Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) are issuing a joint Notice of Final Rulemaking (FRM) to establish standards for light-duty highway vehicles that will reduce greenhouse gas emissions (GHG) and improve fuel economy. EPA is issuing greenhouse gas emissions standards under the Clean Air Act, and NHTSA is issuing Corporate Average Fuel Economy standards under the Energy Policy and Conservation Act (EPCA), as amended. These standards apply to passenger cars, light-duty trucks, and medium-duty passenger vehicles, covering model years (MY) 2017 through 2025. The standards will require these vehicles to meet an estimated combined average emissions level of 163 grams of CO_2 per mile in MY 2025 under EPA's GHG program. These standards are designed such that compliance can be achieved with a single national vehicle fleet whose emissions and fuel economy performance improves year over year. The National Program will result in approximately 2 billion metric tons of CO_2 equivalent emission reductions and approximately 4 billion barrels of oil savings over the lifetime of vehicles sold in model years 2017 through 2025.

Mobile sources are significant contributors to air pollutant emissions (both GHG and non-GHG) across the country, internationally, and into the future. The Agency has determined that these emissions cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare, and is therefore establishing standards to control these emissions as required by section 202 (a) of the Clean Air Act.[A] The health- and environmentally-related effects associated with these emissions are a classic example of an externality-related market failure. An externality occurs when one party's actions impose uncompensated costs on another party. EPA's final rule will deliver additional environmental and energy benefits, as well as cost savings, on a nationwide basis that would likely not be available if the rule were not in place.

Table 1 shows EPA's estimated lifetime discounted cost, benefits and net benefits for all vehicles projected to be sold in model years 2017-2025. It is important to note that there is significant overlap in costs and benefits for NHTSA's CAFE program and EPA's GHG program and therefore combined program costs and benefits are not a sum of the individual programs.

[A] "Technical Support Document for Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act" Docket: EPA-HQ-OAR-2010-0799, http://epa.gov/climatechange/endangerment.html. See also State of Massachusetts v. EPA, 549 U.S. 497, 533 ("If EPA makes a finding of endangerment, the Clean Air Act requires the agency to regulate emissions of the deleterious pollutant from new motor vehicles").

Table 1 EPA's Estimated 2017-2025 Model Year Lifetime Discounted Costs, Benefits, and Net Benefits assuming the 3% discount rate SCC Value[a,b,c,d] (Billions of 2010 dollars)

Lifetime Present Value[c] – 3% Discount Rate	
Program Costs	$150
Fuel Savings	$475
Benefits	$126
Net Benefits[d]	$451
Annualized Value[e] – 3% Discount Rate	
Annualized costs	$6.49
Annualized fuel savings	$20.5
Annualized benefits	$5.46
Net benefits	$19.5
Lifetime Present Value[c] - 7% Discount Rate	
Program Costs	$144
Fuel Savings	$364
Benefits	$106
Net Benefits[d]	$326
Annualized Value[e] – 7% Discount Rate	
Annualized costs	$10.8
Annualized fuel savings	$27.3
Annualized benefits	$7.96
Net benefits	$24.4

Notes:
[a] The agencies estimated the benefits associated with four different values of a one ton CO_2 reduction (model average at 2.5% discount rate, 3%, and 5%; 95th percentile at 3%), which each increase over time. For the purposes of this overview presentation of estimated costs and benefits, however, we are showing the benefits associated with the marginal value deemed to be central by the interagency working group on this topic: the model average at 3% discount rate, in 2010 dollars. Section III.H provides a complete list of values for the 4 estimates.
[b] Note that net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, and 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to Section III.H for more detail.
[c] Projected results using 2008 based fleet projection analysis.
[d] Present value is the total, aggregated amount that a series of monetized costs or benefits that occur over time is worth in a given year. For this analysis, lifetime present values are calculated for the first year of each model year for MYs 2017-2025 (in year 2010 dollar terms). The lifetime present values shown here are the present values of each MY in its first year summed across MYs.
[e] Net benefits reflect the fuel savings plus benefits minus costs.
[f] The annualized value is the constant annual value through a given time period (the lifetime of each MY in this analysis) whose summed present value equals the present value from which it was derived. Annualized SCC values are calculated using the same rate as that used to determine the SCC value, while all other costs and benefits are annualized at either 3% or 7%.

This Regulatory Impact Analysis (RIA) contains supporting documentation to the EPA rulemaking. NHTSA has prepared its own RIA in support of its CAFE standards (see

NHTSA's docket for the rulemaking, NHTSA-2010-0131). While the two sets of standards are similar, there are also differences in the analyses that require separate discussion. This is largely because EPA and NHTSA act under different statutes. EPA's authority comes under the Clean Air Act, and NHTSA's authority comes under EPCA (Energy Policy and Conservation Act of 1975) and EISA (Energy Independence and Security Act), and each statute has somewhat different requirements and flexibilities. As a result, each agency has followed a unique approach where warranted by these differences. Where each agency has followed the same approach or rely on the same inputs —e.g., development of technology costs and effectiveness—the supporting documentation is contained in the joint Technical Support Document (joint TSD can be found in EPA's docket EPA-HQ-OAR-2010-0799). Therefore, this RIA should be viewed as a companion document to the Joint TSD and the two documents together provide the details of EPA's technical analysis in support of its rulemaking.

This document contains the following;

Chapter 1: Technology Packages, Cost and Effectiveness, The details of the vehicle technology costs and packages used as inputs to EPA's Optimization Model for Emissions of Greenhouse gases from Automobiles (OMEGA) are presented. These vehicle packages represent potential ways of meeting the CO_2 stringency established by this rule and are based on the technology costs and effectiveness analyses discussed in Chapter 3 of the Joint TSD. This chapter also contains details on the lumped parameter model, which is a major part of EPA's determination of the effectiveness of these packages. More detail on the effectiveness of technologies and the Lumped Parameter model can be found in Chapter 3 of the Joint TSD.

Chapter 2: EPA's Vehicle Simulation Tool, The development and application of the EPA vehicle simulation tool, called ALPHA (Advanced Light-Duty Powertrain and Hybrid Analysis), are discussed. This chapter first provides a detailed description of the simulation tool including overall architecture, systems, and components of the vehicle simulation model. The chapter also describes applications and results of the vehicle simulation runs for estimating impact of A/C usage on fuel consumption and calculating off-cycle credits particularly for active aerodynamic technologies. For the result of the A/C study, the impact of A/C usage was estimated at for cars and trucks separately using the ALPHA tool. The result corresponds to an impact of approximately 14.0 CO_2 g/mile for the (2012) fleet, which is comparable to the 2012-2016 final rule result. For the off-cycle credits, EPA based its analysis on manufacturer data as well as the ALPHA tool, where active grill shutters (one of the active aerodynamic technologies considered) provide a reduction of 0-5% in aerodynamic drag (C_d) when deployed. EPA expects that most other active aerodynamic technologies will provide a reduction of drag in the same range as active grill shutters. Based on this analysis, EPA will provide a credit for active aerodynamic technologies that can demonstrate a reduction in aerodynamic drag of 3% or more.

Chapter3: Results of Final and Alternative Standards, This chapter provides the methodology for and results of the technical assessment of the future vehicle scenarios presented in this final rulemaking. As in the analysis of the MY 2012-2016 rulemaking, evaluating these scenarios included identifying potentially available technologies and assessing their effectiveness, cost, and impact on relevant aspects of vehicle performance and utility. The wide number of technologies which are available and likely to be used in combination required a method to account for their combined cost and effectiveness, as well as estimates of their availability to be applied to vehicles. These topics are discussed.

Chapter 4: Projected Impacts on Emissions, Fuel Consumption, and Safety, This chapter documents EPA's analysis of the emission, fuel consumption and safety impacts of the final emission standards for light duty vehicles. These final standards significantly decrease the magnitude of greenhouse gas emissions from light duty vehicles. Because of anticipated changes to driving behavior, fuel production, and electricity generation, a number of co-pollutants would also be affected by this rule. This analysis quantifies the program's impacts on the greenhouse gases (GHGs) carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and hydrofluorocarbons (HFC-134a); program impacts on "criteria" air pollutants, including carbon monoxide (CO), fine particulate matter ($PM_{2.5}$) and sulfur dioxide (SOx) and the ozone precursors hydrocarbons (VOC) and oxides of nitrogen (NOx); and impacts on several air toxics including benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein.

CO_2 emissions from automobiles are largely the product of fuel combustion, and consequently, reducing CO_2 emissions will also produce a significant reduction in projected fuel consumption. EPA's projections of these impacts (in terms of gallons saved) are also shown in this chapter. RIA Chapter 5 presents the monetized fuel savings.

In addition to the intended effects of reducing CO_2 emission, the agencies also consider the potential of the standards to affect vehicle safety. This topic is introduced in Preamble Section II.G. EPA's analysis of the change in fatalities due to projected usage of mass reduction technology is shown in this chapter.

Chapter 5: Vehicle Program Costs Including Fuel Consumption Impacts, This chapter contains the program costs and fuel savings associated with EPA's final rulemaking. In Chapter 5, we present briefly some of the outputs of the OMEGA model (costs per vehicle) and how we use those outputs to estimate the annual program costs which include the addition of new technology and the potential maintenance associated with that new technology. We also discuss repair costs and our thoughts on the difficulty associated with estimating repair costs. In this chapter, we also present the estimated fuel savings associated with the final standards. We present all of these program costs and the fuel savings for calendar years 2017 through 2050 and for the lifetimes of each of the model years 2017 through 2025 that are the focus of the final rulemaking. We also present our cost per ton analysis showing the cost incurred for each ton of GHG reduced by the program.

Also presented in Chapter 5 is our estimated consumer cost of ownership and what we call our "payback analysis" which looks at how quickly the improved fuel efficiency of new vehicles provides savings to buyers despite the vehicles having new technology (and new costs). The consumer payback analysis shows that fuel savings will outweigh incremental costs in less than four years for people purchasing new 2025MY vehicles with either cash or credit. Further, for those purchasing new vehicles with a typical five-year car loan, the fuel savings will outweigh increased costs in the first month of ownership. We have also looked at the payback periods for buyers of used vehicles meeting the final standards. For buyers that purchase a 5 and/or a 10 year old vehicle meeting the final standards, the payback periods occur in half a year or roughly one year depending on whether the vehicle is purchased with cash or credit.

Chapter 6: Environmental and Health Impacts, This Chapter provides details on both the climate impacts associated with changes in atmospheric CO_2 concentrations and the non-GHG health and environmental impacts associated with criteria pollutants and air toxics.

Based on modeling analysis performed by the EPA, reductions in CO_2 and other GHG emissions associated with this final rule will affect future climate change. Since GHGs are well-mixed in the atmosphere and have long atmospheric lifetimes, changes in GHG emissions will affect atmospheric concentrations of greenhouse gases and future climate for decades to millennia, depending on the gas. This section provides estimates of the projected change in atmospheric CO_2 concentrations based on the emission reductions estimated for this final rule, compared to the reference case. In addition, this section analyzes the response to the changes in GHG concentrations of the following climate-related variables: global mean temperature, sea level rise, and ocean pH. See Chapter 4 in this RIA for the estimated net reductions in global emissions over time by GHG.

There are also health and environmental impacts associated with the non-GHG emissions projected to change as a result of the final standards. To adequately assess these impacts, we conducted full-scale photochemical air quality modeling to project changes in atmospheric concentrations of $PM_{2.5}$, ozone and air toxics in the year 2030.

Based on the magnitude of the emissions changes predicted to result from the final vehicle standards (as shown in Chapter 4), we project that our modeling indicates that there will be very small changes in ambient ozone and $PM_{2.5}$ concentrations across most of the country. However, there will be small decreases in ambient concentrations in some areas of the country and small increases in ambient concentrations in other areas. The nationwide population-weighted average change for ozone is an increase of 0.001 ppb and the nationwide population-weighted average change for $PM_{2.5}$ is a decrease of 0.007 $\mu g/m^3$.

The final rule reduces the net human health risk posed by non-GHG related pollutants. In monetized terms, the present value of PM- and ozone-related impacts associated with the Calendar Year analysis equals between $3.1 and $9.2 billion in benefits, depending on the assumed discount rate (7 percent and 3 percent, respectively). The present value of PM2.5-related benefits associated with the lifetimes of 2017-2025 model year light-duty vehicles (the Model Year analysis) ranges between $4.3 and $5.5 billion dollars, depending on the assumed discount rate (7% and 3%, respectively).

Chapter 7: Other Economic and Social Impacts, This Chapter presents a summary of the total costs, total benefits, and net benefits expected under the final rule as well as an expanded description of the agency's approach to the monetization of GHG emission reductions and benefits from less frequent refueling. Table 2 presents a summary of all economic impacts on an annual basis and as present values in 2012 for the years 2017 through 2050 at both 3% and 7% discount rates. Additional tables in Chapter 7 present the total value of each category of costs and benefits from this rule over the lifetime of MY 2017-2025 vehicles as well as in select calendar years through 2050. We note that several of the cost and benefit categories we would typically discuss in an RIA are considered joint economic assumptions common to EPA and NHTSA and are discussed in more detail in EPA and NHTSA's Joint TSD Chapter 4. For the reader's reference, Chapter 7 includes a summary table with a number of the economic values discussed in the Joint TSD, including the value of improving U.S. energy security by reducing imported oil, discount rates, the magnitude of the VMT rebound effect, and the value of accidents, noise, and congestion associated with additional vehicle use due to the rebound effect.

Table 2 Undiscounted Annual Monetized Net Benefits & Net Benefits of the Final Program Discounted Back to 2012 at 3% and 7% Discount Rates (Millions, 2010$)

	2017	2020	2030	2040	2050	NPV, 3%[a]	NPV, 7%[a]
Technology Costs	$2,470	$9,190	$35,900	$41,000	$46,500	$561,000	$247,000
Fuel Savings	$651	$7,430	$86,400	$155,000	$212,000	$1,600,000	$607,000
Total Annual Benefits at each assumed SCC value[b]							
5% (avg SCC)	$97	$1,120	$15,300	$28,500	$31,300	$257,000	$118,000
3% (avg SCC)	$138	$1,590	$21,200	$40,000	$47,200	$395,000	$256,000
2.5% (avg SCC)	$171	$1,960	$25,600	$48,400	$58,100	$515,000	$376,000
3% (95th %ile)	$250	$2,890	$38,500	$74,800	$96,900	$743,000	$604,000
Monetized Net Benefits at each assumed SCC value[c]							
5% (avg SCC)	-$1,690	-$316	$68,000	$146,000	$201,000	$1,290,000	$478,000
3% (avg SCC)	-$1,650	$153	$73,900	$158,000	$217,000	$1,430,000	$616,000
2.5% (avg SCC)	-$1,610	$524	$78,300	$166,000	$228,000	$1,550,000	$736,000
3% (95th %ile)	-$1,530	$1,460	$91,200	$192,000	$267,000	$1,780,000	$964,000

Notes:

[a] Net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail. Annual costs shown are undiscounted values.

[b] RIA Chapter 7.1 notes that SCC increases over time. For the years 2017-2050, the SCC estimates range as follows: for Average SCC at 5%: $6-$16; for Average SCC at 3%: $26-$47; for Average SCC at 2.5%: $41-$68; and for 95th percentile SCC at 3%: $79-$142. RIA Chapter 7.1 also presents these SCC estimates.

[c] Net Benefits equal Fuel Savings minus Technology Costs plus Benefits.

Chapter 8: Vehicle Sales and Employment Impacts, Chapter 8 provides background on analyses of the impacts of this rule on vehicle sales and employment in the auto industry and closely related sectors. Employment effects due to the rule depend in part on the state of the economy when the rule becomes effective. The auto industry (the directly regulated sector) is expected to require additional labor, due both to increased vehicle production and increased production of fuel-saving technologies. Effects on other sectors vary: though the rule is likely to increase employment at dealerships (due to the estimated increased sales) and parts suppliers, and through consumers' ability to use money not spent on fuel for other purposes, employment is expected to be reduced in fuel production and supply sectors. These analyses provide a fuller picture of the impacts of this rule.

Chapter 9: Small Business Flexibility Analysis, Chapter 9 includes EPA's analysis of the small business impacts due to EPA's final rulemaking. EPA is exempting domestic and foreign businesses that meet small business size definitions established by the Small Business Administration.

Chapter 10: **Alternate Analysis Using 2010 MY Baseline**, Results Using the 2010 Baseline Fleet. In this chapter, EPA presents an alternate analysis using the 2010 based fleet as the input to the Omega model.

1 Technology Packages, Cost and Effectiveness

1.1 Overview of Technology

The final program is based on the need to obtain significant GHG emissions reductions from the transportation sector, and the recognition that there are technically feasible, cost effective technologies to achieve such reductions in the MYs 2017-2025 timeframe at reasonable cost per vehicle and short consumer payback periods, with no compromise to vehicle utility or safety. As in many prior mobile source rulemakings, the decision on what standard to set is largely based on the effectiveness of the emissions control technology, the cost (both per manufacturer and per vehicle) and other impacts of implementing the technology, and the lead time needed for manufacturers to employ the control technology. EPA also considers the need for reductions of greenhouse gases, the degree of reductions achieved by the standards, and the impacts of the standards in terms of costs, quantified and unquantified benefits, safety, and other impacts. The availability of technology to achieve reductions and the cost and other aspects of this technology are therefore a central focus of this rulemaking.

CO_2 is a stable compound produced by the complete combustion of fuel. Vehicles combust fuel to perform two basic functions: 1) transport the vehicle, its passengers and its contents, and 2) operate various accessories during the operation of the vehicle such as the air conditioner. Technology can reduce CO_2 emissions by either making more efficient use of the energy that is produced through combustion of the fuel or by reducing the energy needed to perform either of these functions.

This focus on efficiency involves a major change in focus and calls for looking at the vehicle as an entire system. In addition to fuel delivery, combustion, and aftertreatment technology, any aspect of the vehicle that affects the need to produce energy must also be considered. For example, the efficiency of the transmission system, which takes the energy produced by the engine and transmits it to the wheels, and the resistance of the tires to rolling both have major impacts on the amount of fuel that is combusted while operating the vehicle. Braking system drag, the aerodynamic drag of the vehicle, and the efficiency of accessories (such as the air conditioner) all affect how much fuel is combusted.

This need to focus on the efficient use of energy by the vehicle as a system leads to a broad focus on a wide variety of technologies that affect almost all the systems in the design of a vehicle. As discussed below and in detail in Chapter 3 of the joint TSD, there are many technologies that are currently available which can reduce vehicle energy consumption. These technologies are already being commercially utilized to a limited degree in the current light-duty fleet. These technologies include hybrid technologies that use higher efficiency electric motors as the power source in combination with or instead of internal combustion engines. While already commercialized, hybrid technology continues to be developed and offers the potential for even greater efficiency improvements. There are a number of technologies described in the MYs 2012-2016 rule (TSD and RIA) that are also common to this rule. While significant penetration of these technologies is expected within the MY 2016 timeframe, some technologies will experience continued improvement and others will be only partially implemented into the fleet by MY 2016. We describe those technologies for which we expect to see further improvement or a second level of cost and effectiveness—e.g., engine friction reduction, improved accessories, lower rolling resistance tires—in Chapter 3 of the joint TSD and generally denote them as “level 2” versions of each technology. The primary examples of those technologies that we expect to be only partially implemented into the fleet by MY 2016 would be weight reduction greater than 5-10% and electrification of powertrains to hybrid, plug-in electric and full electric, which we do not project manufacturers as needing to utilize to meet their MYs 2012-2016 standards . There are also other advanced technologies under development (that were not projected to be available to meet MYs 2012-2016 standards), such as turbocharged engines with increasingly high levels of boost and lean burn gasoline engines, both of which offer the potential of improved energy generation through enhancements to the basic combustion process. Finally, there may be technologies not considered for this rule that, given the long lead time, can be developed and introduced into the market. These currently unknown technologies (or enhancements of known technologies) could be more cost effective than those included in this analysis. The more cost-effective a new technology is, the more likely it is that an auto manufacturer will implement it.

The large number of possible technologies to consider and the breadth of vehicle systems that are affected mean that consideration of the manufacturer’s design and production process plays a major role in developing the standards. Vehicle manufacturers typically develop their many different models by basing them on a limited number of vehicle platforms. Several different models of vehicles are produced using a common platform, allowing for efficient use of design and manufacturing resources. The platform typically consists of common vehicle architecture and structural components. Given the very large investment put into designing and producing each vehicle model, manufacturers cannot reasonably redesign any given vehicle every year or even every other year, let alone redesign all of their vehicles every year or every other year. At the redesign stage, the manufacturer will upgrade or add all of the technology and make all of the other changes needed so the vehicle model will meet the manufacturer’s plans for the next several years. This includes meeting all of the emissions and other requirements that would apply during the years before the next major redesign of the vehicle.

This redesign often involves a package of changes, designed to work together to meet the various requirements and plans for the model for several model years after the redesign. This typically involves significant engineering, development, manufacturing, and marketing resources to create a new product with multiple new features. In order to leverage this significant upfront investment, manufacturers plan vehicle redesigns with several model years of production in mind. That said, vehicle models are not completely static between redesigns as limited changes are often incorporated for each model year. This interim process is called a refresh of the vehicle and generally does not allow for major technology changes although more minor ones can be done (e.g., aerodynamic improvements, valve timing improvements). More major technology upgrades that affect multiple systems of the vehicle (e.g., hybridization) thus occur at the vehicle redesign stage and not between redesigns.

Given that the regulatory timeframe of the GHG program is nine years (MY 2017 through MY 2025), and given EPA’s belief that full line manufacturers (i.e., those making small cars through large cars, minivans, small trucks and large trucks) cannot redesign, on average, their entire product line more than twice during that timeframe, we have assumed two full redesign cycles in the MYs 2017-2025 timeframe This means that the analysis assumes that each vehicle platform in the US fleet can undergo at least two full redesigns during the regulatory timeframe.

As discussed below, there are a wide variety of emissions control technologies involving several different systems in the vehicle that are available for consideration. Many can involve major changes to the vehicle, such as changes to the engine block and heads, or redesign of the transmission and its packaging in the vehicle. This calls for tying the incorporation of the emissions control technology into the periodic redesign process. This approach would allow manufacturers to develop appropriate packages of technology upgrades that combine technologies in ways that work together and fit with the overall goals of the redesign. It also allows the manufacturer to fit the process of upgrading emissions control technology into its multi-year planning process, and it avoids the large increase in resources and costs that would occur if technology had to be added outside of the redesign process.

Over the nine model years at issue in this rulemaking, MYs 2017-2025, EPA projects that almost the entire fleet of light-duty vehicles will have gone through two redesign cycles. If the technology to control greenhouse gas emissions is efficiently folded into this redesign process, then by MY 2025 the entire light-duty fleet could be designed to employ upgraded packages of technology to reduce emissions of CO_2, and as discussed below, to reduce emissions of harmful refrigerants from the air conditioner.

In determining the projected technology needed to meet the standards, and the cost of those technologies, EPA is using an approach that accounts for and builds on this redesign process. This provides the opportunity for several control technologies to be incorporated into the vehicle during redesign, achieving significant emissions reductions from the model at one time. This is in contrast to what would be a much more costly approach of trying to achieve small increments of reductions over multiple years by adding technology to the vehicle piece by piece outside of the redesign process.

As described below, the vast majority of technology we project as being utilized to meet the GHG standards is commercially available and already being used to a limited extent across the fleet, although far greater penetration of these technologies into the fleet is projected as a result of both the MYs 2012-2016 rule and this final rule. The vast majority of the emission reductions associated with this final rule would result from the increased use of these technologies. EPA also believes the MYs 2017-2025 standards will encourage the development and limited use of more advanced technologies, such as plug-in hybrid electric vehicles (PHEVs) and full electric vehicles (EVs), and is structuring the final rule to encourage these technologies' use.

In section 1.2 below, a summary of technology costs and effectiveness is presented. In section 1.3, the process of combining technologies into packages is described along with package costs and effectiveness. Sections 1.4 and 1.5 discuss the lumped parameter approach which provides background and support for determining technology and package effectiveness.

1.2 Technology Cost and Effectiveness

EPA collected information on the cost and effectiveness of CO_2 emission reducing technologies from a wide range of sources. The primary sources of information were the MYs 2012-2016 FRM, the 2010 Technical Assessment Report (TAR), tear-down analyses done by FEV and the 2008 and 2010 Ricardo studies. In addition, we have considered confidential data submitted by vehicle manufacturers, some of which was submitted in response to NHTSA requests for product plans, along with confidential information shared by automotive industry component suppliers in meetings with EPA and NHTSA staff. These confidential data sources were used primarily as a validation of the estimates since EPA prefers to rely on public data rather than confidential data wherever possible.

Since publication of the MYs 2012-2016 FRM, EPA has continued the work with FEV that consists of complete system tear-downs to evaluate technologies down to the nuts and bolts—i.e., a “bill of materials”—to arrive at very detailed estimates of the costs associated with manufacturing them. Also, cost and effectiveness estimates were adjusted as a result of further meetings between EPA and NHTSA staffs following publication of the 2010 TAR and into the first half of 2011 where both piece costs and fuel consumption efficiencies were discussed in detail, and in consideration of public comments received on the proposal. EPA and NHTSA also met with Department of Energy (DOE) along with scientists and engineers from a number of national laboratories to discuss vehicle electrification. EPA also reviewed the published technical literature which addressed the issue of CO_2 emission control, such as papers published by the Society of Automotive Engineers and the American Society of Mechanical Engineers.[1] The results of these efforts, especially the results of the FEV tear-down and Ricardo studies were used extensively in this final rule as described in detail in Chapter 3 of the joint TSD.

For all of the details behind the cost and effectiveness values used in this analysis the reader is referred to Chapter 3 of the joint TSD. There we present direct manufacturing costs, indirect costs and total costs for each technology in each MY 2017 through MY 2025. We also describe the source for each direct manufacturing cost and how those costs change over time due to learning, and the indirect costs and how they change over time. Note that all costs presented in the tables that follow are total costs and include both direct manufacturing and indirect costs.[2]

For direct manufacturing costs (DMC) related to turbocharging, downsizing, gasoline direct injection, transmissions, as well as non-battery-related costs on hybrid, plug-in hybrid and electric vehicles, the agencies have relied on costs derived from teardown studies. For battery related DMC for HEVs, PHEVs and EVs, the agencies have relied on the BatPaC model developed by Argonne National Laboratory for the Department of Energy. For mass reduction DMC, the agencies have relied on several studies as described in detail in the Joint TSD. For the majority of the other technologies considered in this final rule, the agencies have relied on the MYs 2012-2016 final rule and sources described there for estimates of DMC. We have also considered public comments received in response to the proposal of this rule.

For this analysis, indirect costs are estimated by applying indirect cost multipliers (ICM) to direct cost estimates. ICMs were derived by EPA as a basis for estimating the impact on indirect costs of individual vehicle technology changes that would result from regulatory actions. Separate ICMs were derived for low, medium, and high complexity technologies, thus enabling estimates of indirect costs that reflect the variation in research, overhead, and other indirect costs that can occur among different technologies. ICMs were also applied in the MYs 2012-2016 rulemaking. We have also included an estimate of stranded capital that could result due to introduction of technology on a more rapid pace than the industry norm. We describe our ICMs and the method by which they are applied to direct costs and our stranded capital estimates in the Joint TSD Chapter 3.1.2. Stranded capital is also discussed in this RIA at Chapter 3.5.7 and Chapter 5.1. We have also considered public comments received in response to the proposal of this rule and responded to those comments in section III.H of the preamble to the final rule, and in the Response to Comments Document.

Regarding learning effects, we continue to apply learning effects in the same way as we did in both the MYs 2012-2016 final rule and in the 2010 TAR. However, we have employed some new terminology in an effort to eliminate some confusion that existed with our old terminology. This new terminology was described in the heavy-duty GHG final rule (see 76 FR 57320) and in the proposal to this rule (76 FR 74929). Our previous terminology suggested we were accounting for two completely different learning effects—one based on volume production and the other based on time. This was not the case since, in fact, we were actually relying on just one learning phenomenon, that being the learning-by-doing phenomenon that results from cumulative production volumes.

As a result, we have considered the impacts of manufacturer learning on the technology cost estimates by reflecting the phenomenon of volume-based learning curve cost reductions in our modeling using two algorithms depending on where in the learning cycle (i.e., on what portion of the learning curve) we consider a technology to be – "steep" portion of the curve for newer technologies and "flat" portion of the curve for more mature technologies. The observed phenomenon in the economic literature which supports manufacturer learning cost reductions are based on reductions in costs as production volumes increase with the highest absolute cost reduction occurring with the first doubling of production. The agencies use the terminology "steep" and "flat" portion of the curve to distinguish among newer technologies and more mature technologies, respectively, and how learning cost reductions are applied in cost analyses.

Learning impacts have been considered on most but not all of the technologies expected to be used because some of the expected technologies are already used rather widely in the industry and, presumably, quantifiable learning impacts have already occurred. We have applied the steep learning algorithm for only a handful of technologies considered to be new or emerging technologies such as PHEV and EV batteries which are experiencing heavy development and, presumably, rapid cost declines in coming years. For most technologies, we have considered them to be more established and, hence, we have applied the lower flat learning algorithm. For more discussion of the learning approach and the technologies to which each type of learning has been applied the reader is directed to Chapter 3.2.3 of the Joint TSD.

Fuel consumption reductions are possible from a variety of technologies whether they be engine-related (e.g., turbocharging), transmission-related (e.g., six forward gears in place of four), accessory-related (e.g., electric power steering), or vehicle-related (e.g., lower rolling resistance tires). Table 1.2-1 through Table 1.2-20 present the costs associated with the technologies we believe would be the enabling technologies for compliance with the new standards. Note that many of these technologies are expected to have penetrated the fleet as much as 85 to 100 percent by the 2016 MY and, as such, would represent reference case technologies in this final rule. That is, technologies such as lower rolling resistance tires and level 1 aerodynamic treatments are expected to exceed 85 percent penetration by MY 2016 so they cannot be added "again" to comply with the MYs 2017-2025 standards. However, we list all such technologies in the tables that follow for completeness and comparison to earlier analyses.

One thing that is immediately clear from the cost tables that follow is that we have updated our costing approach relative to the MYs 2012-2016 FRM and 2010 TAR for some technologies in an effort to provide better granularity in our estimates. This is easily seen in Table 1.2-1 and Table 1.2-2 where we list costs for technologies by engine configuration—in-line or "I" versus "V"—and/or by number of cylinders. In the MYs 2012-2016 final rule, we showed costs for a small car, large car, large truck, etc. The limitation of that approach was that different vehicle classes can have many different sized engines. This is exacerbated when estimating costs for turbocharged and downsized engines. For example, we project that many vehicles in the large car class which, today, have V8 engines would have highly turbocharged I4 engines under this final rule. As such, we would not want to estimate the large car costs of engine friction reduction (EFR)—which have always and continue to be based on the number of cylinders—assuming (incorrectly) that all large cars have V8 engines. With our new approach, the large cars that remain V8 would carry EFR costs for a V8, one downsized to a V6 would carry EFR costs for a V6 and one downsized further to an I4 would carry EFR costs for an I4. Our old approach would have applied the EFR cost for a V8 to each.

Note that Table 1.2-20 and Table 1.2-21 present costs for mass reduction technology on each of the 19 vehicle types used in OMEGA. We present costs for only a 10% and a 20% applied weight reduction. We use the term "applied" weight reduction to reflect the amount of weight reduction technology—or weight reduction cost—applied to the package. We also use the term "net" weight reduction when determining costs for hybrid, plug-in hybrid, and full electric vehicles (see Table 1.2-7 through Table 1.2-18). The net weight reduction is the applied weight reduction less the added weight of the hybrid and/or electric vehicle technologies. Table 1.2-7 shows costs for P2 hybrids. For the subcompact P2 HEV with an applied weight reduction of 10%, the net weight reduction is shown as 5%. Therefore, our cost analysis would add the costs for 10% weight reduction for such a P2 HEV even though the net weight reduction was only 5%. Likewise, we would add the cost of P2 HEV technology assuming only a 5% weight reduction since that is the net weight reduction of the vehicle. Note that the higher the net weight reduction the lower the cost for HEV and/or EV technologies since smaller batteries and motors can be used as the vehicle gets lighter). How we determined the necessary battery pack sizes and the resultant net weight impacts is described in Chapter 3.3.3 of the joint TSD. We note that the approach described there is a departure from our earlier efforts—in the MYs 2012-2016 FRM and 2010 TAR—where the weight increase of the electrification components was not fully recognized. Importantly, that had little impact on the analysis used to support the MYs 2012-2016 rule since that rule projected very low penetration of HEVs and no PHEV or EV penetrations.

All costs continue to be relative to a baseline vehicle powertrain system (unless otherwise noted) consisting of a multi-point, port fuel injected, naturally aspirated gasoline engine operating at a stoichiometric air-fuel ratio with fixed valve timing and lift paired with a 4-speed automatic transmission. This configuration was chosen as the baseline vehicle because it was the predominant technology package sold in the United States in the baseline model year 2008. Costs are presented in terms of their hardware incremental compliance cost. This means that they include all potential product development costs associated with their application on vehicles, not just the cost of their physical parts. A more detailed description of these and the following estimates of cost and effectiveness of CO_2 reducing technologies can be found in Chapter 3 of the joint TSD, along with a more detailed description of the comprehensive technical evaluation underlying the estimates.

Note that the costs presented in the tables that follow make mention of both a 2008 and a 2010 baseline. In the proposal, we used a fleet derived from a 2008 model year baseline. In evaluating impacts for this final rule, the agencies are using a reference fleet reflecting both a MY 2008 based market forecast and a MY 2010 based market forecast. While costs used for both are presented here and detailed in Chapter 3 of the joint TSD, the results of our analysis based on the MY 2008 based market forecast are presented in Chapters 3 through 9 of this RIA, while the results of our analysis based on the MY 2010 based market forecast are presented in Chapter 10 of this RIA. The reader is directed to Section II.B of the preamble and Chapter 1 of the joint TSD for further detail on the two baseline fleets.

Note also that all costs presented in the tables that follow are expressed in 2010 dollars while the proposal expressed costs in 2009 dollars. We discuss this change and the factors used to update costs to 2010 dollars in Chapter 3.1.4 of the joint TSD.

We have placed in the docket a compact disk that contains the spreadsheets used to generate the costs presented here.[3]

Table 1.2-1 Costs for Engine Technologies for both the 2008 & 2010 Baselines (2010$)

Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
Conversion to Atkinson	$0	$0	$0	$0	$0	$0	$0	$0	$0
CCP-OHC-I	$46	$46	$43	$42	$42	$41	$40	$40	$39
CCP-OHC-V	$93	$91	$86	$84	$83	$82	$80	$79	$78
CCP-OHV-V	$46	$46	$43	$42	$42	$41	$40	$40	$39
CVVL-OHC-I4	$244	$241	$220	$216	$213	$209	$206	$203	$200
CVVL-OHC-V6	$448	$441	$403	$396	$390	$384	$378	$372	$367
CVVL-OHC-V8	$489	$482	$439	$432	$426	$419	$412	$406	$400
DCP-OHC-I	$95	$94	$86	$84	$83	$82	$80	$79	$78
DCP-OHC-V	$205	$202	$184	$181	$178	$176	$173	$170	$168
DCP-OHV-V	$104	$102	$93	$92	$90	$89	$88	$86	$85
Deac-V6	$196	$193	$176	$173	$170	$168	$165	$162	$160
Deac-V8	$220	$217	$198	$195	$191	$189	$186	$183	$180
DVVL-OHC-I4	$163	$161	$146	$144	$142	$140	$137	$135	$133
DVVL-OHC-V6	$236	$233	$212	$209	$206	$202	$199	$196	$193

DVVL-OHC-V8	$338	$333	$303	$298	$294	$289	$285	$280	$276
EFR1-I3	$44	$44	$43	$43	$43	$43	$43	$43	$43
EFR1-I4	$59	$59	$57	$57	$57	$57	$57	$57	$57
EFR1-V6	$89	$89	$85	$85	$85	$85	$85	$85	$85
EFR1-V8	$118	$118	$113	$113	$113	$113	$113	$113	$113
EFR2-I3	$97	$97	$97	$97	$97	$97	$97	$97	$93
EFR2-I4	$126	$126	$126	$126	$126	$126	$126	$126	$121
EFR2-V6	$185	$185	$185	$185	$185	$185	$185	$185	$178
EFR2-V8	$244	$244	$244	$244	$244	$244	$244	$244	$234
EGR-I	$305	$301	$296	$292	$288	$284	$280	$276	$249
EGR-V	$305	$301	$296	$292	$288	$284	$280	$276	$249
LUB	$4	$4	$4	$4	$4	$4	$4	$4	$4
Stoich GDI-I4	$277	$273	$248	$244	$240	$236	$233	$229	$226
Stoich GDI-I4>I3	$277	$273	$248	$244	$240	$236	$233	$229	$226
Stoich GDI-V6	$417	$411	$373	$367	$362	$356	$351	$346	$340
Stoich GDI-V8	$501	$494	$449	$442	$435	$429	$422	$416	$409
V6 OHV to V6 DOHC	$682	$666	$604	$590	$576	$562	$554	$545	$537
V6 SOHC to V6 DOHC	$214	$211	$192	$189	$186	$183	$180	$178	$175
V8 OHV to V8 DOHC	$747	$730	$661	$646	$631	$616	$606	$597	$588
V8 SOHC 3V to V8 DOHC	$154	$152	$138	$136	$134	$132	$130	$128	$126
V8 SOHC to V8 DOHC	$247	$243	$221	$218	$214	$211	$208	$205	$202
VVTI-OHC-I	$46	$46	$43	$42	$42	$41	$40	$40	$39
VVTI-OHC-V	$93	$91	$86	$84	$83	$82	$80	$79	$78
VVTI-OHV-V	$46	$46	$43	$42	$42	$41	$40	$40	$39

CCP=coupled cam phasing; CVVL=continuous variable valve lift; DCP=dual cam phasing; Deac=cylinder deactivation; DOHC=dual overhead cam; DVVL=discrete variable valve lift; EFR1=engine friction reduction level 1; EFR2=EFR level 2; EGR=exhaust gas recirculation; GDI=gasoline direct injection; I=inline engine; I3=inline 3 cylinder; I4=inline 4 cylinder; LUB=low friction lube; OHC=overhead cam; OHV=overhead valve; SOHC=single overhead cam; Stoic=stoichiometric air/fuel; V=V-configuration engine; V6=V-configuration 6 cylinder; V8=V-configuration 8 cylinder; VVTI=intake variable valve timing; 3V=3 valves per cylinder.
All costs are incremental to the baseline case.

Table 1.2-2 Costs for Turbocharging & Downsizing for both the 2008 & 2010 Baselines (2010$)

Technology	BMEP	2017	2018	2019	2020	2021	2022	2023	2024	2025
I4 to I3 wT	18 bar	$427	$423	$359	$356	$352	$348	$344	$340	$337
I4 to I3 wT	24 bar	$690	$681	$654	$647	$639	$632	$624	$617	$551
I4 to I3 wT	27 bar	$1,214	$1,199	$1,164	$1,149	$1,134	$1,120	$1,106	$1,092	$979
I4 DOHC to I4 DOHC wT	18 bar	$482	$476	$421	$415	$410	$404	$399	$393	$388
I4 DOHC to I4 DOHC wT	24 bar	$744	$734	$716	$707	$697	$688	$679	$670	$602
I4 DOHC to I4 DOHC wT	27 bar	$1,269	$1,251	$1,226	$1,209	$1,192	$1,176	$1,160	$1,145	$1,031
V6 DOHC to I4 wT	18 bar	$248	$250	$157	$159	$161	$163	$165	$167	$169
V6 DOHC to I4 wT	24 bar	$510	$508	$452	$450	$449	$447	$445	$444	$383
V6 DOHC to I4 wT	27 bar	$1,035	$1,026	$962	$953	$944	$935	$927	$918	$811
V6 SOHC to	18 bar	$331	$330	$251	$251	$250	$249	$248	$248	$247

I4 wT										
V6 SOHC to I4 wT	24 bar	$594	$589	$546	$542	$537	$533	$529	$524	$461
V6 SOHC to I4 wT	27 bar	$1,119	$1,106	$1,056	$1,044	$1,032	$1,021	$1,010	$999	$890
V6 OHV to I4 DOHC wT	18 bar	$914	$898	$815	$799	$784	$770	$758	$746	$735
V6 OHV to I4 DOHC wT	24 bar	$1,177	$1,156	$1,110	$1,090	$1,072	$1,053	$1,038	$1,023	$949
V6 OHV to I4 DOHC wT	27 bar	$1,701	$1,674	$1,619	$1,593	$1,567	$1,542	$1,519	$1,498	$1,378
V8 DOHC to V6 DOHC wT	18 bar	$746	$738	$635	$628	$620	$613	$606	$599	$592
V8 DOHC to V6 DOHC wT	24 bar	$1,188	$1,174	$1,132	$1,118	$1,105	$1,092	$1,078	$1,066	$953
V8 DOHC to I4 DOHC wT	27 bar	$789	$794	$716	$722	$726	$731	$728	$725	$623
V8 SOHC to V6 DOHC wT	18 bar	$842	$831	$744	$733	$723	$712	$702	$692	$682
V8 SOHC to V6 DOHC wT	24 bar	$1,284	$1,267	$1,241	$1,224	$1,207	$1,191	$1,175	$1,159	$1,043
V8 SOHC to I4 DOHC wT	27 bar	$910	$910	$846	$845	$845	$844	$838	$832	$727
V8 SOHC 3V to V6 DOHC wT	18 bar	$806	$796	$703	$693	$684	$675	$666	$657	$648
V8 SOHC 3V to V6 DOHC wT	24 bar	$1,248	$1,232	$1,200	$1,184	$1,169	$1,153	$1,138	$1,124	$1,010
V8 SOHC 3V to I4 DOHC wT	27 bar	$864	$866	$797	$799	$800	$801	$796	$791	$688
V8 OHV to V6 DOHC wT	18 bar	$1,339	$1,316	$1,194	$1,172	$1,151	$1,131	$1,113	$1,096	$1,080
V8 OHV to V6 DOHC wT	24 bar	$1,781	$1,752	$1,691	$1,663	$1,636	$1,609	$1,586	$1,563	$1,441
V8 OHV to I4 DOHC wT	27 bar	$1,164	$1,152	$1,116	$1,105	$1,093	$1,082	$1,069	$1,056	$944

DOHC=dual overhead cam; I3=inline 3 cylinder; I4=inline 4 cylinder; OHV=overhead valve; SOHC=single overhead cam; V6=V-configuration 6 cylinder; V8=V-configuration 8 cylinder; 3V=3 valves per cylinder; wT=with turbo.
All costs are incremental to the baseline case.

Table 1.2-3 Costs for Transmission Technologies for both the 2008 & 2010 Baselines (2010$)

Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
ASL	$33	$32	$30	$30	$29	$29	$28	$28	$27
ASL2	$34	$33	$32	$32	$31	$30	$30	$29	$27
5sp AT	$104	$103	$97	$95	$94	$92	$91	$89	$88
6sp AT	-$9	-$9	-$10	-$9	-$9	-$9	-$9	-$8	-$8
6sp DCT-dry	-$116	-$112	-$131	-$127	-$123	-$119	-$116	-$112	-$109
6sp DCT-wet	-$82	-$79	-$92	-$89	-$87	-$84	-$82	-$79	-$77
6sp MT	-$169	-$165	-$172	-$167	-$163	-$159	-$155	-$151	-$147
8sp AT	$62	$61	$55	$54	$54	$53	$52	$51	$50
8sp DCT-dry	-$16	-$15	-$15	-$14	-$14	-$13	-$13	-$12	-$15

8sp DCT-wet	$47	$47	$46	$45	$45	$44	$44	$43	$39
HEG	$251	$245	$239	$233	$227	$222	$218	$215	$202
TORQ	$30	$29	$27	$27	$27	$26	$26	$25	$25

ASL=aggressive shift logic; ASL2=aggressive shift logic level 2 (shift optimizer); AT=automatic transmission; DCT=dual clutch transmission; HEG=high efficiency gearbox; MT=manual transmission; sp=speed; TORQ=early torque converter lockup.
All costs are incremental to the baseline case.

Table 1.2-4 Costs for Electrification & Improvement of Accessories for both the 2008 & 2010 Baselines (2010$)

Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
EPS/EHPS	$109	$108	$101	$100	$98	$96	$95	$93	$92
IACC	$89	$88	$82	$81	$80	$78	$77	$76	$75
IACC2	$143	$141	$133	$131	$128	$126	$124	$122	$120
Stop-start (12V) for Small car, Standard car	$401	$392	$354	$346	$338	$330	$322	$315	$308
Stop-start (12V) for Large car, Small MPV, Large MPV	$454	$444	$402	$392	$383	$374	$366	$357	$349
Stop-start (12V) for Truck	$498	$487	$441	$430	$420	$410	$401	$392	$383

EPS=electric power steering; EHPS=electro-hydraulic power steering; IACC=improved accessories level 1; IACC2=IACC level 2; 12V=12 volts.
All costs are incremental to the baseline case.

Table 1.2-5 Costs for Vehicle Technologies for both the 2008 & 2010 Baselines (2010$)

Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aero1	$49	$48	$45	$45	$44	$43	$42	$42	$41
Aero2	$213	$210	$205	$202	$199	$196	$193	$190	$176
LDB	$74	$74	$71	$71	$71	$71	$71	$71	$71
LRRT1	$7	$7	$6	$6	$6	$6	$6	$6	$6
LRRT2	$73	$73	$60	$60	$50	$49	$48	$47	$44
SAX	$98	$96	$91	$89	$88	$86	$85	$83	$82

Aero1=aerodynamic treatments level 1; Aero2=aero level 2; LDB=low drag brakes; LRRT1=lower rolling resistance tires level 1; LRRT2=LRRT level 2; SAX=secondary axle disconnect.
All costs are incremental to the baseline case.

Table 1.2-6 Costs for Advanced Diesel Technology for both the 2008 & 2010 Baselines (2010$)

Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
Small car	$2,965	$2,922	$2,653	$2,612	$2,572	$2,533	$2,495	$2,457	$2,420
Standard car	$2,965	$2,922	$2,653	$2,612	$2,572	$2,533	$2,495	$2,457	$2,420
Large car	$3,631	$3,578	$3,249	$3,200	$3,151	$3,103	$3,056	$3,010	$2,964
Small MPV	$2,971	$2,928	$2,659	$2,618	$2,578	$2,539	$2,501	$2,463	$2,426
Large MPV	$2,996	$2,953	$2,682	$2,641	$2,600	$2,561	$2,522	$2,484	$2,446
Truck	$4,154	$4,094	$3,718	$3,661	$3,605	$3,550	$3,496	$3,443	$3,392

All costs are incremental to the baseline case.

Table 1.2-7 Costs for P2-Hybird Technology for the 2008 Baseline (2010$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Small car	10%	5%	$3,484	$3,431	$3,025	$2,975	$2,926	$2,878	$2,832	$2,786	$2,591
Small car	15%	10%	$3,452	$3,398	$2,996	$2,946	$2,898	$2,851	$2,805	$2,760	$2,567
Small car	20%	15%	$3,419	$3,366	$2,967	$2,918	$2,870	$2,823	$2,778	$2,733	$2,542
Standard car	10%	5%	$3,847	$3,788	$3,339	$3,284	$3,230	$3,177	$3,126	$3,076	$2,861
Standard car	15%	10%	$3,800	$3,742	$3,298	$3,244	$3,191	$3,139	$3,088	$3,038	$2,826
Standard car	20%	15%	$3,754	$3,696	$3,257	$3,204	$3,151	$3,100	$3,050	$3,001	$2,792
Large car	10%	5%	$4,481	$4,412	$3,889	$3,825	$3,762	$3,701	$3,641	$3,583	$3,332
Large car	15%	10%	$4,402	$4,334	$3,821	$3,757	$3,696	$3,635	$3,577	$3,519	$3,273
Large car	20%	15%	$4,324	$4,257	$3,752	$3,690	$3,629	$3,570	$3,513	$3,456	$3,215
Small MPV	10%	5%	$3,705	$3,648	$3,218	$3,165	$3,113	$3,062	$3,012	$2,964	$2,755
Small MPV	15%	10%	$3,664	$3,608	$3,182	$3,129	$3,078	$3,027	$2,978	$2,931	$2,724
Small MPV	20%	15%	$3,623	$3,567	$3,146	$3,093	$3,043	$2,993	$2,945	$2,897	$2,694
Large MPV	10%	5%	$4,229	$4,164	$3,670	$3,609	$3,550	$3,492	$3,436	$3,381	$3,145
Large MPV	15%	10%	$4,170	$4,106	$3,617	$3,558	$3,499	$3,442	$3,387	$3,332	$3,101
Large MPV	20%	15%	$4,110	$4,047	$3,565	$3,506	$3,449	$3,393	$3,338	$3,284	$3,057
Truck	10%	6%	$4,575	$4,504	$3,982	$3,916	$3,851	$3,788	$3,726	$3,666	$3,399
Truck	15%	11%	$4,500	$4,431	$3,916	$3,851	$3,788	$3,726	$3,665	$3,606	$3,344
Truck	20%	16%	$4,426	$4,357	$3,851	$3,787	$3,724	$3,663	$3,604	$3,546	$3,288

WR=weight reduction.
All costs are incremental to the baseline case.

Table 1.2-8 Costs for P2-Hybird Technology for the 2010 Baseline (2010$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Small car	10%	5%	$3,505	$3,451	$3,043	$2,993	$2,943	$2,895	$2,849	$2,803	$2,606
Small car	15%	10%	$3,470	$3,417	$3,013	$2,963	$2,914	$2,867	$2,820	$2,775	$2,580
Small car	20%	15%	$3,435	$3,383	$2,982	$2,933	$2,885	$2,838	$2,792	$2,747	$2,555
Standard car	10%	5%	$3,888	$3,828	$3,375	$3,319	$3,264	$3,211	$3,159	$3,108	$2,891
Standard car	15%	10%	$3,838	$3,779	$3,331	$3,276	$3,222	$3,170	$3,119	$3,069	$2,854
Standard car	20%	15%	$3,789	$3,731	$3,288	$3,234	$3,181	$3,129	$3,078	$3,029	$2,818
Large car	10%	5%	$4,567	$4,497	$3,963	$3,897	$3,833	$3,771	$3,710	$3,650	$3,396
Large car	15%	10%	$4,484	$4,415	$3,890	$3,826	$3,763	$3,702	$3,642	$3,584	$3,334
Large car	20%	15%	$4,401	$4,333	$3,818	$3,755	$3,693	$3,633	$3,574	$3,517	$3,273
Small MPV	10%	5%	$3,765	$3,707	$3,269	$3,215	$3,162	$3,111	$3,060	$3,011	$2,799
Small MPV	15%	10%	$3,721	$3,664	$3,230	$3,177	$3,125	$3,074	$3,024	$2,976	$2,767
Small MPV	20%	15%	$3,677	$3,620	$3,192	$3,139	$3,087	$3,037	$2,988	$2,940	$2,734
Large MPV	10%	5%	$4,261	$4,196	$3,696	$3,635	$3,576	$3,517	$3,461	$3,405	$3,169
Large MPV	15%	10%	$4,200	$4,135	$3,643	$3,582	$3,524	$3,466	$3,410	$3,356	$3,124
Large MPV	20%	15%	$4,138	$4,075	$3,589	$3,529	$3,472	$3,415	$3,360	$3,306	$3,078
Truck	10%	6%	$4,615	$4,543	$4,016	$3,950	$3,884	$3,821	$3,758	$3,698	$3,428
Truck	15%	11%	$4,538	$4,468	$3,950	$3,884	$3,820	$3,757	$3,696	$3,636	$3,372
Truck	20%	16%	$4,462	$4,393	$3,883	$3,818	$3,755	$3,693	$3,633	$3,575	$3,315

WR=weight reduction.
All costs are incremental to the baseline case.

Table 1.2-9 Costs for Plug-in Hybrid Technology with 20 Mile EV Range, or PHEV20, for the 2008 Baseline (2010$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Small car	10%	3%	$11,041	$9,938	$9,282	$8,392	$8,345	$8,298	$8,252	$8,207	$6,804
Small car	15%	8%	$10,828	$9,743	$9,103	$8,229	$8,182	$8,136	$8,091	$8,047	$6,669
Small car	20%	13%	$10,614	$9,549	$8,924	$8,065	$8,019	$7,975	$7,931	$7,888	$6,534
Standard car	10%	3%	$13,148	$11,860	$11,048	$10,009	$9,950	$9,892	$9,835	$9,779	$8,145
Standard car	15%	8%	$12,793	$11,540	$10,751	$9,739	$9,682	$9,625	$9,570	$9,516	$7,924
Standard car	20%	13%	$12,439	$11,219	$10,453	$9,469	$9,413	$9,358	$9,304	$9,252	$7,704
Large car	10%	2%	$17,521	$15,878	$14,710	$13,383	$13,298	$13,214	$13,132	$13,052	$10,971
Large car	15%	7%	$17,010	$15,409	$14,282	$12,989	$12,907	$12,826	$12,747	$12,670	$10,642
Large car	20%	12%	$16,499	$14,940	$13,853	$12,596	$12,516	$12,438	$12,362	$12,287	$10,314
Small MPV	10%	3%	$12,394	$11,159	$10,418	$9,423	$9,369	$9,316	$9,264	$9,213	$7,644
Small MPV	15%	8%	$12,126	$10,915	$10,194	$9,218	$9,165	$9,114	$9,063	$9,013	$7,475
Small MPV	20%	13%	$11,859	$10,672	$9,970	$9,013	$8,962	$8,911	$8,862	$8,814	$7,306

WR=weight reduction.
All costs are incremental to the baseline case.

Table 1.2-10 Costs for Plug-in Hybrid Technology with 20 Mile EV Range, or PHEV20, for the 2010 Baseline (2010$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Small car	10%	3%	$11,251	$10,129	$9,458	$8,554	$8,505	$8,457	$8,410	$8,363	$6,939
Small car	15%	8%	$11,031	$9,929	$9,273	$8,385	$8,337	$8,290	$8,244	$8,199	$6,799
Small car	20%	13%	$10,810	$9,728	$9,088	$8,216	$8,169	$8,123	$8,078	$8,034	$6,659
Standard car	10%	3%	$13,507	$12,191	$11,349	$10,287	$10,226	$10,166	$10,107	$10,049	$8,379
Standard car	15%	8%	$13,138	$11,857	$11,039	$10,006	$9,946	$9,887	$9,830	$9,774	$8,148
Standard car	20%	13%	$12,769	$11,523	$10,729	$9,724	$9,666	$9,609	$9,554	$9,499	$7,918
Large car	10%	2%	$18,043	$16,363	$15,146	$13,789	$13,700	$13,613	$13,528	$13,444	$11,317
Large car	15%	7%	$17,506	$15,870	$14,696	$13,375	$13,290	$13,206	$13,123	$13,043	$10,972
Large car	20%	12%	$16,969	$15,378	$14,247	$12,962	$12,879	$12,798	$12,719	$12,641	$10,626
Small MPV	10%	3%	$12,857	$11,583	$10,806	$9,779	$9,723	$9,667	$9,613	$9,559	$7,942
Small MPV	15%	8%	$12,516	$11,276	$10,520	$9,520	$9,465	$9,411	$9,358	$9,306	$7,731
Small MPV	20%	13%	$12,175	$10,968	$10,234	$9,260	$9,207	$9,154	$9,103	$9,052	$7,520

WR=weight reduction.
All costs are incremental to the baseline case.

Table 1.2-11 Costs for Plug-in Hybrid Technology with 40 Mile EV Range, or PHEV40, for the 2008 Baseline (2010$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Small car	15%	2%	$14,158	$12,589	$11,931	$10,669	$10,620	$10,573	$10,527	$10,482	$8,478
Small car	20%	7%	$13,853	$12,317	$11,673	$10,438	$10,391	$10,345	$10,300	$10,256	$8,294
Standard car	15%	3%	$17,077	$15,199	$14,388	$12,877	$12,818	$12,760	$12,703	$12,647	$10,250
Standard car	20%	8%	$16,632	$14,802	$14,013	$12,540	$12,483	$12,426	$12,371	$12,317	$9,981
Large car	15%	1%	$23,903	$21,308	$20,132	$18,044	$17,958	$17,874	$17,792	$17,711	$14,401
Large car	20%	6%	$22,998	$20,505	$19,369	$17,363	$17,280	$17,199	$17,119	$17,041	$13,861
Small MPV	15%	3%	$16,263	$14,447	$13,706	$12,246	$12,192	$12,139	$12,087	$12,036	$9,717
Small MPV	20%	8%	$15,872	$14,099	$13,377	$11,951	$11,898	$11,847	$11,796	$11,747	$9,482

WR=weight reduction.
All costs are incremental to the baseline case.

Table 1.2-12 Costs for Plug-in Hybrid Technology with 40 Mile EV Range, or PHEV40, for the 2010 Baseline (2010$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Small car	15%	3%	$14,401	$12,806	$12,135	$10,852	$10,803	$10,755	$10,708	$10,662	$8,626
Small car	20%	8%	$14,076	$12,517	$11,862	$10,607	$10,559	$10,512	$10,467	$10,422	$8,431
Standard car	15%	3%	$17,551	$15,628	$14,785	$13,238	$13,177	$13,116	$13,057	$13,000	$10,545
Standard car	20%	8%	$17,082	$15,208	$14,390	$12,883	$12,824	$12,765	$12,708	$12,652	$10,261
Large car	15%	2%	$24,466	$21,821	$20,604	$18,476	$18,387	$18,300	$18,215	$18,131	$14,758
Large car	20%	7%	$23,613	$21,061	$19,886	$17,832	$17,746	$17,662	$17,580	$17,499	$14,244
Small MPV	15%	3%	$16,769	$14,908	$14,131	$12,634	$12,578	$12,522	$12,467	$12,414	$10,038
Small MPV	20%	8%	$16,358	$14,540	$13,785	$12,323	$12,268	$12,214	$12,161	$12,109	$9,789

WR=weight reduction.
All costs are incremental to the baseline case.

Table 1.2-13 Costs for Full Electric Vehicle Technology with 75 Mile Range, or EV75, for the 2008 Baseline (2010$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Small car	10%	10%	$14,165	$12,084	$12,078	$10,413	$10,407	$10,402	$10,398	$10,394	$7,658
Small car	15%	15%	$13,771	$11,732	$11,729	$10,097	$10,093	$10,090	$10,088	$10,085	$7,421
Small car	20%	20%	$13,378	$11,381	$11,379	$9,781	$9,780	$9,778	$9,777	$9,776	$7,184
Standard car	10%	10%	$17,684	$15,244	$15,216	$13,259	$13,232	$13,206	$13,189	$13,172	$9,795
Standard car	15%	15%	$17,101	$14,723	$14,697	$12,791	$12,767	$12,744	$12,729	$12,714	$9,443
Standard car	20%	20%	$16,518	$14,201	$14,179	$12,322	$12,302	$12,282	$12,269	$12,256	$9,092
Large car	10%	10%	$23,296	$20,186	$20,134	$17,638	$17,589	$17,542	$17,512	$17,482	$13,057
Large car	15%	15%	$22,333	$19,320	$19,275	$16,858	$16,815	$16,774	$16,747	$16,720	$12,471
Large car	20%	20%	$21,369	$18,454	$18,415	$16,078	$16,041	$16,005	$15,982	$15,959	$11,886
Small MPV	10%	9%	$15,909	$13,478	$13,483	$11,539	$11,545	$11,550	$11,553	$11,556	$8,460
Small MPV	15%	14%	$15,453	$13,068	$13,077	$11,170	$11,178	$11,186	$11,191	$11,196	$8,183
Small MPV	20%	19%	$14,997	$12,658	$12,670	$10,801	$10,812	$10,822	$10,829	$10,836	$7,906

WR=weight reduction.
All costs are incremental to the baseline case.

Table 1.2-14 Costs for Full Electric Vehicle Technology with 75 Mile Range, or EV75, for the 2010 Baseline (2010$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Small car	10%	10%	$14,581	$12,450	$12,442	$10,737	$10,729	$10,722	$10,718	$10,713	$7,899
Small car	15%	15%	$14,203	$12,110	$12,105	$10,430	$10,425	$10,421	$10,417	$10,414	$7,669
Small car	20%	20%	$13,824	$11,771	$11,768	$10,124	$10,122	$10,119	$10,117	$10,115	$7,439
Standard car	10%	9%	$18,311	$15,806	$15,773	$13,764	$13,733	$13,703	$13,684	$13,665	$10,173
Standard car	15%	14%	$17,700	$15,259	$15,230	$13,273	$13,245	$13,219	$13,202	$13,185	$9,805
Standard car	20%	19%	$17,089	$14,712	$14,687	$12,781	$12,758	$12,735	$12,720	$12,705	$9,436
Large car	10%	10%	$24,054	$20,863	$20,807	$18,245	$18,193	$18,141	$18,108	$18,076	$13,512
Large car	15%	15%	$23,052	$19,963	$19,913	$17,435	$17,388	$17,343	$17,313	$17,284	$12,904
Large car	20%	20%	$22,051	$19,063	$19,020	$16,624	$16,583	$16,544	$16,518	$16,493	$12,295
Small MPV	10%	9%	$16,315	$13,854	$13,855	$11,886	$11,888	$11,889	$11,890	$11,891	$8,724
Small MPV	15%	14%	$15,834	$13,421	$13,426	$11,496	$11,501	$11,505	$11,508	$11,511	$8,431
Small MPV	20%	19%	$15,353	$12,989	$12,997	$11,107	$11,114	$11,121	$11,126	$11,131	$8,138

WR=weight reduction.
All costs are incremental to the baseline case.

Table 1.2-15 Costs for Full Electric Vehicle Technology with 100 Mile Range, or EV100, for the 2008 Baseline (2010$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Small car	10%	4%	$17,352	$14,815	$14,806	$12,774	$12,766	$12,758	$12,752	$12,747	$9,398
Small car	15%	9%	$16,916	$14,426	$14,420	$12,427	$12,421	$12,414	$12,411	$12,407	$9,138
Small car	20%	14%	$16,480	$14,038	$14,033	$12,079	$12,075	$12,071	$12,069	$12,066	$8,878
Standard car	10%	4%	$21,247	$18,304	$18,271	$15,911	$15,880	$15,850	$15,831	$15,812	$11,750
Standard car	15%	9%	$20,636	$17,758	$17,728	$15,422	$15,394	$15,367	$15,350	$15,333	$11,384
Standard car	20%	14%	$20,024	$17,212	$17,186	$14,932	$14,908	$14,884	$14,869	$14,854	$11,017
Large car	10%	5%	$26,749	$23,167	$23,109	$20,235	$20,181	$20,128	$20,093	$20,060	$14,977
Large car	15%	10%	$25,745	$22,267	$22,215	$19,426	$19,377	$19,329	$19,299	$19,269	$14,370
Large car	20%	15%	$24,741	$21,367	$21,322	$18,616	$18,573	$18,531	$18,504	$18,478	$13,762
Small MPV	10%	3%	$20,028	$17,005	$17,007	$14,589	$14,591	$14,593	$14,594	$14,596	$10,707
Small MPV	15%	8%	$19,490	$16,526	$16,531	$14,160	$14,165	$14,169	$14,172	$14,175	$10,385
Small MPV	20%	13%	$18,952	$16,046	$16,054	$13,731	$13,738	$13,746	$13,750	$13,755	$10,064

WR=weight reduction.
All costs are incremental to the baseline case.

Table 1.2-16 Costs for Full Electric Vehicle Technology with 100 Mile Range, or EV100, for the 2010 Baseline (2010$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Small car	10%	4%	$17,837	$15,239	$15,229	$13,149	$13,139	$13,129	$13,123	$13,116	$9,676
Small car	15%	9%	$17,390	$14,841	$14,833	$12,793	$12,785	$12,777	$12,772	$12,768	$9,409
Small car	20%	14%	$16,943	$14,443	$14,437	$12,436	$12,431	$12,426	$12,422	$12,419	$9,143
Standard car	10%	3%	$21,905	$18,893	$18,856	$16,440	$16,406	$16,372	$16,350	$16,329	$12,147
Standard car	15%	8%	$21,294	$18,346	$18,313	$15,950	$15,918	$15,888	$15,868	$15,849	$11,779
Standard car	20%	13%	$20,684	$17,800	$17,770	$15,459	$15,431	$15,404	$15,386	$15,369	$11,411
Large car	10%	4%	$27,850	$24,147	$24,083	$21,111	$21,051	$20,993	$20,955	$20,918	$15,632
Large car	15%	9%	$26,820	$23,223	$23,166	$20,280	$20,226	$20,173	$20,140	$20,106	$15,009
Large car	20%	14%	$25,790	$22,300	$22,249	$19,449	$19,401	$19,354	$19,324	$19,295	$14,385
Small MPV	10%	3%	$20,501	$17,439	$17,437	$14,988	$14,986	$14,984	$14,982	$14,981	$11,009
Small MPV	15%	8%	$19,943	$16,942	$16,943	$14,542	$14,543	$14,543	$14,544	$14,545	$10,674
Small MPV	20%	13%	$19,385	$16,444	$16,448	$14,096	$14,100	$14,103	$14,106	$14,108	$10,340

WR=weight reduction.
All costs are incremental to the baseline case.

Table 1.2-17 Costs for Full Electric Vehicle Technology with 150 Mile Range, or EV150, for the 2008 Baseline (2010$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Small car	20%	2%	$23,024	$19,643	$19,633	$16,926	$16,916	$16,907	$16,901	$16,895	$12,448
Standard car	20%	2%	$29,050	$24,946	$24,911	$21,623	$21,591	$21,559	$21,539	$21,519	$15,947
Large car	20%	3%	$34,259	$29,569	$29,508	$25,747	$25,690	$25,635	$25,599	$25,564	$19,029
Small MPV	20%	1%	$28,183	$23,945	$23,946	$20,555	$20,556	$20,557	$20,557	$20,558	$15,090

WR=weight reduction.
All costs are incremental to the baseline case.

Table 1.2-18 Costs for Full Electric Vehicle Technology with 150 Mile Range, or EV150, for the 2010 Baseline (2010$)

Vehicle Class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
Small car	20%	1%	$23,795	$20,314	$20,302	$17,515	$17,504	$17,492	$17,485	$17,478	$12,885
Standard car	20%	1%	$29,822	$25,632	$25,594	$22,236	$22,200	$22,165	$22,142	$22,120	$16,406
Large car	20%	3%	$35,277	$30,469	$30,403	$26,547	$26,486	$26,426	$26,388	$26,350	$19,626
Small MPV	20%	1%	$28,767	$24,474	$24,471	$21,036	$21,033	$21,029	$21,027	$21,025	$15,452

WR=weight reduction.
All costs are incremental to the baseline case.

Table 1.2-19 Costs for EV/PHEV In-home Chargers for both the 2008 & 2010 Baselines (2010$)

Technology	Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
PHEV20 Charger	All	$79	$66	$66	$56	$56	$56	$56	$56	$41
PHEV40 Charger	Small car	$414	$347	$347	$294	$294	$294	$294	$294	$216
	Standard car	$481	$404	$404	$342	$342	$342	$342	$342	$251
	Large car Small MPV	$526	$441	$441	$373	$373	$373	$373	$373	$274
EV Charger	All	$526	$441	$441	$373	$373	$373	$373	$373	$274
Charger labor	All	$1,020	$1,020	$1,020	$1,020	$1,020	$1,020	$1,020	$1,020	$1,020

EV=electric vehicle; PHEV=plug-in electric vehicle; PHEV20=PHEV with 20 mile range; PHEV40=PHEV with 40 mile range.
All costs are incremental to the baseline case.

Table 1.2-20 Costs for 10% and 20% Weight Reduction for the 19 Vehicle Types[a] for the 2008 Baseline (2010$)

Vehicle Type	Base Weight	Applied WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
1	2633	10%	$143	$139	$130	$127	$124	$121	$119	$117	$115
		20%	$639	$624	$610	$597	$584	$571	$563	$555	$503
2	3094	10%	$168	$164	$153	$149	$146	$142	$140	$138	$135
		20%	$751	$734	$717	$701	$686	$671	$661	$652	$591
3	3554	10%	$193	$188	$176	$172	$167	$163	$161	$158	$155
		20%	$863	$843	$824	$806	$788	$771	$760	$749	$679
4	3558	10%	$193	$189	$176	$172	$168	$163	$161	$158	$156
		20%	$863	$844	$825	$807	$789	$772	$760	$749	$680
5	3971	10%	$216	$210	$197	$192	$187	$182	$179	$176	$174
		20%	$964	$942	$921	$900	$880	$861	$849	$836	$758
6	3651	10%	$198	$193	$181	$176	$172	$168	$165	$162	$160
		20%	$886	$866	$847	$828	$809	$792	$780	$769	$697
7	3450	10%	$187	$183	$171	$167	$163	$159	$156	$153	$151
		20%	$837	$818	$800	$782	$765	$748	$737	$727	$659
8	4326	10%	$235	$229	$214	$209	$204	$199	$195	$192	$189
		20%	$1,050	$1,026	$1,003	$981	$959	$938	$924	$911	$826
9	4334	10%	$235	$230	$215	$209	$204	$199	$196	$193	$189
		20%	$1,052	$1,028	$1,005	$983	$961	$940	$926	$913	$828
10	4671	10%	$254	$248	$231	$226	$220	$215	$211	$208	$204
		20%	$1,134	$1,108	$1,083	$1,059	$1,036	$1,013	$998	$984	$892
11	5174	10%	$281	$274	$256	$250	$244	$238	$234	$230	$226
		20%	$1,255	$1,227	$1,200	$1,173	$1,147	$1,122	$1,106	$1,090	$988
12	5251	10%	$285	$278	$260	$254	$247	$241	$237	$233	$230
		20%	$1,274	$1,245	$1,218	$1,190	$1,164	$1,139	$1,122	$1,106	$1,003
13	3904	10%	$212	$207	$193	$189	$184	$179	$176	$174	$171
		20%	$947	$926	$905	$885	$866	$847	$834	$822	$746
14	4157	10%	$226	$220	$206	$201	$196	$191	$188	$185	$182
		20%	$1,009	$986	$964	$943	$922	$902	$888	$876	$794
15	4397	10%	$239	$233	$218	$212	$207	$202	$199	$195	$192
		20%	$1,067	$1,043	$1,019	$997	$975	$953	$940	$926	$840
16	5270	10%	$286	$279	$261	$255	$248	$242	$238	$234	$230
		20%	$1,279	$1,250	$1,222	$1,195	$1,168	$1,143	$1,126	$1,110	$1,007
17	4967	10%	$270	$263	$246	$240	$234	$228	$224	$221	$217
		20%	$1,205	$1,178	$1,152	$1,126	$1,101	$1,077	$1,062	$1,046	$949
18	4959	10%	$269	$263	$246	$240	$234	$228	$224	$220	$217
		20%	$1,203	$1,176	$1,150	$1,124	$1,100	$1,075	$1,060	$1,045	$947
19	5026	10%	$273	$266	$249	$243	$237	$231	$227	$223	$220
		20%	$1,220	$1,192	$1,165	$1,140	$1,114	$1,090	$1,074	$1,059	$960

[a] See section 1.3 for details on the 19 vehicle types—what they are and how they are used.
WR=weight reduction.
All costs are incremental to the baseline case.

Table 1.2-21 Costs for 10% and 20% Weight Reduction for the 19 Vehicle Types[a] for the 2010 Baseline (2010$)

Vehicle Type	Base Weight	Applied WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
1	2753	10%	$149	$146	$136	$133	$130	$126	$124	$122	$120

		20%	$668	$653	$638	$624	$610	$597	$588	$580	$526
2	3204	10%	$174	$170	$159	$155	$151	$147	$145	$142	$140
		20%	$778	$760	$743	$726	$710	$695	$685	$675	$612
3	3651	10%	$198	$193	$181	$176	$172	$168	$165	$162	$160
		20%	$886	$866	$847	$828	$810	$792	$780	$769	$697
4	3608	10%	$196	$191	$179	$174	$170	$166	$163	$160	$158
		20%	$876	$856	$837	$818	$800	$782	$771	$760	$689
5	4144	10%	$225	$220	$205	$200	$195	$190	$187	$184	$181
		20%	$1,006	$983	$961	$939	$919	$899	$886	$873	$792
6	3842	10%	$209	$204	$190	$186	$181	$177	$174	$171	$168
		20%	$932	$911	$891	$871	$852	$833	$821	$809	$734
7	3517	10%	$191	$186	$174	$170	$166	$162	$159	$156	$154
		20%	$853	$834	$815	$797	$780	$763	$752	$741	$672
8	4316	10%	$234	$229	$214	$209	$203	$198	$195	$192	$189
		20%	$1,047	$1,024	$1,001	$979	$957	$936	$922	$909	$824
9	4352	10%	$236	$231	$216	$210	$205	$200	$197	$193	$190
		20%	$1,056	$1,032	$1,009	$987	$965	$944	$930	$917	$831
10	4355	10%	$237	$231	$216	$210	$205	$200	$197	$194	$190
		20%	$1,057	$1,033	$1,010	$987	$965	$944	$931	$917	$832
11	5381	10%	$292	$285	$267	$260	$254	$247	$243	$239	$235
		20%	$1,306	$1,276	$1,248	$1,220	$1,193	$1,167	$1,150	$1,134	$1,028
12	5716	10%	$310	$303	$283	$276	$269	$263	$258	$254	$250
		20%	$1,387	$1,356	$1,325	$1,296	$1,267	$1,240	$1,222	$1,204	$1,092
13	3667	10%	$199	$194	$182	$177	$173	$168	$166	$163	$160
		20%	$890	$870	$850	$831	$813	$795	$784	$772	$700
14	4151	10%	$225	$220	$206	$201	$196	$191	$188	$184	$181
		20%	$1,007	$984	$962	$941	$920	$900	$887	$874	$793
15	4591	10%	$249	$243	$228	$222	$216	$211	$207	$204	$201
		20%	$1,114	$1,089	$1,065	$1,041	$1,018	$996	$981	$967	$877
16	5382	10%	$292	$285	$267	$260	$254	$247	$243	$239	$235
		20%	$1,306	$1,277	$1,248	$1,220	$1,193	$1,167	$1,150	$1,134	$1,028
17	5025	10%	$273	$266	$249	$243	$237	$231	$227	$223	$220
		20%	$1,219	$1,192	$1,165	$1,139	$1,114	$1,090	$1,074	$1,059	$960
18	5252	10%	$285	$278	$260	$254	$247	$241	$237	$233	$230
		20%	$1,274	$1,246	$1,218	$1,191	$1,164	$1,139	$1,122	$1,106	$1,003
19	5224	10%	$284	$277	$259	$252	$246	$240	$236	$232	$228
		20%	$1,268	$1,239	$1,211	$1,184	$1,158	$1,133	$1,117	$1,100	$998

[a] See section 1.3 for details on the 19 vehicle types—what they are and how they are used.
WR=weight reduction.
All costs are incremental to the baseline case.

Table 1.2-22 through Table 1.2-26 summarize the CO_2 reduction estimates of various technologies which can be applied to cars and light-duty trucks. A more detailed discussion of effectiveness is provided in Chapter 3 of the joint TSD.

Table 1.2-22 Engine Technology Effectiveness

Technology	Absolute CO_2 Reduction (% from baseline vehicle)				
	Small Car	Large Car	Minivan	Small Truck	Large Truck
Low friction lubricants	0.6	0.8	0.7	0.6	0.7
Engine friction reduction level 1	2.0	2.7	2.6	2.0	2.4
Engine friction reduction level 2	3.5	4.8	4.5	3.4	4.2
Cylinder deactivation (includes imp. oil pump, if	n.a.	6.5	6.0	4.7	5.7

applicable)					
VVT – intake cam phasing	2.1	2.7	2.5	2.1	2.4
VVT – coupled cam phasing	4.1	5.5	5.1	4.1	4.9
VVT – dual cam phasing	4.1	5.5	5.1	4.1	4.9
Discrete VVLT	4.1	5.6	5.2	4.0	4.9
Continuous VVLT	5.1	7.0	6.5	5.1	6.1
Stoichiometric Gasoline Direct Injection	1.5	1.5	1.5	1.5	1.5
Turbo+downsize (incremental to GDI-S) (18-27 bar)*	10.8-16.6	13.6-20.6	12.9-19.6	10.7-16.4	12.3-18.8
Cooled Exhaust Gas Recirculation (incremental to 24 bar TRBDS+SGDI)	3.6	3.6	3.6	3.5	3.6
Advanced diesel engine (T2B2 emissions level)	19.5	22.1	21.5	19.1	21.3

* Note: turbo downsize engine effectiveness does not include effectiveness of valvetrain improvements

Table 1.2-23 Transmission Technology Effectiveness

Technology	Absolute CO_2 Reduction (% from baseline vehicle)				
	Small Car	Large Car	Minivan	Small Truck	Large Truck
5-speed automatic (from 4-speed auto)	1.1	1.6	1.4	1.1	1.4
Aggressive shift logic 1	2.0	2.7	2.5	1.9	2.4
Aggressive shift logic 2	5.2	7.0	6.6	5.1	6.2
Early torque converter lockup	0.4	0.4	0.4	0.5	0.5
High Efficiency Gearbox	4.8	5.3	5.1	5.4	4.3
6-speed automatic (from 4-speed auto)	1.8	2.3	2.2	1.7	2.1
6-speed dry DCT (from 4-speed auto)	6.4	7.6	7.2	7.1	8.1

Table 1.2-24 Hybrid Technology Effectiveness

Technology	Absolute CO_2 Reduction (% from baseline vehicle)				
	Small Car	Large Car	Minivan	Small Truck	Large Truck
12V Start-Stop	1.8	2.4	2.2	1.8	2.2
HV Mild Hybrid*	7.4	7.2	6.9	6.8	8.0
P2 Hybrid drivetrain**	15.5	15.4	14.6	13.4	15.7
Plug-in hybrid electric vehicle – 20 mile range***	40	40	40	40	n.a.
Plug-in hybrid electric vehicle – 40 mile range***	63	63	63	63	n.a.
Full electric vehicle (EV)	100	100	n.a.	n.a.	n.a.

* Only includes the effectiveness related to the hybridized drivetrain (battery and electric motor) and supported accessories.
** Only includes the effectiveness related to the hybridized drivetrain (battery and electric motor) and supported accessories. Does not include advanced engine technologies. Will vary based on electric motor size; table values are based on motor sizes in Ricardo vehicle simulation results (ref Joint TSD, Section 3.3.1)
***Based on utility factors used for 20-mile (40%) and 40-mile (63%) range PHEV

Table 1.2-25 Accessory Technology Effectiveness

Technology	Absolute CO_2 Reduction (% from baseline vehicle)				
	Small Car	Large Car	Minivan	Small Truck	Large Truck
Improved high efficiency alternator & electrification of accessories (12 volt)	1.7	1.3	1.2	1.3	1.8
Electric power steering	1.5	1.1	1.0	1.2	0.8
Improved high efficiency alternator & electrification of accessories (42 volt)	3.3	2.5	2.4	2.6	3.5

Table 1.2-26 Other Vehicle Technology Effectiveness

Technology	Absolute CO_2 Reduction (% from baseline vehicle)				
	Small Car	Large Car	Minivan	Small Truck	Large Truck
Aero drag reduction (20% on cars, 10% on trucks)	4.7	4.7	4.7	4.7	2.3
Low rolling resistance tires (20% on cars, 10% on trucks)	3.9	3.9	3.9	3.9	1.9
Low drag brakes	0.8	0.8	0.8	0.8	0.8
Secondary axle disconnect (unibody only)	1.3	1.3	1.3	1.3	1.3

1.3 Vehicle Package Cost and Effectiveness

Individual technologies can be used by manufacturers to achieve incremental CO_2 reductions. However, EPA believes that manufacturers are more likely to bundle technologies into "packages" to capture synergistic aspects and reflect progressively larger CO_2 reductions with additions or changes to any given package. In addition, manufacturers typically apply new technologies in packages during model redesigns that occur approximately once every five years, rather than adding new technologies one at a time on an annual or biennial basis. This way, manufacturers can more efficiently make use of their redesign resources and more effectively plan for changes necessary to meet future standards.

Therefore, the approach taken by EPA is to group technologies into packages of increasing cost and effectiveness. Costs for the packages are a sum total of the costs for the technologies included. Effectiveness is somewhat more complex, as the effectiveness of individual technologies cannot simply be summed. To quantify the CO_2 (or fuel consumption) effectiveness, EPA relies on its Lumped Parameter Model, which is described in greater detail in the following section as well as in Chapter 3 of the joint TSD.

As was done in the MYs 2012-2016 rule and then updated in the 2010 TAR, EPA uses 19 different vehicle types to represent the entire fleet in the OMEGA model. This was the result of analyzing the existing light duty fleet with respect to vehicle size and powertrain configurations. All vehicles, including cars and trucks, were first distributed based on their relative size, starting from compact cars and working upward to large trucks. Next, each vehicle was evaluated for powertrain, specifically the engine size, I4, V6, and V8, then by valvetrain configuration (DOHC, SOHC, OHV), and finally by the number of valves per cylinder.

For the proposal, EPA used the same 19 vehicle types that were used in the 2010 TAR. However, new for this final rule are 19 new vehicle types. These new vehicle types are conceptually identical to the vehicle types used in the proposal, but we have changed them in an effort to group cars, MPVs (multi-purpose vehicles which are minivans, sport utility and cross-over utility vehicles) and trucks into corresponding vehicle types. In the proposal, we had considerable cross-over of cars mapped into truck vehicle types and vice versa. We also wanted to better reflect towing versus non-towing in our vehicle types, a consideration that was not really made when we developed the 19 vehicle types used up to this point. As a result, we now have six car, or auto vehicle types that are non-towing vehicle types, six MPV vehicle types with five of those being towing vehicle types, and seven truck (really pickup truck) vehicle types with six of those being towing vehicle types.

EPA believes (at this time) that these 19 vehicle types broadly encompass the diversity in the fleet as the analysis is appropriate for "average" vehicles. EPA believes that modeling each and every vehicle in the fleet individually is cumbersome and can even give a false sense of accuracy in the analysis of a future fleet. Each of these 19 vehicle types is mapped into one of six vehicle classes: Small car, Standard car, Large car, Small MPV, Large MPV, and Truck. Note that our six vehicle classes are not meant to correlate one-to-one with consumer-level vehicle classes. For example, we have many sport utility and cross-over utility vehicles (SUVs and CUVs) in one of our "Truck" vehicle classes. Similarly, we have some pickup trucks placed in MPV vehicle classes. We do this to group them with respect to technology effectiveness and some technology costs. For example, the largest MPVs are in a "Truck" vehicle class which gives them the truck effectiveness values and truck costs because their size, weight and use are presumably similar to large pickups. Similarly, we have placed some smaller pickups in the "Small MPV" vehicle class since their smaller size and general use is presumably more similar to a small MPV than to a large pickup truck. Importantly, the vehicle class designation is not what drives credit generation for certain technologies when applied to certain vehicles. For credits, we apply pickup truck credits to pickup trucks and not to MPVs regardless of the vehicle class designation we use for costs and effectiveness.[B]

As such, the six OMEGA vehicle classes serve primarily to determine the effectiveness levels of new technologies by determining which vehicle class is chosen within the lumped parameter model (see sections 1.4 and 1.5 below). So, any vehicle models mapped into a Large MPV vehicle type will get technology-specific effectiveness results for that vehicle class. The same is true for vehicles mapped into the other vehicle classes. Similarly, any vehicle models mapped into a Large MPV vehicle type will get technology-specific cost results for that vehicle class. The same is true for vehicles mapped into the other vehicle classes. This is true only for applicable technologies, i.e., those costs developed on a vehicle class basis such as advanced diesel, hybrid and other electrified powertrains (see Table 1.2-6 through Table 1.2-19 which show costs by vehicle class). Note that most technology costs are not developed according to vehicle classes but are instead developed according to engine size, valvetrain configuration, etc. (see Table 1.2-1 through Table 1.2-5 which show costs by specific technology). Lastly, note that these 19 vehicle types span the range of vehicle footprints which served as the basis for the MYs 2012-2016 GHG standards and the standards in this final rule. A detailed table showing the 19 vehicle types, their baseline engines, their descriptions and some example models for each is contained in Table 1.3-1 .

[B] See Chapter 3 (?) for full details of the credits mentioned here.

Table 1.3-1 List of 19 Vehicle Types used to Model the light-duty Fleet

Vehicle Type #	Base Engine	Base Trans	Vehicle Class	Description	Example Models	Towing?
1	I4 DOHC 4v	4sp AT	Small car	Subcompact car I4	Ford Focus, Chevy Aveo, Honda Fit	No
2	I4 DOHC 4v	4sp AT	Standard car	Compact car I4	Ford Fusion, Chevy Cobalt, Honda Civic	No
3	V6 DOHC 4v	4sp AT	Standard car	Midsize car V6	Ford Fusion, Chevy Malibu, Honda Accord	No
4	V6 SOHC 2v	4sp AT	Standard car	Midsize car V6	Ford Mustang, Buick Lacrosse, Chevy Impala	No
5	V8 DOHC 4v	4sp AT	Large car	Large car V8	Ford Crown Vic, Ford Mustang, Cadillac STS	No
6	V8 OHV 2v	4sp AT	Large car	Large car V8	Chrysler 300, Ford Mustang, Chevy Corvette	No
7	I4 DOHC 4v	4sp AT	Small MPV	Small MPV I4	Ford Escape, Honda Element, Toyota RAV4	No
8	V6 DOHC 4v	4sp AT	Large MPV	Midsize MPV V6	Ford Edge, Chevy Equinox, Kia Sorento	Yes
9	V6 SOHC 2v	4sp AT	Large MPV	Midsize MPV V6	Dodge Durango, Jeep Grand Cherokee, Ford Explorer	Yes
10	V6 OHV 2v	4sp AT	Large MPV	Midsize MPV V6	Dodge Caravan, Jeep Wrangler, Chevy Equinox	Yes
11	V8 DOHC 4v	4sp AT	Truck	Large MPV V8	Jeep Grand Cherokee, Toyota 4Runner, VW Touareg	Yes
12	V8 OHV 2v	4sp AT	Truck	Large MPV V8	Chrylser Aspen, Ford Expedition, Chevy Tahoe,	Yes
13	I4 DOHC 4v	4sp AT	Small MPV	Small truck I4	Chevy Colorado, Nissan Frontier, Toyota Tacoma	No
14	V6 DOHC 4v	4sp AT	Large MPV	Full-sized Pickup truck V6	Ford F150, Honda Ridgeline, Toyota Tacoma	Yes
15	V6 OHV 2v	4sp AT	Large MPV	Full-sized Pickup truck V6	Dodge Dakota, Ford Ranger, Chevy Silverado	Yes
16	V8 DOHC 4v	4sp AT	Truck	Full-sized Pickup truck V8	Nissan Titan, Toyota Tundra	Yes
17	V8 SOHC 2v	4sp AT	Truck	Full-sized Pickup truck V8	Dodge Ram, Ford F150	Yes
18	V8 SOHC 3v	4sp AT	Truck	Full-sized Pickup truck V8	Ford F150	Yes
19	V8 OHV 2v	4sp AT	Truck	Full-sized Pickup truck V8	Dodge Ram, Chevy Silverado, GMC Sierra	Yes

Note: I4=inline 4 cylinder; V6/8=V-configuration 6/8 cylinder; DOHC=dual overhead cam; SOHC=single overhead cam; OHV=overhead valve; 4v/3v/2v=4/3/2 valves per cylinder; sp=speed; AT=automatic transmission; MPV=multi-purpose vehicle.

Note that we refer throughout this discussion of package building to a “baseline” vehicle or a “baseline” package. This should not be confused with the baseline fleet, which is the fleet of roughly 16 million 2008MY individual vehicles comprised of over 1,100 vehicle models as described in Chapter 1 of the joint TSD. In this discussion, when we refer to "baseline" vehicle we are referring to the "baseline" configuration of the given vehicle type. So, we have 19 baseline vehicles in the context of building packages. Each of those 19 baseline vehicles is equipped with a port fuel injected engine and a 4 speed automatic transmission. The valvetrain configuration and the number of cylinders changes for each vehicle type to cover the diversity in the 2008 baseline fleet as discussed above. When we apply a package of technologies to an individual vehicle model in the baseline fleet, we must first determine which package of technologies are already present on the individual vehicle model. From this information, we can determine the effectiveness and cost of the individual vehicle model in the baseline fleet relative to the baseline vehicle that defines the vehicle type. Once we have that, we can determine the incremental increase in effectiveness and cost for each individual vehicle model in the baseline fleet once it has added the package of interest. This process is known as the TEB-CEB process, which is short for Technology Effective Basis - Cost Effective Basis. This process allows us to accurately reflect the level of technology already in the 2008 baseline fleet as well as the level of technology expected in the MYs 2017-2025 reference case (i.e., the fleet as it is expected to exist as a result of the MY 2016 standards in the MYs 2012-2016 final rule, which reference fleet serves as the starting point for the larger analysis supporting this final rule). But again, the discussion here is focused solely on building packages. Therefore, while the baseline vehicle that defines the vehicle type is relevant here, the baseline and reference case fleets of real vehicles are relevant to the discussion presented later in Chapter 3 of this RIA.

Importantly, the effort in creating the packages attempts to maintain a constant utility and acceleration performance for each package as compared to the baseline package. As such, each package is meant to provide equivalent driver-perceived performance to the baseline package. There are two possible exceptions. The first is the towing capability of vehicle types which we have designated "non-towing." This requires a brief definition of what we consider to be a towing vehicle versus a non-towing vehicle. Nearly all vehicles sold today, with the exception of the smaller subcompact and compact cars, are able to tow up to 1,500 pounds provided the vehicle is equipped with a towing hitch. These vehicles require no special OEM "towing package" of add-ons which typically include a set of more robust brakes and some additional transmission cooling. We do not consider such vehicles to be towing vehicles. We reserve that term for those vehicles capable of towing significantly more than 1,500 lbs. For example, a base model Ford Escape can tow 1,500 pounds while the V6 equipped towing version can tow up to 3,500 pounds. The former would not be considered a true towing vehicle while the latter would. Note that all large trucks and large MPV vehicle classes are considered towing vehicles in our analysis.

The importance of this distinction can be found in the types of hybrid and plug-in hybrid technologies we apply to towing versus non-towing vehicle types.[C] For the towing vehicle types, we apply a P2 hybrid technology with a turbocharged and downsized gasoline direct injected engine. These packages are expected to maintain equivalent towing capacity to

[C] This towing/non towing distinction is not an issue for non-HEVs, EPA maintains whatever towing capability existed in the baseline when adding/substituting technology.

the baseline engine they replace. For the non-towing vehicle types, we apply a P2 hybrid technology with an Atkinson engine that has not been downsized relative to the baseline engine. The Atkinson engine, more correctly called the "Atkinson-cycle" engine, is used in the current Toyota Prius and Ford Escape hybrid. We have maintained the original engine size (i.e., no downsizing) to maintain utility as best as possible, but EPA acknowledges that due to its lower power output, an Atkinson cycle engine cannot tow loads as well as a standard Otto-cycle engine of the same size. However, the presence of the hybrid powertrain would be expected to maintain towing utility for these vehicle types in all but the most severe operating extremes. Such extremes would include towing in the Rocky Mountains (i.e, up very long duration grades) or towing up Pike's Peak (i.e., up a shorter but very steep grade). Under these extreme towing conditions, the battery on a hybrid powertrain would eventually cease to provide sufficient supplemental power and the vehicle would be left with the Atkinson engine doing all the work. A loss in utility would result (note that the loss in utility should not result in breakdown or safety concerns, but rather loss in top speed and/or acceleration capability). Importantly, those towing situations involving driving outside mountainous regions would not be affected.

We do not address towing at the vehicle level. Instead, we deal with towing at the vehicle type level. In the proposal, as a result of the discretization of our vehicle types, we believed that some towing vehicle models had been mapped into non-towing vehicle types while some non-towing vehicle models had been mapped into towing vehicle types. One prime example was the Ford Escape mentioned above. We had mapped all Escapes into non-towing vehicle types. This was done because the primary driver behind the vehicle type into which a vehicle was mapped was the engine technology in the base engine (number of cylinders, valvetrain configuration, etc.). Towing capacity was not an original driver in the decision. Because of this, our model outputs in the proposal put Atkinson-HEVs on some vehicle models that were more properly treated as towing vehicles[D], and would put turbocharged/downsized HEVs on some vehicle models that are more properly treated as non-towing vehicles. Table 1.3-2 shows some of these vehicle models that were mapped into a non-towing vehicle type even though they may have been towing vehicles (the right column). The table also shows some vehicle models that were mapped into a towing vehicle type even though they may not have been towing vehicles (the left column). The vehicles in the right column would be expected to experience some loss of towing utility on a long grade for any that have been converted to Atkinson-HEV although they would not have a lower tow rating. The vehicles in the left column would be expected, when converted to HEV, to be costlier and slightly less effective (less CO_2 reduction) since they would be converted to turbocharged/downsized HEVs rather than Atkinson-HEVs. Due to these potential flaws in the modeling done for our proposal, we stated that we hoped to have better data on towing capacity for the final rule analysis which could result in creating revised vehicle types to more properly model towing and non-towing vehicles. As described above, we have indeed created all new vehicle types and no longer treat any towing vehicles as non-towing and vice-versa.

[D] The Ford Escape HEV does utilize an Atkinson engine and has a tow rating of 1,500 pounds which is identical to the base I4 (non-HEV) Ford Escape.

Table 1.3-2 Potential Inconsistencies in our Treatment of Towing & Non-towing Vehicles in our Proposal[a]

Non-towing vehicles mapped into towing vehicle types in the proposal but now mapped into non-towing vehicle types	Towing vehicles mapped into non-towing vehicle types in the proposal but now mapped into towing vehicle types
Mercedes-Benz SLR Ford Mustang Buick Lacrosse/Lucerne Chevrolet Impala Pontiac G6/Grand Prix	Dodge Magnum V8 Ford Escape AWD V6 Jeep Liberty V6 Mercury Mariner AWD V6 Saturn Vue AWD V6 Honda Ridgeline 4WD V6 Hyundai Tuscon 4WD V6 Mazda Tribute AWD V6 Mitsubishi Outlander 4WD V6 Nissan Xterra V6 Subaru Forester AWD V6 Subaru Outback Wagon AWD V6 Suzuki Grand Vitara 4WD V6 Land Rover LR2 V6 Toyota Rav4 4WD V6

[a] All of the vehicles listed here are now in appropriate vehicle types so that the potential inconsistencies no longer exist.

The second possible exception to our attempt at maintaining utility is the electric vehicle range. We have built electric vehicle packages with ranges of 75, 100 and 150 miles. Clearly these vehicles would not provide the same utility as a gasoline vehicle which typically has a range of over 300 miles. However, from an acceleration performance standpoint, the utility would be equal if not perhaps better. We believe that buyers of electric vehicles in the MYs 2017-2025 timeframe will be purchasing the vehicles with a full understanding of the range limitations and will not attempt to use their EVs for long duration trips. As such, we believe that the buyers of EVs will experience no loss of expected utility.

To prepare inputs for the OMEGA model, EPA builds "master-sets" of technology packages[E]. The master-set of packages for each vehicle type are meant to reflect both appropriate groupings of technologies (e.g., we do not apply turbochargers unless an engine has dual overhead cams, some degree of downsizing, direct injection and dual cam phasing) and limitations associated with phase-in caps (see joint TSD 3.5). We then filter that list by

[E] We build a master-set of packages for each model year for which we run OMEGA because phase-in caps results in different technologies being available and costs change over time resulting in different costs every year.

determining which packages provide the most cost effective groups of technologies within each vehicle type—those that provide the best trade-off of costs versus CO_2 reduction improvements. This is done by ranking those groupings based on the Technology Application Ranking Factor (TARF). The TARF is the factor used by the OMEGA model to rank packages and determine which are the most cost effective to apply. The TARF is calculated as the net incremental cost (or savings) of a package per kilogram of CO_2 reduced by the package relative to the previous package. The net incremental cost is calculated as the incremental cost of the technology package less the incremental discounted fuel savings of the package over 5 years. The incremental CO_2 reduction is calculated as the incremental CO_2/mile emission level of the package relative to the prior package multiplied by the lifetime miles travelled. More detail on the TARF can be found in the OMEGA model supporting documentation (see EPA-420-B-10-042). We also describe the TARF ranking process in more detail below. Grouping "reasonable technologies" simply means grouping those technologies that are complementary (e.g., turbocharging plus downsizing) and not grouping technologies that are not complementary (e.g., dual cam phasing and coupled cam phasing).

To generate the master-set of packages for each of the vehicle types, EPA has built packages in a step-wise fashion looking first at "simpler" conventional gasoline and vehicle technologies, then more advanced gasoline technologies such as turbocharged (with very high levels of boost) and downsized engines with gasoline direct injection and then hybrid and other electrified vehicle technologies. This was done by assuming that auto makers would first concentrate efforts on conventional gasoline engine and transmission technologies paired with some level of mass reduction to improve CO_2 emission performance. Mass reduction varied from no mass reduction up to 20 percent as the maximum considered in this analysis.[F]

Once the conventional gasoline engine and transmission technologies have been fully implemented, we expect that auto makers would apply more complex (and costly) technologies such as the highly boosted (i.e. 24 bar and 27 bar brake mean effective pressure, BMEP) gasoline engines and/or converting conventional gasoline engines to advanced diesel engines in the next redesign cycle. The projected penetrations of these more advanced technologies are presented in Chapter 3.8 of this RIA.

From there, auto makers needing further technology penetration to meet their individual standards would most likely move to hybridization. For this analysis, we have built all of our hybrid packages using the newly emerging P2 technology. This technology and why we believe it will be the predominant hybrid technology used in the 2017-2025 timeframe is described in Chapter 3 of the joint TSD. As noted above, we have built two types of P2 hybrid packages for analysis. The first type is for non-towing vehicle types and uses an Atkinson-cycle engine with no downsizing relative to the baseline engine. The

[F] Importantly, the mass reduction associated for each of the 19 vehicle types was based on the vehicle-type sales weighted average curb weight. Although considerations of vehicle safety are an important part of EPA's consideration in establishing the standards, note that allowable weight reductions giving consideration to safety is not part of the package building process so we have built packages for the full range of 0-20% weight reduction considered in this analysis. Weight consideration for safety is handled within OMEGA as described in Chapter 3 of this RIA.

second P2 hybrid type is for towing vehicle types and uses a turbocharged and downsized engine (rather than an Atkinson-cycle engine) to ensure no loss of towing capacity.[G]

Lastly, for some vehicle types (i.e., the non-towing vehicle types), we anticipate that auto makers would move to more advanced electrification in the form of both plug-in hybrid (PHEV, sometimes referred to as range extended electric vehicles (REEV)) and full battery electric vehicles (EV).

Importantly, the HEV, PHEV and EV (called collectively P/H/EV) packages take into consideration the impact of the weight of the electrified components, primarily the battery packs. Because these battery packs can be quite heavy, if one removes 20 percent of the mass from a gasoline vehicle but then converts it to an electric vehicle, the resultant net weight reduction will be less than 20 percent. We discuss this in more below where we provide additional discussion regarding the P/H/EV packages.

Focusing first on the conventional and more advanced (higher boost, cooled EGR) gasoline packages, the first step in creating these packages was to consider the following 12 primary categories of conventional gasoline engine technologies. These are:

1. Our “anytime technologies”.[H] These consist of low friction lubes, engine friction reduction, aggressive shift logic, early torque converter lock-up (automatic transmission only), improved accessories, electric power steering (EPS) or electrohydraulic power steering (EHPS, used for large trucks), aerodynamic improvements, lower rolling resistance tires, high efficiency gearbox technology (HEG). Many of these technologies consist of two levels:

    - low friction lubes with engine friction reduction level 1 and with EFR level 2 (which includes low friction lubes), aggressive shift logic levels 1 & 2, improved accessories levels 1 & 2, lower rolling resistance tires levels 1 & 2, aerodynamic treatments levels 1 & 2.

2. Variable valve timing (VVT) consisting of coupled cam phasing (CCP, for OHV and SOHC engines) and dual cam phasing (DCP, for DOHC engines)

[G] While consistent with the proposal, this is a departure from the 2010 TAR where we built several flavors of P2 HEV packages in the same manner for each of the 19 vehicle types. We built P2 HEV packages with downsized engines, some with turbocharged and downsized engines, some with cooled EGR, etc. We then used the TARF ranking process (described below) to determine which packages were most cost effective. We also did not, in the 2010 TAR, consider the weight impacts of the hybrid powertrain, which we have done in this analysis. The effect of the changes used in this analysis has been to decrease the effectiveness of HEV packages relative to the TAR and to increase their costs since heavier batteries and motors are now part of the packages.

[H] Note that the term “anytime technology,” is a carryover term from the 2012-2016 rule. At this point, we continue to use the term, but it has become merely convenient nomenclature to denote very cost effective technologies that are relatively easy to implement and would likely be implemented very early by auto makers when considering compliance with CO_2 standards. This is true also of the term “other” technologies. We group these technologies largely because they are very cost effective so will likely be implemented early in some form and combination.

3. Variable valve lift (VVL) consisting of discrete variable valve lift (DVVL, for DOHC engines) and cylinder deactivation (Deac, considered for OHV and SOHC engines)

4. Gasoline direct injection (GDI)

5. Turbocharging and downsizing (TDS, which always includes a conversion to GDI and DCP) with and without cooled EGR. Note that 27 bar BMEP engines must include the addition of cooled EGR in our analysis and we have applied no cooled EGR to 18 bar BMEP engines.

6. Stop-start

7. Secondary axle disconnect (SAX)

8. Conversion to advanced diesel, which includes removal of the gasoline engine and gasoline fuel system and aftertreatment, and replacement by a diesel engine with diesel fuel system, a selective catalytic reduction (SCR) system and advanced fuel and SCR controls.

9. Mass reduction consisting of 0%, 5%, 10%, 15% and 20%.

In this first step, we also considered the 6 primary transmission technologies. These are:

10. 6 and 8 speed automatic transmissions (6sp AT/8sp AT)

11. 6 and 8 speed dual clutch transmissions with wet clutch (6sp wet-DCT/8sp wet-DCT)

12. 6 and 8 speed dual clutch transmission with dry clutch (6sp dry-DCT/8sp wet-DCT)

In considering the transmissions, we had to first determine how each transmission could reasonably be applied. DCTs, especially dry-DCTs, cannot be applied to every vehicle type due to low end torque demands at launch (another example of how the standards are developed to preserve all vehicle utility). In addition, dry-DCTs tend to be more efficient than wet-DCTs, which are more efficient than 6sp ATs primarily due to the elimination of wet clutches and torque converter in the dry-DCT. Further, each transmission has progressively lower costs. Therefore, moving from wet-DCT to dry-DCT will result in lower costs and increased effectiveness. As done in the proposal but unlike the TAR analysis, we have limited towing vehicle types to use of automatic transmissions (both 6 and 8 speed). Like the proposal and the TAR, we have added dry-DCTs to vehicle types in baseline I4 engines and wet-DCTs to vehicle types with baseline V8 engines. This was done to ensure no loss of launch performance. For the V6 baseline vehicle types, and again as was done in the proposal and the 2010 TAR, we have added dry versus wet DCTs depending on the baseline weight of the vehicle type. If the vehicle type were below 2,800 pounds curb weight, or removed enough weight in the package such that the package weight would be below 2,800 pounds, we added a dry-DCT. Otherwise, we added a wet-DCT. In the end, this allowed change from wet- to dry-DCT impacted only vehicle types 3 and 4 and only in packages with 25% or 30% weight reduction applied, neither of which we allowed for this analysis. Therefore, all V6 base engines are equipped with wet-clutch DCTs where appropriate, never dry-clutch.

Table 1.3-3 shows the vehicle types, baseline curb weights and transmissions added in this analysis. It is important to note that these heavier towing vehicles (including pickup trucks) have no access to the more effective technologies such as Atkinson engine, dry-DCT transmission, PHEV, or EV (for the reasons we describe below). Together these result in a decrease in effectiveness potential for the heavier towing vehicle types compared to the non-towing vehicle types.

Table 1.3-3 Application of Transmission Technologies in Building OMEGA Packages

Vehicle Type	Vehicle class	Base engine	Base weight	Mass Reduction				
				0%	5%	10%	15%	20%
1	Small car	I4	2,633	6/8 speed dry-DCT				
2	Standard car	I4	3,094	6/8 speed dry-DCT				
3	Standard car	V6	3,554	6/8 speed wet-DCT				
4	Standard car	V6	3,558	6/8 speed wet-DCT				
5	Large car	V8	3,971	6/8 speed wet-DCT				
6	Large car	V8	3,651	6/8 speed wet-DCT				
7	Small MPV	I4	3,450	6/8 speed dry-DCT				
8	Large MPV	V6	4,326	6/8 speed AT				
9	Large MPV	V6	4,334	6/8 speed AT				
10	Large MPV	V6	4,671	6/8 speed AT				
11	Truck	V8	5,174	6/8 speed AT				
12	Truck	V8	5,251	6/8 speed AT				
13	Small MPV	I4	3,904	6/8 speed dry-DCT				
14	Large MPV	V6	4,157	6/8 speed AT				
15	Large MPV	V6	4,397	6/8 speed AT				
16	Truck	V8	5,270	6/8 speed AT				
17	Truck	V8	4,967	6/8 speed AT				
18	Truck	V8	4,959	6/8 speed AT				
19	Truck	V8	5,026	6/8 speed AT				

We start building a "master-set" of packages for a given model year by building non-electrified (i.e., gasoline and diesel) packages for each vehicle type consisting of nearly every combination of each of the 12 primary engine technologies listed above. The initial package for each vehicle type represents what we expect a manufacturer will most likely implement as a first step on all vehicles because the technologies included are so attractive from a cost effectiveness standpoint. This package consists of first level anytime technologies but no weight reduction or transmission changes. We then add the other technologies as appropriate, still with no weight reduction or transmission changes or HEG (we do not consider the addition of HEG without a simultaneous improvement in the transmission itself). We then add HEG and a transmission improvement. The subsequent packages would iterate on nearly all possible combinations with the result being numerous packages per vehicle type. Table 1.3-4 shows a subset of packages built for vehicle type 3, a midsized/large car with a 4 valve DOHC V6 in the baseline. These are packages built for the 2025 MY, so costs shown represent 2025 MY costs. Shown in this table are packages built with 5% weight reduction only, and excluded are packages with an 8 speed transmission. So this table represents roughly one-tenth of the packages built for vehicle type 3. Note that we have placed in the docket a compact disk containing all of the master-sets of packages used in our final analysis.[4]

Table 1.3-4 A Subset of 2025 MY Non-HEV/PHEV/EV Packages Built for Vehicle Type 3 (Midsize carDOHC V6, costs in 2010$)[a]

TP#	MR	Description	Trans	2025	CO2%
3.0000	base	Auto 4VDV6		$0	0.0%
3.0129	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +WR5% +6sp	6sp DCT-wet	$733	26.4%
3.0130	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +WR5% +6sp	6sp DCT-wet	$950	31.2%
3.0131	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +WR5% +6sp	6sp DCT-wet	$822	29.8%
3.0132	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +WR5% +6sp	6sp DCT-wet	$1,039	34.3%
3.0133	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +WR5% +6sp	6sp DCT-wet	$926	28.4%
3.0134	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +WR5% +6sp	6sp DCT-wet	$1,143	32.8%
3.0135	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +WR5% +6sp	6sp DCT-wet	$1,015	31.7%
3.0136	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +WR5% +6sp	6sp DCT-wet	$1,232	35.9%
3.0137	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +WR5% +6sp	6sp DCT-wet	$1,073	27.5%
3.0138	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +WR5% +6sp	6sp DCT-wet	$1,290	32.3%
3.0139	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +WR5% +6sp	6sp DCT-wet	$1,162	30.9%
3.0140	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +WR5% +6sp	6sp DCT-wet	$1,379	35.3%
3.0141	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +WR5% +6sp	6sp DCT-wet	$1,266	29.5%
3.0142	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +WR5% +6sp	6sp DCT-wet	$1,483	33.8%
3.0143	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +WR5% +6sp	6sp DCT-wet	$1,355	32.7%
3.0144	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +WR5% +6sp	6sp DCT-wet	$1,572	36.8%
3.0145	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +SS +WR5% +6sp	6sp DCT-wet	$1,041	27.6%
3.0146	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +SS +WR5% +6sp	6sp DCT-wet	$1,258	32.3%
3.0147	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +SS +WR5% +6sp	6sp DCT-wet	$1,129	30.8%

3.0148	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +SS +WR5% +6sp	6sp DCT-wet	$1,347	35.2%
3.0149	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +SS +WR5% +6sp	6sp DCT-wet	$1,234	29.5%
3.0150	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +SS +WR5% +6sp	6sp DCT-wet	$1,451	33.8%
3.0151	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +SS +WR5% +6sp	6sp DCT-wet	$1,323	32.6%
3.0152	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +SS +WR5% +6sp	6sp DCT-wet	$1,540	36.7%
3.0153	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +WR5% +6sp	6sp DCT-wet	$1,381	28.7%
3.0154	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +WR5% +6sp	6sp DCT-wet	$1,598	33.3%
3.0155	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +WR5% +6sp	6sp DCT-wet	$1,470	31.8%
3.0156	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +WR5% +6sp	6sp DCT-wet	$1,687	36.2%
3.0157	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +WR5% +6sp	6sp DCT-wet	$1,574	30.5%
3.0158	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +WR5% +6sp	6sp DCT-wet	$1,791	34.8%
3.0159	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +WR5% +6sp	6sp DCT-wet	$1,663	33.6%
3.0160	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +WR5% +6sp	6sp DCT-wet	$1,880	37.6%
3.0161	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +SAX +WR5% +6sp	6sp DCT-wet	$815	27.0%
3.0162	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +SAX +WR5% +6sp	6sp DCT-wet	$1,032	31.8%
3.0163	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +SAX +WR5% +6sp	6sp DCT-wet	$904	30.4%
3.0164	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +SAX +WR5% +6sp	6sp DCT-wet	$1,121	34.8%
3.0165	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +SAX +WR5% +6sp	6sp DCT-wet	$1,008	29.0%
3.0166	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +SAX +WR5% +6sp	6sp DCT-wet	$1,225	33.3%
3.0167	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +SAX +WR5% +6sp	6sp DCT-wet	$1,097	32.2%
3.0168	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +SAX +WR5% +6sp	6sp DCT-wet	$1,314	36.4%
3.0169	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SAX +WR5% +6sp	6sp DCT-wet	$1,155	28.1%
3.0170	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SAX +WR5% +6sp	6sp DCT-wet	$1,372	32.8%
3.0171	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SAX +WR5% +6sp	6sp DCT-wet	$1,244	31.4%
3.0172	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SAX +WR5% +6sp	6sp DCT-wet	$1,461	35.8%
3.0173	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SAX +WR5% +6sp	6sp DCT-wet	$1,348	30.0%
3.0174	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SAX +WR5% +6sp	6sp DCT-wet	$1,565	34.3%
3.0175	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SAX +WR5% +6sp	6sp DCT-wet	$1,437	33.3%

3.0176	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SAX +WR5% +6sp	6sp DCT-wet	$1,654	37.3%
3.0177	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,123	28.1%
3.0178	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,340	32.8%
3.0179	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,211	31.3%
3.0180	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,428	35.7%
3.0181	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,316	30.0%
3.0182	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,533	34.3%
3.0183	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,405	33.1%
3.0184	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,622	37.1%
3.0185	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,463	29.2%
3.0186	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,680	33.8%
3.0187	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,552	32.3%
3.0188	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,769	36.7%
3.0189	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,656	31.0%
3.0190	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,873	35.3%
3.0191	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,745	34.1%
3.0192	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +SAX +WR5% +6sp	6sp DCT-wet	$1,962	38.1%
3.0193	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +TDS18 +WR5% +6sp	6sp DCT-wet	$1,009	33.9%
3.0194	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS18 +WR5% +6sp	6sp DCT-wet	$1,226	37.8%
3.0195	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +TDS18 +WR5% +6sp	6sp DCT-wet	$1,070	36.8%
3.0196	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS18 +WR5% +6sp	6sp DCT-wet	$1,287	40.4%
3.0197	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +TDS18 +WR5% +6sp	6sp DCT-wet	$1,142	34.6%
3.0198	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +TDS18 +WR5% +6sp	6sp DCT-wet	$1,359	38.3%
3.0199	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +TDS18 +WR5% +6sp	6sp DCT-wet	$1,203	37.4%
3.0200	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +TDS18 +WR5% +6sp	6sp DCT-wet	$1,420	41.0%
3.0201	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +TDS18 +WR5% +6sp	6sp DCT-wet	$1,317	34.8%
3.0202	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +TDS18 +WR5% +6sp	6sp DCT-wet	$1,534	38.6%
3.0203	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +TDS18 +WR5% +6sp	6sp DCT-wet	$1,378	37.5%

3.0204	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +TDS18 +WR5% +6sp	6sp DCT-wet	$1,595	41.1%
3.0205	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +TDS18 +WR5% +6sp	6sp DCT-wet	$1,450	35.4%
3.0206	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +TDS18 +WR5% +6sp	6sp DCT-wet	$1,667	39.1%
3.0207	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +TDS18 +WR5% +6sp	6sp DCT-wet	$1,511	38.1%
3.0208	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +TDS18 +WR5% +6sp	6sp DCT-wet	$1,728	41.6%
3.0209	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,091	34.4%
3.0210	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,308	38.3%
3.0211	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,152	37.2%
3.0212	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,369	40.9%
3.0213	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,224	35.1%
3.0214	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,441	38.8%
3.0215	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,285	37.9%
3.0216	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,502	41.4%
3.0217	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,399	35.3%
3.0218	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,616	39.0%
3.0219	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,460	38.0%
3.0220	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,677	41.6%
3.0221	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,532	35.9%
3.0222	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,749	39.5%
3.0223	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,593	38.6%
3.0224	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$1,810	42.1%
3.0225	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +TDS24 +WR5% +6sp	6sp DCT-wet	$1,223	36.4%
3.0226	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS24 +WR5% +6sp	6sp DCT-wet	$1,440	40.0%
3.0227	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +TDS24 +WR5% +6sp	6sp DCT-wet	$1,284	39.1%
3.0228	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS24 +WR5% +6sp	6sp DCT-wet	$1,501	42.5%
3.0229	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +TDS24 +WR5% +6sp	6sp DCT-wet	$1,357	36.6%
3.0230	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +TDS24 +WR5% +6sp	6sp DCT-wet	$1,574	40.0%
3.0231	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +TDS24 +WR5% +6sp	6sp DCT-wet	$1,417	39.3%

3.0232	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +TDS24 +WR5% +6sp	6sp DCT-wet	$1,634	42.6%
3.0233	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +TDS24 +WR5% +6sp	6sp DCT-wet	$1,531	37.2%
3.0234	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +TDS24 +WR5% +6sp	6sp DCT-wet	$1,748	40.7%
3.0235	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +TDS24 +WR5% +6sp	6sp DCT-wet	$1,592	39.7%
3.0236	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +TDS24 +WR5% +6sp	6sp DCT-wet	$1,809	43.1%
3.0237	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +TDS24 +WR5% +6sp	6sp DCT-wet	$1,665	37.3%
3.0238	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +TDS24 +WR5% +6sp	6sp DCT-wet	$1,882	40.7%
3.0239	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +TDS24 +WR5% +6sp	6sp DCT-wet	$1,725	39.9%
3.0240	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +TDS24 +WR5% +6sp	6sp DCT-wet	$1,942	43.2%
3.0241	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$1,305	36.9%
3.0242	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$1,522	40.4%
3.0243	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$1,366	39.6%
3.0244	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$1,583	42.9%
3.0245	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$1,439	37.0%
3.0246	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$1,656	40.5%
3.0247	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$1,499	39.7%
3.0248	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$1,716	43.0%
3.0249	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$1,613	37.7%
3.0250	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$1,830	41.1%
3.0251	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$1,674	40.2%
3.0252	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$1,891	43.5%
3.0253	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$1,747	37.8%
3.0254	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$1,964	41.2%
3.0255	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$1,807	40.4%
3.0256	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$2,024	43.6%
3.0257	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,472	38.7%
3.0258	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,690	42.1%
3.0259	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,533	41.3%

3.0260	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,750	44.5%
3.0261	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,606	38.8%
3.0262	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,823	42.2%
3.0263	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,666	41.4%
3.0264	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,883	44.6%
3.0265	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,780	39.4%
3.0266	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,997	42.8%
3.0267	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,841	41.9%
3.0268	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,058	45.1%
3.0269	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,914	39.5%
3.0270	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,131	42.8%
3.0271	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,974	42.0%
3.0272	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,191	45.2%
3.0273	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,554	39.2%
3.0274	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,771	42.6%
3.0275	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,615	41.7%
3.0276	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,832	45.0%
3.0277	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,688	39.3%
3.0278	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,905	42.6%
3.0279	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,748	41.9%
3.0280	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,965	45.1%
3.0281	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,862	39.9%
3.0282	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,079	43.2%
3.0283	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,923	42.3%
3.0284	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,140	45.5%
3.0285	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$1,996	40.0%
3.0286	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,213	43.3%
3.0287	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,056	42.5%

3.0288	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,273	45.6%
3.0289	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$1,901	39.4%
3.0290	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,118	42.7%
3.0291	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$1,961	41.9%
3.0292	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,178	45.1%
3.0293	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,034	39.4%
3.0294	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,251	42.6%
3.0295	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,095	41.9%
3.0296	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,312	45.0%
3.0297	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,209	40.1%
3.0298	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,426	43.4%
3.0299	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,269	42.5%
3.0300	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,486	45.6%
3.0301	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,342	40.1%
3.0302	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,559	43.2%
3.0303	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,403	42.5%
3.0304	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,620	45.5%
3.0305	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$1,983	39.9%
3.0306	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,200	43.2%
3.0307	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,043	42.4%
3.0308	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,260	45.5%
3.0309	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,116	39.8%
3.0310	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,333	43.0%
3.0311	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,177	42.4%
3.0312	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,394	45.4%
3.0313	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,291	40.5%
3.0314	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,508	43.8%
3.0315	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +SS +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,351	42.9%

3.0316	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,568	46.0%
3.0317	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,424	40.5%
3.0318	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,641	43.6%
3.0319	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +SS +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,485	43.0%
3.0320	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +SS +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$2,702	45.9%
3.1681	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +MHEV +WR5% +6sp	6sp DCT-wet	$1,981	34.9%
3.1682	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +MHEV +WR5% +6sp	6sp DCT-wet	$2,153	38.8%
3.1683	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +MHEV +WR5% +6sp	6sp DCT-wet	$2,070	37.9%
3.1684	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +MHEV +WR5% +6sp	6sp DCT-wet	$2,242	41.5%
3.1685	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +MHEV +WR5% +6sp	6sp DCT-wet	$2,175	36.6%
3.1686	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +MHEV +WR5% +6sp	6sp DCT-wet	$2,346	40.4%
3.1687	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +MHEV +WR5% +6sp	6sp DCT-wet	$2,263	39.5%
3.1688	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +MHEV +WR5% +6sp	6sp DCT-wet	$2,435	43.1%
3.1689	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +WR5% +6sp	6sp DCT-wet	$2,322	35.9%
3.1690	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +WR5% +6sp	6sp DCT-wet	$2,493	39.7%
3.1691	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +WR5% +6sp	6sp DCT-wet	$2,411	38.8%
3.1692	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +WR5% +6sp	6sp DCT-wet	$2,582	42.4%
3.1693	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +WR5% +6sp	6sp DCT-wet	$2,515	37.6%
3.1694	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +WR5% +6sp	6sp DCT-wet	$2,687	41.3%
3.1695	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +WR5% +6sp	6sp DCT-wet	$2,604	40.4%
3.1696	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +WR5% +6sp	6sp DCT-wet	$2,775	43.9%
3.1697	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,063	35.5%
3.1698	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,235	39.3%
3.1699	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,152	38.4%
3.1700	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,324	42.0%
3.1701	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,256	37.2%
3.1702	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,428	40.9%
3.1703	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,345	40.0%

3.1704	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,517	43.6%
3.1705	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,404	36.5%
3.1706	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,575	40.2%
3.1707	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,492	39.3%
3.1708	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,664	42.9%
3.1709	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,597	38.1%
3.1710	5%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,768	41.8%
3.1711	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,686	40.9%
3.1712	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +WR5% +6sp	6sp DCT-wet	$2,857	44.4%
3.1713	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS18 +WR5% +6sp	6sp DCT-wet	$2,258	41.4%
3.1714	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS18 +WR5% +6sp	6sp DCT-wet	$2,429	44.9%
3.1715	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS18 +WR5% +6sp	6sp DCT-wet	$2,318	43.9%
3.1716	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS18 +WR5% +6sp	6sp DCT-wet	$2,490	47.2%
3.1717	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS18 +WR5% +6sp	6sp DCT-wet	$2,391	42.0%
3.1718	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS18 +WR5% +6sp	6sp DCT-wet	$2,563	45.5%
3.1719	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS18 +WR5% +6sp	6sp DCT-wet	$2,452	44.5%
3.1720	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS18 +WR5% +6sp	6sp DCT-wet	$2,623	47.8%
3.1721	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$2,340	42.0%
3.1722	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$2,511	45.4%
3.1723	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$2,400	44.4%
3.1724	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$2,572	47.7%
3.1725	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$2,473	42.5%
3.1726	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$2,645	45.9%
3.1727	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$2,533	45.0%
3.1728	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS18 +WR5% +6sp	6sp DCT-wet	$2,705	48.2%
3.1729	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS24 +WR5% +6sp	6sp DCT-wet	$2,472	43.7%
3.1730	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +WR5% +6sp	6sp DCT-wet	$2,644	47.0%
3.1731	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS24 +WR5% +6sp	6sp DCT-wet	$2,532	46.0%

3.1732	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +WR5% +6sp	6sp DCT-wet	$2,704	49.2%
3.1733	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +WR5% +6sp	6sp DCT-wet	$2,605	43.8%
3.1734	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +WR5% +6sp	6sp DCT-wet	$2,777	47.1%
3.1735	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +WR5% +6sp	6sp DCT-wet	$2,666	46.1%
3.1736	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +WR5% +6sp	6sp DCT-wet	$2,837	49.3%
3.1737	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$2,554	44.1%
3.1738	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$2,725	47.4%
3.1739	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$2,614	46.4%
3.1740	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$2,786	49.6%
3.1741	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$2,687	44.2%
3.1742	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$2,859	47.5%
3.1743	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$2,748	46.6%
3.1744	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +WR5% +6sp	6sp DCT-wet	$2,919	49.7%
3.1745	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,721	45.7%
3.1746	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,893	48.9%
3.1747	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,782	47.9%
3.1748	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,953	51.0%
3.1749	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,854	45.8%
3.1750	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$3,026	49.0%
3.1751	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,915	48.0%
3.1752	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$3,086	51.1%
3.1753	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,803	46.1%
3.1754	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,975	49.3%
3.1755	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,864	48.3%
3.1756	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$3,035	51.4%
3.1757	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,936	46.2%
3.1758	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$3,108	49.4%
3.1759	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$2,997	48.5%

3.1760	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +EGR +WR5% +6sp	6sp DCT-wet	$3,168	51.5%
3.1761	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,149	46.3%
3.1762	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,321	49.4%
3.1763	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,210	48.5%
3.1764	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,382	51.5%
3.1765	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,283	46.2%
3.1766	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,454	49.4%
3.1767	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,343	48.5%
3.1768	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,515	51.5%
3.1769	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,231	46.7%
3.1770	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,403	49.9%
3.1771	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,292	48.9%
3.1772	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,464	51.9%
3.1773	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,365	46.7%
3.1774	5%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,536	49.9%
3.1775	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,425	48.9%
3.1776	5%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS27 +EGR +WR5% +6sp	6sp DCT-wet	$3,597	51.9%
3.2449	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DSL-Adv +WR5% +6sp	6sp DCT-wet	$3,242	39.1%
3.2450	5%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +DSL-Adv +WR5% +6sp	6sp DCT-wet	$3,459	42.5%

As stated, the packages are meant to maintain utility relative to the baseline vehicle. Having built nearly 2500 packages for each vehicle type suggests the question "how can EPA know that each has the same utility as the baseline vehicle for a given vehicle type?" We believe that this is inherent in the effectiveness values used, given that they are based on the recent Ricardo work which had maintenance of baseline performance as a constraint in estimating technology effectiveness values. Maintaining utility is also included in the cost of the technologies with proper consideration of engine sizing (number of cylinders), motor and battery sizing, etc. This is discussed in more detail throughout Section 3.2 of the joint TSD. Therefore, with the possible exception of the towing issue raised above—maintenance of towing capacity over operating extremes for "non-towing" vehicles—we are confident that the packages we have built for OMEGA modeling maintain utility relative to the baseline for the "average" vehicles represented by our 19 vehicle types.

The next packages built are the strong HEVs (P2 HEV) and, new for this final rule, the mild HEVs (MHEV). As done with non-electrified packages, we paired the HEV powertrain with increasing levels of engine technologies. For non-towing vehicle types we have paired the hybrid powertrain with an Atkinson engine. With each Atkinson engine, we include dual cam phasing, discrete variable valve lift and stoichiometric gasoline direct injection. Since most non-towing vehicle types are DOHC engines in the baseline, these costs were simply added to the baseline engine to ensure that the Atkinson engine is consistent with those modeled by Ricardo to ensure that our effectiveness values are consistent. But for those vehicle types that are SOHC or OHV in the baseline, the package by definition included costs associated with converting the valvetrain to a DOHC configuration. For towing vehicle types, we have paired the hybrid powertrain with a turbocharged and downsized engine. By definition, such engines include both dual cam phasing and stoichiometric gasoline direct injection. Further, such engines might be 18/24/27 bar BMEP and the 24 bar BMEP engines may or may not include cooled EGR while the 27 bar BMEP engines must include cooled EGR as explained in Chapter 3.4.1 of the Joint TSD. As a result, we have built more HEV packages for towing vehicle types than for non-towing types. Lastly, we built strong HEV packages with a constant weight reduction across the board in the year of interest. For example, in building packages for a 2016MY OMEGA run, we built HEV packages with 10% weight reduction as this was the maximum weight reduction (i.e., applicable phase-in cap) in MY 2016 allowed in the analysis. This maximum allowed weight reduction was 15% for the 2021MY and 20% for MY 2025 based on the technology penetration caps set forth and explained in Chapter 3 of the joint TSD. For MHEVs, we built packages with weight reduction at 5%, 10% for MY 2016, 5%, 10%, 15% for MY 2021, and 5%, 10%, 15% and 20% for MY 2025. Table 1.3-5 shows the HEV packages built for vehicle type 3 which is a non-towing vehicle type (the table shows only packages built with 20% weigh reduction and a 6 speed transmission).

Table 1.3-5 A Subset of 2025 MY Strong HEV & Mild HEV Packages Built for Vehicle Type 3 (Midsize car DOHC V6, costs in 2010$)[a]

TP#	MR	Description	Trans	2025	CO2%
3.0000	base	Auto 4VDV6		$0	0.0%
3.1665	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +HEV +ATKCS +WR20% +6sp	6sp DCT-wet	$4,698	50.0%
3.1666	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +HEV +ATKCS +WR20% +6sp	6sp DCT-wet	$4,870	53.2%
3.1667	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +HEV +ATKCS +WR20% +6sp	6sp DCT-wet	$4,787	52.4%
3.1668	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +HEV +ATKCS +WR20% +6sp	6sp DCT-wet	$4,959	55.3%
3.1669	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +HEV +SAX +ATKCS +WR20% +6sp	6sp DCT-wet	$4,780	50.5%
3.1670	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +HEV +SAX +ATKCS +WR20% +6sp	6sp DCT-wet	$4,952	53.6%
3.1671	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +HEV +SAX +ATKCS +WR20% +6sp	6sp DCT-wet	$4,869	52.8%
3.1672	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +HEV +SAX +ATKCS +WR20% +6sp	6sp DCT-wet	$5,041	55.7%
3.2257	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +MHEV +WR20% +6sp	6sp DCT-wet	$2,621	39.4%

3.2258	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +MHEV +WR20% +6sp	6sp DCT-wet	$2,793	43.1%
3.2259	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +MHEV +WR20% +6sp	6sp DCT-wet	$2,710	42.1%
3.2260	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +MHEV +WR20% +6sp	6sp DCT-wet	$2,882	45.6%
3.2261	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +MHEV +WR20% +6sp	6sp DCT-wet	$2,815	41.0%
3.2262	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +MHEV +WR20% +6sp	6sp DCT-wet	$2,986	44.6%
3.2263	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +MHEV +WR20% +6sp	6sp DCT-wet	$2,903	43.7%
3.2264	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +MHEV +WR20% +6sp	6sp DCT-wet	$3,075	47.1%
3.2265	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +WR20% +6sp	6sp DCT-wet	$2,962	40.3%
3.2266	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +WR20% +6sp	6sp DCT-wet	$3,133	43.9%
3.2267	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +WR20% +6sp	6sp DCT-wet	$3,051	43.0%
3.2268	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +WR20% +6sp	6sp DCT-wet	$3,222	46.5%
3.2269	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +WR20% +6sp	6sp DCT-wet	$3,155	41.9%
3.2270	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +WR20% +6sp	6sp DCT-wet	$3,327	45.4%
3.2271	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +WR20% +6sp	6sp DCT-wet	$3,244	44.5%
3.2272	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +WR20% +6sp	6sp DCT-wet	$3,415	47.9%
3.2273	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$2,703	39.9%
3.2274	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$2,875	43.6%
3.2275	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$2,792	42.6%
3.2276	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$2,964	46.1%
3.2277	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$2,897	41.5%
3.2278	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$3,068	45.1%
3.2279	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$2,985	44.1%
3.2280	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$3,157	47.5%
3.2281	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$3,044	40.8%
3.2282	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$3,215	44.4%
3.2283	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$3,133	43.5%
3.2284	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$3,304	46.9%
3.2285	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$3,237	42.4%

3.2286	20%	Auto 4VDV6 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$3,409	45.9%
3.2287	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$3,326	45.0%
3.2288	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +WR20% +6sp	6sp DCT-wet	$3,497	48.3%
3.2289	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS18 +WR20% +6sp	6sp DCT-wet	$2,898	45.5%
3.2290	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS18 +WR20% +6sp	6sp DCT-wet	$3,069	48.8%
3.2291	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS18 +WR20% +6sp	6sp DCT-wet	$2,958	47.8%
3.2292	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS18 +WR20% +6sp	6sp DCT-wet	$3,130	50.9%
3.2293	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS18 +WR20% +6sp	6sp DCT-wet	$3,031	46.0%
3.2294	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS18 +WR20% +6sp	6sp DCT-wet	$3,203	49.3%
3.2295	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS18 +WR20% +6sp	6sp DCT-wet	$3,092	48.3%
3.2296	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS18 +WR20% +6sp	6sp DCT-wet	$3,263	51.5%
3.2297	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS18 +WR20% +6sp	6sp DCT-wet	$2,980	46.0%
3.2298	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS18 +WR20% +6sp	6sp DCT-wet	$3,151	49.2%
3.2299	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS18 +WR20% +6sp	6sp DCT-wet	$3,040	48.2%
3.2300	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS18 +WR20% +6sp	6sp DCT-wet	$3,212	51.4%
3.2301	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS18 +WR20% +6sp	6sp DCT-wet	$3,113	46.5%
3.2302	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS18 +WR20% +6sp	6sp DCT-wet	$3,285	49.7%
3.2303	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS18 +WR20% +6sp	6sp DCT-wet	$3,174	48.8%
3.2304	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS18 +WR20% +6sp	6sp DCT-wet	$3,345	51.9%
3.2305	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS24 +WR20% +6sp	6sp DCT-wet	$3,112	47.5%
3.2306	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +WR20% +6sp	6sp DCT-wet	$3,284	50.7%
3.2307	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS24 +WR20% +6sp	6sp DCT-wet	$3,173	49.7%
3.2308	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +WR20% +6sp	6sp DCT-wet	$3,344	52.7%
3.2309	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +WR20% +6sp	6sp DCT-wet	$3,245	47.6%
3.2310	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +WR20% +6sp	6sp DCT-wet	$3,417	50.8%
3.2311	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +WR20% +6sp	6sp DCT-wet	$3,306	49.8%
3.2312	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +WR20% +6sp	6sp DCT-wet	$3,477	52.9%
3.2313	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS24 +WR20% +6sp	6sp DCT-wet	$3,194	48.0%

3.2314	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +WR20% +6sp	6sp DCT-wet	$3,366	51.1%
3.2315	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS24 +WR20% +6sp	6sp DCT-wet	$3,255	50.1%
3.2316	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +WR20% +6sp	6sp DCT-wet	$3,426	53.1%
3.2317	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +WR20% +6sp	6sp DCT-wet	$3,327	48.1%
3.2318	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +WR20% +6sp	6sp DCT-wet	$3,499	51.2%
3.2319	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +WR20% +6sp	6sp DCT-wet	$3,388	50.3%
3.2320	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +WR20% +6sp	6sp DCT-wet	$3,559	53.3%
3.2321	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,361	49.4%
3.2322	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,533	52.5%
3.2323	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,422	51.5%
3.2324	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,593	54.4%
3.2325	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,494	49.5%
3.2326	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,666	52.5%
3.2327	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,555	51.6%
3.2328	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,727	54.5%
3.2329	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,443	49.8%
3.2330	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,615	52.9%
3.2331	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,504	51.9%
3.2332	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,675	54.8%
3.2333	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,576	49.9%
3.2334	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,748	53.0%
3.2335	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,637	52.0%
3.2336	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS24 +EGR +WR20% +6sp	6sp DCT-wet	$3,809	54.9%
3.2337	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$3,790	50.0%
3.2338	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$3,961	53.0%
3.2339	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$3,850	52.0%
3.2340	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$4,022	54.9%
3.2341	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$3,923	49.9%

3.2342	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$4,094	53.0%
3.2343	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$3,983	52.0%
3.2344	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$4,155	54.9%
3.2345	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$3,872	50.4%
3.2346	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$4,043	53.4%
3.2347	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +MHEV +SAX +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$3,932	52.4%
3.2348	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$4,104	55.3%
3.2349	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$4,005	50.4%
3.2350	20%	Auto 4VDI4 +LUB +EFR1 +ASL1 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$4,176	53.4%
3.2351	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$4,065	52.4%
3.2352	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS27 +EGR +WR20% +6sp	6sp DCT-wet	$4,237	55.3%

The last step was to build the PHEVs (also known as REEVs) and EVs for vehicle types 1 through 7 and 13. We did not consider the other vehicle types for electrification beyond HEVs for purposes of the current analysis, either because of their expected towing demands or because of their high vehicle weight which would make the electrification of the vehicle prohibitively costly. We have developed two primary types of PHEV packages and three primary types of EV packages all of which are included in the master-set of packages. The PHEVs consist of packages with battery packs capable of 20 miles of all electric operation (REEV20) and packages with battery packs capable of 40 miles of all electric operation (REEV40). For EVs, we have built packages capable of 75, 100 and 150 miles of all electric operation, EV75, EV100 and EV150, respectively. These ranges were selected to represent an increasing selection of ranges (and costs) that consumers would likely require and that we believe will be available in the 2017-2025 timeframe. For each of these packages, we have estimated specific battery-pack costs based on the net weight reduction of the vehicle where the net weight reduction is the difference between the weight reduction technology applied to the "glider" (i.e., the vehicle less any powertrain elements) and the weight increase that results from the inclusion of the electrification components (batteries, motors, etc.). The applied and net weight reductions for HEVs, PHEVs and EVs are presented in Chapter 3 of the joint TSD, and full system costs for each depending on the net weight reduction are presented there and are also presented in Table 1.2-7 through Table 1.2-18. We have built all EV and REEV packages with a 20% weight reduction applied (the net weight reduction would be lower) despite the maximum allowed for a given model year for two reasons. First, some PHEV and EV packages cannot be built unless a 20% applied weight reduction is available because the weight of the electrification components is such that the net weight reduction would be less than zero without the ability to apply a 20% reduction (i.e., the vehicle would increase in weight). We did not want to build packages with net weight increases and we did not have the ability to properly determine their effectiveness values even if we wanted to build them. Second, we believe it is reasonable that auto makers would be more aggressive with respect to weight reduction on PHEVs and EVs (so as to be able to utilize lower weight, and hence less expensive batteries) and that it is reasonable to believe that PHEVs and EVs could achieve higher levels of weight reduction in the MY 2016 and 2021 MYs than we have considered likely for other vehicle technologies.[I] Table 1.3-6 shows all of the EV and REEV packages built for this final rule.

Table 1.3-6 Full EV and Plug-in HEV (REEV) Packages Built for this Analysis (costs shown are for the 2025MY in 2010$)

Vehicle Type	TP#	MR	Description	Trans	2025	CO2%
1	1.2465	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV20 +WR20% +8sp	8sp DCT-dry	$9,327	73.7%
1	1.2466	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV40 +WR20% +8sp	8sp DCT-dry	$11,262	83.3%
1	1.2467	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV75 mile +WR20% +0sp		$9,367	100.0%
1	1.2468	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV100 mile +WR20% +0sp		$11,061	100.0%
1	1.2469	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV150 mile +WR20% +0sp		$14,630	100.0%
2	2.2465	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV20 +WR20% +8sp	8sp DCT-dry	$10,585	74.4%
2	2.2466	20%	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV40 +WR20% +8sp	8sp DCT-dry	$13,072	83.9%
2	2.2467	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV75 mile +WR20% +0sp		$11,363	100.0%
2	2.2468	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV100 mile +WR20% +0sp		$13,288	100.0%
2	2.2469	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV150 mile +WR20% +0sp		$18,218	100.0%
3	3.2465	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV20 +WR20% +8sp	8sp DCT-wet	$11,047	74.3%
3	3.2466	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV40 +WR20% +8sp	8sp DCT-wet	$13,534	83.8%
3	3.2467	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV75 mile +WR20% +0sp		$11,451	100.0%
3	3.2468	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV100 mile +WR20% +0sp		$13,376	100.0%
3	3.2469	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV150 mile +WR20% +0sp		$18,306	100.0%
4	4.2465	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV20 +CCC +WR20% +8sp	8sp DCT-wet	$11,223	74.7%
4	4.2466	20%	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV40 +CCC +WR20% +8sp	8sp DCT-wet	$13,710	84.0%
4	4.2467	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV75 mile +WR20% +0sp		$11,452	100.0%
4	4.2468	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV100 mile +WR20% +0sp		$13,377	100.0%
4	4.2469	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV150 mile +WR20% +0sp		$18,306	100.0%
5	5.2465	20%	Auto 4VDV8 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV20 +WR20% +8sp	8sp DCT-wet	$13,945	73.9%
5	5.2466	20%	Auto 4VDV8 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV40 +WR20% +8sp	8sp DCT-wet	$17,726	83.4%
5	5.2467	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV75 mile +WR20% +0sp		$14,324	100.0%
5	5.2468	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV100 mile +WR20% +0sp		$16,200	100.0%

[I] Note, as noted above, the weight reduction of a technology package has no impact on the weight reduction allowed under our safety analysis, with the exception that it serves as an upper bound . The safety aspect to weight reduction is not dealt with in the package building process and is instead dealt with in the TEB-CEB process and OMEGA model itself. This is described in Chapter 3 of this RIA.

5	5.2469	[20%	+IACC1 +EPS +Aero2 +LRRT2 +EV150 mile +WR20% +0sp		$21,467	100.0%
6	6.2465	20%	Auto 4VDV8 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV20 +CCC +WR20% +8sp	8sp DCT-wet	$14,472	74.4%
6	6.2466	20%	Auto 4VDV8 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV40 +CCC +WR20% +8sp	8sp DCT-wet	$18,253	83.7%
6	6.2467	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV75 mile +WR20% +0sp		$14,263	100.0%
6	6.2468	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV100 mile +WR20% +0sp		$16,139	100.0%
6	6.2469	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV150 mile +WR20% +0sp		$21,406	100.0%
7	7.2465	20%	MPVnt 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV20 +WR20% +8sp	8sp DCT-dry	$10,255	73.0%
7	7.2466	20%	MPVnt 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV40 +WR20% +8sp	8sp DCT-dry	$12,665	82.9%
7	7.2467	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV75 mile +WR20% +0sp		$10,245	100.0%
7	7.2468	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV100 mile +WR20% +0sp		$12,403	100.0%
7	7.2469	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV150 mile +WR20% +0sp		$17,429	100.0%
13	13.2465	20%	SmT 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV20 +WR20% +8sp	8sp DCT-dry	$10,342	73.0%
13	13.2466	20%	SmT 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV40 +WR20% +8sp	8sp DCT-dry	$12,751	82.9%
13	13.2467	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV75 mile +WR20% +0sp		$10,332	100.0%
13	13.2468	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV100 mile +WR20% +0sp		$12,490	100.0%
13	13.2469	20%	+IACC1 +EPS +Aero2 +LRRT2 +EV150 mile +WR20% +0sp		$17,515	100.0%

This master-set of packages was then ranked by TARF within vehicle type for each of MY 2016 (using MY 2016 costs and MY 2016 penetration caps), MY 2021 (using MY 2021 costs and MY 2021 penetration caps) and MY 2025 (using MY 2025 costs and MY 2025 penetration caps). This is done by first calculating the TARF of each package relative to the baseline package within a given vehicle type. The package with the best TARF is selected as OMEGA package #1 for that vehicle type. The remaining packages for the given vehicle type are then ranked again by TARF, this time relative to OMEGA package #1. The best package is selected as OMEGA package #2, etc. We have considered penetration caps in this TARF ranking process to ensure that the packages chosen by the ranking do not result in exceedance of the caps. As such, if package #2 contains a technology, for example HEG, but the penetration cap for HEG is, say 60%, then only 60% of the population of vehicles in the given vehicle type would be allowed to migrate to package #2 with the remaining 40% left in package #1. Importantly, the credits available to the package are included in this ranking process.[J] Table 1.3-6 presents 2008 baseline data used in the TARF ranking process. Table 1.3-7 presents a ranked-set of packages for vehicle type 3 for the 2025MY.

[J] We have included credits for aerodynamic treatments level 2, 12V stop-start, mild HEV and strong HEV but have not included any other off-cycle credits due to uncertainty.

Table 1.3-7 Lifetime VMT & Baseline CO_2 used for TARF Ranking Process

Vehicle Type	Description	Base engine	Car/ Truck [a]	2016MY Lifetime VMT	2021MY Lifetime VMT	2025MY Lifetime VMT	Base CO_2 (g/mi)[b]
1	Subcompact car I4	I4 DOHC 4v	C	198,065	203,913	208,775	239.8
2	Compact car I4	I4 DOHC 4v	C				254.3
3	Midsize car V6	V6 DOHC 4v	C				321.2
4	Midsize car V6	V6 SOHC 2v	C				332.7
5	Large car V8	V8 DOHC 4v	C				385.9
6	Large car V8	V8 OHV 2v	C				390.0
7	Small MPV I4	I4 DOHC 4v	C				296.6
8	Midsize MPV V6	V6 DOHC 4v	T	211,964	218,399	223,688	372.3
9	Midsize MPV V6	V6 SOHC 2v	T				412.2
10	Midsize MPV V6	V6 OHV 2v	T				372.0
11	Large MPV V8	V8 DOHC 4v	T				461.4
12	Large MPV V8	V8 OHV 2v	T				477.4
13	Small truck I4	I4 DOHC 4v	T				330.8
14	Full-sized Pickup truck V6	V6 DOHC 4v	T				403.1
15	Full-sized Pickup truck V6	V6 OHV 2v	T				420.9
16	Full-sized Pickup truck V8	V8 DOHC 4v	T				477.3
17	Full-sized Pickup truck V8	V8 SOHC 2v	T				455.5
18	Full-sized Pickup truck V8	V8 SOHC 3v	T				480.0
19	Full-sized Pickup truck V8	V8 OHV 2v	T				437.9

[a] Designation here matters only for lifetime VMT determination in the package building and ranking process.
[b] Sales weighted CO_2 within vehicle type.

Table 1.3-8 Ranked-set of Packages for the 2025MY for Vehicle Type 3 (midsize car V6 DOHC)

From Tech Pkg #	To Tech Pkg #	From Step #	To Step #	Engine	Trans	Weight Red	Cost	CO2 % Reduction
3.0000	3.0000		0	Auto 4VDV6		base	$0	0.0%
3.0000	3.0131	0	1	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +WR5% +6sp	6sp DCT-wet	5%	$822	29.8%
3.0131	3.0195	1	2	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero1 +LRRT1 +HEG +DCP +GDI +TDS18 +WR5% +6sp	6sp DCT-wet	5%	$1,070	36.8%
3.0195	3.0196	2	3	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS18 +WR5% +6sp	6sp DCT-wet	5%	$1,287	40.4%

3.0196	3.0388	3	4	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS18 +WR5% +8sp	8sp DCT-wet	5%	$1,402	42.3%
3.0388	3.0772	4	5	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS18 +WR10% +8sp	8sp DCT-wet	10%	$1,519	43.9%
3.0772	3.0804	5	6	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS24 +WR10% +8sp	8sp DCT-wet	10%	$1,733	45.7%
3.0804	3.0836	6	7	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS24 +EGR +WR10% +8sp	8sp DCT-wet	10%	$1,982	47.7%
3.0772	3.1156	5	8	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS18 +WR15% +8sp	8sp DCT-wet	15%	$1,745	45.5%
3.0836	3.1220	7	9	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS24 +EGR +WR15% +8sp	8sp DCT-wet	15%	$2,209	49.2%
3.1156	3.2004	8	10	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS18 +WR10% +8sp	8sp DCT-wet	10%	$2,722	50.2%
3.1220	3.2036	9	11	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR10% +8sp	8sp DCT-wet	10%	$3,185	53.6%
3.2004	3.2196	10	12	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS18 +WR15% +8sp	8sp DCT-wet	15%	$2,948	51.4%
3.1220	3.1604	9	13	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS24 +EGR +WR20% +8sp	8sp DCT-wet	20%	$2,506	50.7%
3.2036	3.2228	11	14	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR15% +8sp	8sp DCT-wet	15%	$3,412	54.7%
3.2196	3.2204	12	15	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS18 +WR15% +8sp	8sp DCT-wet	15%	$3,030	51.8%
3.2204	3.2467	15	16	+IACC1 +EPS +Aero2 +LRRT2 +EV75 mile +WR20% +0sp		20%	$11,451	100.0%
3.1604	3.2036	13	17	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR10% +8sp	8sp DCT-wet	10%	$3,185	53.6%
3.2036	3.2228	17	18	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR15% +8sp	8sp DCT-wet	15%	$3,412	54.7%
3.1604	3.1612	13	19	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +TDS24 +EGR +WR20% +8sp	8sp DCT-wet	20%	$2,814	51.2%
3.2228	3.2236	14	20	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR15% +8sp	8sp DCT-wet	15%	$3,494	55.1%
3.2228	3.2236	18	21	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR15% +8sp	8sp DCT-wet	15%	$3,494	55.1%
3.2204	3.2396	15	22	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS18 +WR20% +8sp	8sp DCT-wet	20%	$3,327	53.0%
3.1612	3.1628	19	23	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +SS +SAX +TDS24 +EGR +WR20% +8sp	8sp DCT-wet	20%	$2,896	51.5%
3.2236	3.2428	20	24	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR20% +8sp	8sp DCT-wet	20%	$3,791	56.2%
3.2236	3.2428	21	25	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR20% +8sp	8sp DCT-wet	20%	$3,791	56.2%
3.2396	3.2468	22	26	+IACC1 +EPS +Aero2 +LRRT2 +EV100 mile +WR20% +0sp		20%	$13,376	100.0%
3.1628	3.2020	23	27	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +WR10% +8sp	8sp DCT-wet	10%	$2,936	51.9%

3.2020	3.2036	27	28	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR10% +8sp	8sp DCT-wet	10%	$3,185	53.6%
3.2036	3.2228	28	29	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR15% +8sp	8sp DCT-wet	15%	$3,412	54.7%
3.2228	3.2236	29	30	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR15% +8sp	8sp DCT-wet	15%	$3,494	55.1%
3.2236	3.2428	30	31	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR20% +8sp	8sp DCT-wet	20%	$3,791	56.2%
3.2396	3.2400	22	32	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +MHEV +SAX +TDS18 +WR20% +8sp	8sp DCT-wet	20%	$3,461	53.4%
3.1628	3.2469	23	33	+IACC1 +EPS +Aero2 +LRRT2 +EV150 mile +WR20% +0sp		20%	$18,306	100.0%
3.2400	3.2220	32	34	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +WR15% +8sp	8sp DCT-wet	15%	$3,245	53.4%
3.2220	3.2036	34	35	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR10% +8sp	8sp DCT-wet	10%	$3,185	53.6%
3.2036	3.2228	35	36	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR15% +8sp	8sp DCT-wet	15%	$3,412	54.7%
3.2228	3.2236	36	37	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR15% +8sp	8sp DCT-wet	15%	$3,494	55.1%
3.2236	3.2428	37	38	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR20% +8sp	8sp DCT-wet	20%	$3,791	56.2%
3.1628	3.2466	23	39	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV40 +WR20% +8sp	8sp DCT-wet	20%	$13,534	83.8%
3.2400	3.2220	32	40	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +WR15% +8sp	8sp DCT-wet	15%	$3,245	53.4%
3.2220	3.2036	40	41	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR10% +8sp	8sp DCT-wet	10%	$3,185	53.6%
3.2036	3.2228	41	42	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +TDS24 +EGR +WR15% +8sp	8sp DCT-wet	15%	$3,412	54.7%
3.2228	3.2236	42	43	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR15% +8sp	8sp DCT-wet	15%	$3,494	55.1%
3.2236	3.2428	43	44	Auto 4VDI4 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +MHEV +SAX +TDS24 +EGR +WR20% +8sp	8sp DCT-wet	20%	$3,791	56.2%
3.1628	3.2465	23	45	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +ATKCS +REEV20 +WR20% +8sp	8sp DCT-wet	20%	$11,047	74.3%
3.2428	3.1680	24	46	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +HEV +SAX +ATKCS +WR20% +8sp	8sp DCT-wet	20%	$5,156	57.3%
3.2428	3.1680	25	47	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +HEV +SAX +ATKCS +WR20% +8sp	8sp DCT-wet	20%	$5,156	57.3%
3.2428	3.1680	31	48	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +HEV +SAX +ATKCS +WR20% +8sp	8sp DCT-wet	20%	$5,156	57.3%
3.2428	3.1680	38	49	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +HEV +SAX +ATKCS +WR20% +8sp	8sp DCT-wet	20%	$5,156	57.3%
3.2428	3.1680	44	50	Auto 4VDV6 +EFR2 +ASL2 +LDB +IACC1 +EPS +Aero2 +LRRT2 +HEG +DCP +DVVL +GDI +HEV +SAX +ATKCS +WR20% +8sp	8sp DCT-wet	20%	$5,156	57.3%

Note that the packages shown in Table 1.3-7 do not always flow from a given package to the next package listed. For example, step 8 actually comes from step 5 rather than from step 7. As such, within OMEGA, the incremental cost for step 8 would be the cost for step 8 less the cost for step 5, or \$1745-\$1519=\$227, and the incremental effectiveness improvement would be 45.5%-43.9%=1.6%. A similar table could be shown for each of the 19 vehicle types. We have placed in the docket a compact disk containing all of the ranked-sets of packages used for our analysis.[5]

The end result of this ranking is a ranked-set of up to 50 OMEGA packages for each vehicle type that includes the package progression that OMEGA must follow when determining which package to employ next. The package progression is key because OMEGA evaluates each package in a one-by-one, or linear progression. The packages must be ordered correctly so that no single package will prevent the evaluation of the other packages. For example, if we simply listed packages according to increasing effectiveness, there could well be a situation where an HEV with higher effectiveness and a better TARF than a turbocharged and downsized package with a poor TARF could never be chosen because the turbocharged and downsized package, having a poor TARF, would never get chosen and would effectively block the HEV from consideration. For that reason, it is important to first rank by TARF so that the proper package progression can be determined. These ranked-sets of packages are reformatted and used as Technology Input Files for the OMEGA model.

1.4 Use of the Lumped Parameter Approach in Determining Package Effectiveness

1.4.1 Background

While estimating the GHG and fuel consumption reduction effectiveness of individual vehicle technologies can often be confirmed with existing experimental and field data, it is more challenging to predict the combined effectiveness of multiple technologies for a future vehicle. In 2002 the National Research Council published "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards[6]." It was one of the first and most authoritative analyses of potential fuel consumption-reducing technologies available to future light-duty vehicles, and is still widely referenced to this day. However, it was criticized for not fully accounting for system interactions ("synergies") between combinations of multiple engine, transmission and vehicle technologies that could reduce the overall package effectiveness.

Comments to the 2002 NRC report recommended the use of a more sophisticated method to account for vehicle technology package synergies – that of detailed, physics-based vehicle simulation modeling. This method simulates the function of a vehicle by physically modeling and linking all of the key components in a vehicle (engine, transmission, accessory drive, road loads, test cycle speed schedule, etc) and requires an intricate knowledge of the inputs that define those components. If the inputs are well-defined and plausible, it is generally accepted as the most accurate method for estimating future vehicle fuel efficiency.

In one of the most thorough technical responses to the NRC report, Patton et al[7] critiqued the overestimation of potential benefits of NRC's "Path 2" and "Path 3" technology packages. They presented a vehicle energy balance analysis to highlight the synergies that arise with the combination of multiple vehicle technologies. The report then demonstrated an alternative methodology (to vehicle simulation) to estimate these synergies, by means of a "lumped parameter" approach. This approach served as the basis for EPA's lumped parameter model. The lumped parameter model was created for the MYs 2012-2016 light duty vehicle GHG and CAFE standards, and has been improved to reflect updates required for the final MYs 2017-2025 light duty GHG rule.

1.4.2 Role of the model

It is widely acknowledged that full-scale physics-based vehicle simulation modeling is the most thorough approach for estimating future benefits of a package of new technologies. This is especially important for quantifying the efficiency of technologies and groupings (or packages) of technologies that do not currently exist in the fleet or as prototypes. However, developing and running detailed vehicle simulations is very time and resource-intensive, and generally not practical to implement over a large number of vehicle technology packages (in our case, hundreds). As part of rulemakings EPA analyzes a wide array of potential technology options rather than attempt to pre-select the "best" solutions. For example, in analysis for the MYs 2012-2016 Light Duty Vehicle GHG rule[8], EPA built over 140 packages for use in its OMEGA compliance model, which spanned 19 vehicle classes and over 1100 vehicle models; for this rulemaking the number of packages has increased by another order of magnitude over the previous rule. The lumped parameter approach was chosen as the most practical surrogate to estimate the package effectiveness (including synergies) of many technology combinations. However, vehicle simulation modeling was a key part of the process to ensure that the lumped parameter model was thoroughly validated. An overview of the vehicle simulation study (conducted by Ricardo, PLC) for this rulemaking is provided in Section 3.3.1 of the Joint TSD. Additional details can be found in the project report[9].

1.4.3 Overview of the lumped parameter model

The basis for EPA's lumped parameter analysis is a first-principles energy balance that estimates the manner in which the chemical energy of the fuel is converted into various forms of thermal and mechanical energy on the vehicle. The analysis accounts for the dissipation of energy into the different categories of energy losses, including each of the following:

- Second law losses (thermodynamic losses inherent in the combustion of fuel),
- Heat lost from the combustion process to the exhaust and coolant,
- Pumping losses, i.e., work performed by the engine during the intake and exhaust strokes,
- Friction losses in the engine,

- Transmission losses, associated with friction and other parasitic losses of the gearbox, torque converter (when applicable) and driveline

- Accessory losses, related directly to the parasitics associated with the engine accessories,

- Vehicle road load (tire and aerodynamic) losses;

- Inertial losses (energy dissipated as heat in the brakes)

The remaining energy is available to propel the vehicle. It is assumed that the baseline vehicle has a fixed percentage of fuel lost to each category. Each technology is grouped into the major types of engine loss categories it reduces. In this way, interactions between multiple technologies that are applied to the vehicle may be determined. When a technology is applied, the lumped parameter model estimates its effects by modifying the appropriate loss categories by a given percentage. Then, each subsequent technology that reduces the losses in an already improved category has less of a potential impact than it would if applied on its own.

Using a lumped parameter approach for calculating package effectiveness provides necessary grounding to physical principles. Due to the mathematical structure of the model, it naturally limits the maximum effectiveness achievable for a family of similar technologies[K]. This can prove useful when computer-simulated packages are compared to a "theoretical limit" as a plausibility check. Additionally, the reduction of certain energy loss categories directly impacts the effects on others. For example, as mass is reduced the benefits of brake energy recovery decreases because there is not as much inertia energy to recapture.

Figure 1.4-1 is an example spreadsheet used by EPA to estimate the package effectiveness and the synergistic impacts of a technology package for a standard-size car.

[K] For example, if only 4% of fuel energy is lost (in a baseline engine) to pumping work, leveraging multiple technologies to theoretically eliminate all pumping losses would yield an aggregate reduction of no more than 15% in fuel consumption.

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Evaluate New Package

Reset LP Model

Vehicle Energy Effects Estimator

Vehicle Type	Rated Power		Rated Torque		ETW		50mph RL		Package Notes
Standard car	158	hp	161	ft-lb	3625	lb	11.3	hp	12V Stop-Start
	0		0		0		0.0		Stoich GDI Turbo

	Mass Braking / Inertia	Drag Aero Load	Tires Rolling Load	Gearbox, T.C. Trans Losses	Access Losses	Friction Losses	Pumping Losses	Heat Lost To Exhaust & Coolant Ind Eff Losses	Irreversibilities, etc. Second Law	Check
(Gross Indicated Energy / Brake Energy / Road Loads / Total Engine Friction)										
% of tractive energy	23%	37%	40%							
Baseline % of fuel	4.0%	6.4%	6.9%	4.2%	1.3%	7.9%	5.3%	34.0%	30.0%	100.0%
Reduction	0%	8%	7%	22.3%	41.7%	15.4%	81.2%		n/a	OK
% of NEW fuel	4.0%	5.9%	6.5%	4.4%	0.8%	7.1%	1.0%	32.0%	30%	
Road load kWh	0.47	0.71	0.77							

	Indicated Efficiency	Mech Efficiency	Brake Efficiency	Drivetrain Efficiency	Cycle Efficiency	Fuel Efficiency	Road Loads
2008 Baseline	36.0%	59.6%	21.5%	80.6%	100.0%	17.3%	100.0%
New	38.0%	76.5%	29.0%	84.9%	100.0%	24.7%	94.2%

2008 Ricardo baseline values		includes some techs
Fuel Economy	32.0	mpg (combined)
Fuel Consumption	0.031	gal/mi
GHG emissions	284	g/mi CO2E
Regressed baseline values		assumes no techs
req'd fuel energy	11.95	kWh
fuel economy	30.4	mpg (unadj)
fuel consumption	0.033	gal/mi
GHG emissions	299	g/mi CO2E
Current package values		
fuel economy	46.03	mpg (unadj)
fuel consumption	0.022	gal/mi
GHG emissions	197	g/mi CO2E

Tractive 1.95
Original friction/brake ratio
Based on PMEP/IMEP >>>>
(GM study)

PMEP Losses	Brake Efficiency
11%	25%

=71.1% mech efficiency

Current Results	
66.1%	Fuel Consumption (GGE/mile)
33.9%	**FC Reduction vs no-techs**
51.2%	FE Improvement (mpgge)
51.2%	FE Improvement (mpg)
30.5%	GHG reduction vs 2008 Ricardo baseline
33.9%	GHG reduction vs no-techs

Technology	**Independent FC Estimate***		**Loss Category**	**Implementation into estimator**	% or Level	**User Picklist Include? (0/1)**	**Dev status**	
Vehicle mass reduction	5-6%	per 10%	Braking/stopped, inertia, rolling resistance		0%	0		
Aero Drag Reduction	2.1%	per 10%	Aero	14.4% aero (cars), 9.5% aero (truc	10%	1		
Rolling Resistance Reduction	1.5%		Rolling	9.5% rolling	10%	1		
Low Fric Lubes	0.5%		Friction	2% friction		0		
EF Reduction			Friction	**variable% friction**	1	1		
4V on 2V Baseline	3.0%		Pumping, friction	20.5% pumping, -2.5% fric		0		
ICP	2.0%		Pumping	13.5% pumping, +0.2% IE, -3.5% fric		0		Pick one max
DCP	4.0%	total VVT	Pumping	23.5% pumping, +0.2% IE, -2.5% fric		1		
CCP	4.0%	total VVT	Pumping	23.5% pumping, +0.2% IE, -2.5% fric		0		
Deac	6.0%		Pumping, friction	**30%** pumping, -2.5% frict		0		Pick one max
DVVL	4.0%		Pumping	27% pumping, -3% friction	0%	1		
CVVL	5.0%		Pumping	33% pumping, -3% friction		0		
Turbo/Downsize (gas engines only)			Pumping	**variable IE ratio, P, F**	35%	1		
5-spd gearbox	2.5%		Pumping	**6%** pumping		0		Pick one
6-spd gearbox	5.5%		Pumping	**8%** pumping, +0.1% IE		0		
8-spd gearbox			Pumping	15% pumping, 13% trans, +0.5% IE		1		
CVT	6.0%		Trans, pumping	**41%** pumping, -5% trans		0		
DCT Wet	6.7%		Trans	21% trans (increment)		0		Additive to trans; Included in P2
DCT Dry	10.0%		Trans	25% trans (increment)		0		
Early upshift (formerly **ASL**)	2.0%		Pumping	**10.5%** pumping		0		Pick one max
Optimized shift strategy	5.5%		Pumping, IE, friction	11% pumping, 11% frict, +0.1% IE		1		
Agg TC Lockup	0.5%		Trans	2% trans		1		
High efficiency gearbox (auto)			Trans	variable % Trans	7%	1		
12V SS (idle off only)	2.0%		P,F,trans	3% pumping, 3% friction, 2% trans		1		Pick one max
High voltage SS, with launch (BAS)	7.5%		B/I, P, F, trans	11% B/I, 3% P, 3% F, 2% trans		0		
Alternator regen on braking	**2.0%**		Access	**10% pumping**		1		included in 12V SS
EPS	2.0%		Access	**22%** access	100%	1		included in BAS, hybı
Electric access (12V)	1.5%		Access	12% access		1		Pick one max
Electric access (high V)	3.0%		Access	42% access		0		
High efficiency alternator (70%)			Access	**15% access**		1		included in BAS
GDI (stoich)	1.5%		Ind Eff	+ 0.55% IE		1		Pick one max
GDI (stoich) w/ cooled EGR				+1.9% IE, 41% pumping		0		
GDI (lean)			Ind. Eff, pumping	+1.3% IE, 41% pumping		0		
Diesel - LNT (2008)	30.0%		Ind Eff, P, F, trans	see comment		0		
Diesel - SCR (2008)	35.0%		Ind Eff, P, F, trans	see comment	Motor kW	0		
Hybrid drivetrain (need to select transmission style!)			Inertia, trans, acc IE, F, P		0	0		
Secondary axle disconnect	1.3%		Trans	6% trans		0		
Low drag brakes	0.8%		Braking/inertia	3.5% B/I		0		
Atkinson cycle engine			Ind. Eff, - pumping	+6% IE, -30% pumping		0		
Advanced Diesel (2020)			Ind Eff, P, F, trans	see comment		0		
Plug-In				%EV=	50%	0		

Figure 1.4-1 Sample lumped parameter model spreadsheet

The LP model has been updated from the MYs 2012-2016 final rule to support the MYs 2017-2025 standards. Changes were made to include new technologies for 2017 and beyond, improve fidelity for baseline attributes and technologies, and better represent hybrids based on more comprehensive vehicle simulation modeling. Section 1.5 provides details of the methodology used to update and refine the model.

1.5 Lumped Parameter Model Methodology

1.5.1 Changes to the LP model for the final rulemaking

The LP model was updated in conjunction with this rulemaking to provide more flexibility to assess package effectiveness, to incorporate new technologies not previously analyzed, and to improve the calculation methodology in an effort to increase calibration accuracy with respect to the supporting vehicle simulation data.

Flexibility was added in several ways. First, the model now provides the user with the capability of estimating package effectiveness for multiple vehicle classes. Second, several compound technologies in the MYs 2012-2016 rulemaking version have been "deconstructed" into separate components so that there is more flexibility in adding different technology combinations. The most visible example of that is in the new model's treatment of hybrids. In the last generation LP model, a hybrid vehicle package served as a technology in and of itself – irrespective of engine type, ancillary technologies or road load reductions. In the latest version the LP model offers a "hybrid drivetrain" technology which can be combined with any engine technology and subset of road load reductions (e.g., mass reduction, rolling resistance and aerodynamic drag reductions) and other technologies. In this way, there is more resolution and effectiveness distinction between the many combinations of technologies on hybrids.

The LP model also added new technologies, most stemming from the 2011 Ricardo simulation project, which included multiple steps of transmission shift logic, more mechanically efficient transmissions ("gearboxes"), alternator technologies, an Atkinson-cycle engine for hybrids, highly downsized and turbocharged engines including lean-burn and cooled EGR options, and stop-start (idle-off without launch assist). The effectiveness of some of these technologies vary based on additional required user inputs. For example, turbocharging and downsizing effectiveness is now based on a percentage of displacement reduction, and hybrid effectiveness is tied to electric motor size.

EPA revisited the calculation methodology of the model with more rigor. Through more detailed analysis of simulation data, physical trends became more apparent, such as:

- the relationship between mass reduction and rolling resistance – naturally, as vehicle weight decreases, the normal force on the tires decreases, and should reduce rolling resistance

- Reduced road loads (with other variables held constant) changed the required tractive forces and usually resulted in reduced engine efficiency.

- For hybrids, mass reduction was synergistic with the hybrid drivetrain, as there was less recoverable braking energy with a lighter vehicle.

All of these trends were identified through the analysis of the simulation data and performance metrics (detailed further in the Joint TSD, Section 3.3.1), and were incorporated during the development of the model.

1.5.2 Development of the model

The LP model must be flexible in accommodating a wide variety of possible vehicle and technology package combinations and also must reasonably reflect the physical system effects of each technology added to a vehicle. Finally, its outputs must be well calibrated to the existing vehicle simulation results for it to serve as a reliable tool for use in generating OMEGA model inputs. To properly build the LP model with all of these requirements in mind, several steps were needed:

- Develop a baseline energy loss distribution for each vehicle class
- Calibrate baseline fuel economy for each vehicle class based on simulation and vehicle certification data
- Add technologies to the model and identify the significant loss categories that each applied technology affects, and
- Assign numerical loss category modifiers for each individual technology to achieve the estimated independent effectiveness
- Calibrate LP technology package effectiveness with simulation results

1.5.3 Baseline loss categories

In 2007, EPA contracted with PQA, who subcontracted Ricardo, LLC to conduct a vehicle simulation modeling project in support of the MYs 2012-2016 light-duty vehicle GHG rule. Further simulation work was conducted by Ricardo from 2010-2011 to support EPA's analysis for the MYs 2017-2025 vehicle GHG rule. In both projects, Ricardo built versions of its EASY5 and WAVE models to generate overall vehicle package GHG reduction effectiveness results and corresponding 10-hz output files of the intermediate data. EPA's detailed analysis of the Ricardo 2008 and 2010 baseline[L] vehicle simulation output files for the FTP and HWFE test cycles helped quantify the distribution of fuel energy losses

[L] The 2008 baseline vehicles are those originally used in the 2008 Ricardo simulation project and represent actual vehicles in production. The 2010 "baseline" vehicles (from the 2011 Ricardo report) have additional content including stop-start, improved alternator with regenerative capability, and a six-speed automatic transmission. For more information reference the Joint TSD, Section 3.3.1.8.

in the baseline LP model. City/highway combined cycle average data were obtained for brake efficiency, torque converter and driveline efficiencies, accessory losses, and wheel (tractive) energy. These values were regressed against basic vehicle parameters (power, weight, etc) to generate curve fits for the baseline vehicle category attributes.

The distribution of energy loss categories in the baseline vehicle were estimated as follows:

- Indicated efficiency was assumed at a combined test cycle average of 36% for all vehicles[M]

- Baseline engine brake efficiency was estimated as a function of (ETW, road load, engine torque, and alternator regeneration or "regen"). These inputs were used in a linear regression, shown in Figure 1.5-1, which fits the 2008 and 2010 Ricardo baseline data from the output summaries.

Regression data used - net engine brake efficiency

	Vehicle	Power	Torque	ETW	50mph RL	Alt regen	Net BE%	predicted	% error
2008 baselines	Camry	154	**160**	**3625**	**11.33**	0	**21.5%**	**21.5%**	0.1%
	Vue	169	**161**	**4000**	**15.08**	0	**24.0%**	**23.7%**	1.3%
	Caravan	205	**240**	**4500**	**15.84**	0	**21.2%**	**21.7%**	**2.3%**
	300	250	**250**	**4000**	**14.78**	0	**21.3%**	**21.0%**	1.3%
	F-150	300	**365**	**6000**	**22.86**	0	**21.8%**	**21.9%**	0.5%
2010 baselines	Yaris	106	**103**	**2625**	**10.82**	1	**25.0%**	**25.3%**	1.3%
	Camry	158	**161**	**3625**	**11.33**	1	**23.8%**	**23.5%**	1.3%
	Vue	169	**161**	**4000**	**15.08**	1	**25.8%**	**25.7%**	0.5%
	Caravan	205	**240**	**4500**	**15.84**	1	**23.1%**	**23.7%**	**2.3%**
	300	250	**250**	**4000**	**14.78**	1	**23.2%**	**23.0%**	0.9%
	F-150	300	**365**	**6000**	**22.86**	1	**24.0%**	**23.9%**	0.8%
								avg error	1.1%

	Coefficients
Intercept	0.207831
Torque	-0.00028
ETW	-6.2E-06
50mph RL	0.006531
Alt regen	0.019809

Figure 1.5-1 Regression data used to establish engine brake efficiency formula

- Pumping and friction losses are scaled based on the difference between (brake efficiency + accessory losses) and indicated efficiency. The distribution of pumping and friction losses was based on a combination of literature (Patton, Heywood[10]) and prior success with values used in the LP model for the MYs 2012-2016 rule. It is assumed that pumping and friction losses for fixed valve, naturally aspirated engines, distributed over the test cycles, average roughly 60% and 40% of total friction, respectively.

- Accessory loss (as % of total fuel) is based on a regression of engine torque and ETW, and comes directly from Ricardo output file data.

- Baseline driveline losses are estimated in the following manner:

[M] Indicated efficiency data was not included as an output in the Ricardo model. Very little data on indicated efficiency exists in the literature. The value of 36% was assumed because it fits fairly well within the LP model, and it is comparable to the few values presented in the Patton paper.

a) Torque converter efficiency, which is a function of (engine torque/power ratio, RL and ETW)

b) Transmission efficiency, which is calculated at 87% for 2008 vehicles (based on the average gear efficiency values used by Ricardo in the baseline models) For 4WD vehicles a multiplier of 96.2% is applied to represent the rear axle efficiency

c) Losses through the TC and transmission are then determined and added to represent driveline losses as the total % of fuel energy lost.

- Baseline tractive wheel energy (the energy delivered to the wheels to actually move the vehicle) is a simple relationship of ETW and road load.

- The remaining terms (braking losses, inertia load, aero load, and rolling load) make up the remainder of the losses and are proportioned similarly to the original LP model.

Reference the “input page” tab in the LP model to see the breakdown for each predefined vehicle class[N].

1.5.4 Baseline fuel efficiency by vehicle class

The new LP model estimates the basic fuel energy consumption, E_{fuel}, for an “unimproved” vehicle (naturally aspirated fixed valve engine with 4 speed automatic transmission). It is calculated for each vehicle class with Equation 1.5-1:

$$E_{fuel} = \frac{E_{wheel}}{\eta_{engine} \times \eta_{D/L}}$$

Equation 1.5-1

To estimate the terms in the above equation, EPA regressed several known vehicle parameters (rated engine power, rated engine torque, ETW, RL (chassis dyno road load at 50 mph)) against simulation output data. Definitions for each term and the relevant parameters are listed below:

[N] For the “custom” vehicle class, values were regressed based on the following inputs: rated engine power, torque, vehicle weight (ETW) and road load, in hp, at 50 mph (from certification data). Note that the defined vehicle classes were validated by simulation work, while the custom vehicle data was not validated – it is for illustrative purposes and represents a rougher estimate

1) E_{wheel}: required wheel (or tractive) energy over the city/HW test cycle = f(ETW, RL)
2) η_{engine}: net engine brake efficiency = f(torque, ETW, RL, alternator regen[O])
3) $\eta_{D/L}$: driveline efficiency is derived from the losses associated with the torque converter, transmission, and final drive, where TC losses = f(torque, power, RL, ETW) and transmission efficiency is based on vintage of the baseline[P]

E_{fuel} (kWh) was then converted to fuel economy in mpg by applying the energy content of gasoline (assumed at 33.7 kWh/gallon – for diesel it is 37.6 kWh/gallon) and factoring in the distance traveled (10.64 miles) over the combined FTP/HWFE test cycle.

The LP model predicted baseline fuel economy for each class was then validated to 2008 baseline vehicle simulation results. Baseline unimproved vehicle FE values were first estimated with the regression as mentioned above. From there, all other technologies consistent with the 2008 Ricardo modeled baseline packages were added. Similarly, the following technologies were added to the 2008 vehicles for comparison to the 2010 Ricardo "baseline" packages: 6-speed automatic transmission, higher efficiency gearbox, 12V SS, alternator regeneration during coastdowns, and 70% efficient alternator. The predicted LP fuel economy values of both the 2008 baseline and 2010 vehicles all fall within roughly 2% of the modeled data, as shown in Figure 1.5-2 below.

Vehicle Class	Trans	EPS	Valvetrain	2008 simulated comb. mpg	2008 LP model comb. mpg	% FE error	2010 simulated comb. mpg	2010 LP model comb. mpg	% FE error
Small car	4 spd auto	Y	ICP	41.5	41.3	-0.5%	43.4	44.1	1.7%
Standard car	5 spd auto	N	DCP	32.0	32.3	0.9%	34.9	34.7	-0.6%
Large car	5 spd auto	N	fixed	25.5	25.2	-1.0%	27.4	27.3	-0.4%
Small MPV	4 spd auto	Y	DCP	28.8	29.1	1.1%	30.5	31.1	2.0%
Large MPV	4 spd auto	N	fixed	23.1	23.7	2.4%	25.2	25.9	2.6%
Truck	4 spd auto	N	CCP	17.6	17.4	-1.1%	18.6	18.6	-0.1%

2010 packages add 6spd auto trans, higher efficiency gearbox, 12V SS, alternator regen on decel, 70% efficient alternator

Figure 1.5-2 Comparison of LP model to Ricardo simulation results for 2008 and 2010 baseline vehicles

[O] When the alternator regeneration technology is included, it changes the efficiency of the engine by moving the average speed and load to a more efficient operating region. It was included in the definition of the 2010 baseline vehicle models.
[P] Two levels of baseline transmission efficiency were included in the simulation work, for 2008 baselines and 2010 baselines ("vintage"). Refer to the Input Page tab in the LP model for more detail.

1.5.5 Identification and calibration of individual technologies

The next step was to identify the individual technologies of interest and categorize how they affect the physical system of the vehicle. Engineering judgment was used in identifying the major loss categories that each individual LP model technology affected. In some cases two or even three, loss categories were defined that were deemed significant. Not all categories were a reduction in losses – some increased the amount of losses (for example, increased frictional losses for various valvetrain technologies). A list of the technologies and the categories they affect is shown in Figure 1.5-3 below. The technologies added for this rule's version of the LP model are highlighted in bold. For a more detailed description of each technology, refer to Section 3.4 of the Joint TSD.

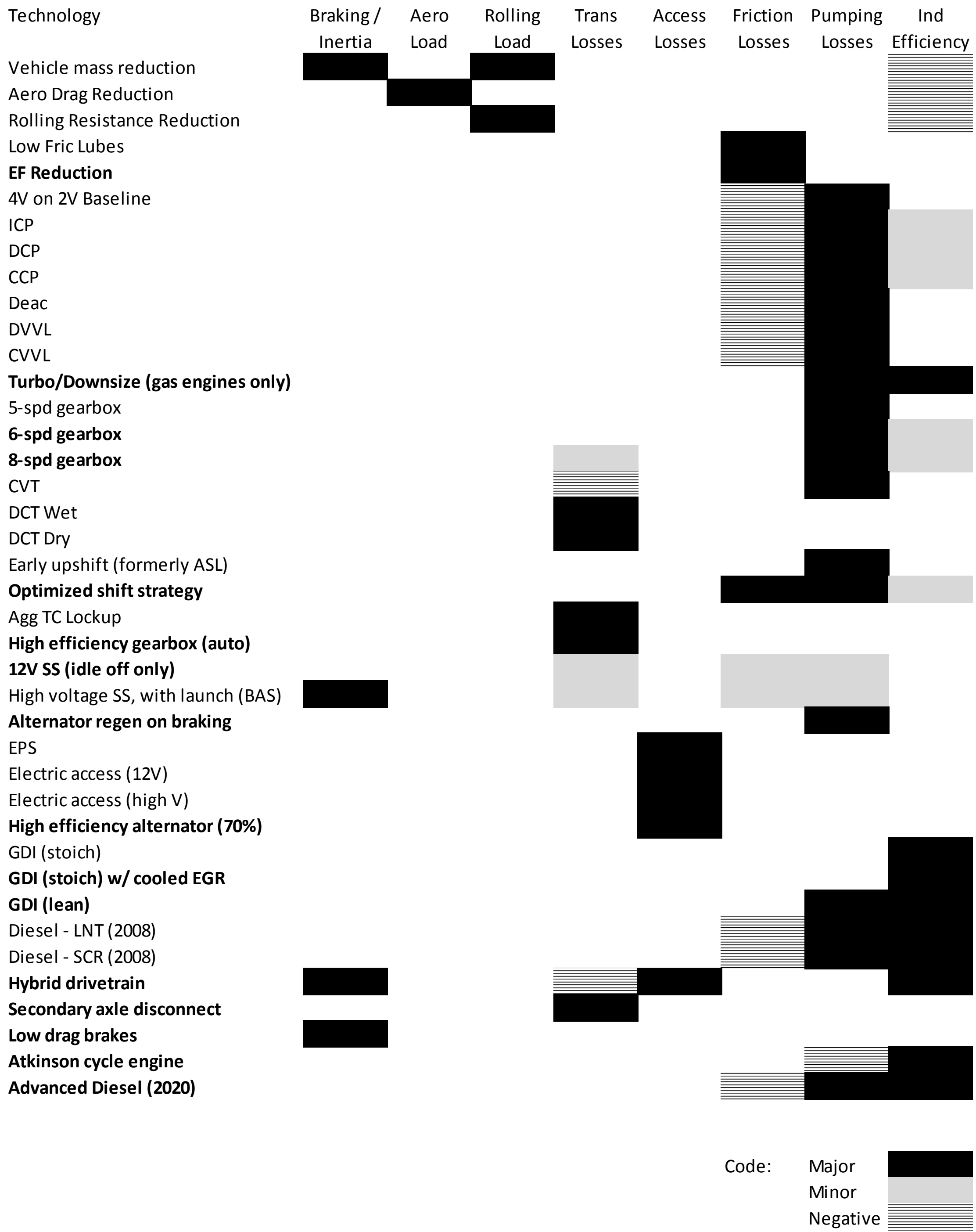

Figure 1.5-3 Loss categories affected by each technology

After losses were identified, EPA calibrated the loss modifiers so that each individual technology would achieve a nominal effectiveness independent of other technologies and consistent with the values given in Section 1.2. For example, discrete variable valve lift (DVVL) can achieve roughly a 4-5% decrease in GHG emissions. It is coded in the LP model as a 27% reduction in pumping losses and a 3% increase (penalty) in friction losses. Depending on the vehicle class, it reflects an effectiveness ranging from 4.1-5.6% reduction in the LP model. Other technologies were coded in the LP model in similar fashion. In cases where more than one loss category was affected, the majority of the effectiveness was linked to the primary loss category, with the remainder of the effectiveness coded via the other secondary loss categories. In some cases the LP model also reflects loss categories that are penalized with certain technologies – for example, the increased mechanical friction associated with advanced variable valvetrains (coded as a negative reduction in the LP model). All technologies were calibrated on an "unimproved" vehicle (without any other technologies present) to avoid any synergies from being accidentally incorporated. Once the entire list of line-item technologies was coded, the next step was to compare the effectiveness of actual (Ricardo-modeled) vehicle simulation packages to the LP model results.

1.5.6 Example build-up of LP package

The following example package for a Large Car demonstrates how synergies build as content is added to a vehicle technology package.

505	4V DOHC I4 +EFR2 +LDB +ASL2 +IACC2 +EPS +Aero2 +LRRT2 +HEG +DCP +GDI +TDS18	8sp DCT-wet	12V	5%	$1,386	42.6%

- Add anytime technologies (EFR2, LDB, ASL2, IACC2, EPS)

These technologies primarily reduce accessory loads, mechanical engine friction and pumping losses. The sum of these technologies is reflected below in Table 1.5-1[Q] and provides a total of 14.9% reduction in GHG.

Table 1.5-1

	Braking / Inertia	Aero Load	Rolling Load	Trans Losses	Access Losses	Friction Losses	Pumping Losses	Ind Eff Losses	Second Law
% of tractive energy	23%	37%	40%						
Baseline % of fuel	3.9%	6.4%	6.9%	3.9%	1.1%	8.3%	5.6%	34.0%	30.0%
Reduction	**4%**	0%	0%	0%	**42%**	**22%**	**20%**		n/a
% of NEW fuel	3.8%	6.4%	6.9%	4.5%	0.6%	6.5%	4.5%	33.9%	30%

	Indicated Efficiency	Mech Efficiency	Brake Efficiency	Drivetrain Efficiency	Cycle Efficiency	Fuel Efficiency	Road Loads		
2008 Baseline	36.0%	58.4%	21.0%	81.6%	100.0%	17.1%	100.0%	85.1%	Fuel Consumption
New	36.1%	67.9%	24.5%	81.6%	100.0%	20.0%	99.2%	**14.9%**	**GHG reduction**

[Q] For this table and similar subsequent tables, the "Reduction" row refers to the percentage reduction in fuel energy for each particular loss category. Each values in that row does **not** translate into an absolute percentage GHG savings, but are listed as indices between 0% (no reduction) and 100% (maximum theoretical reduction) for each loss category. For example, in Table 1.5-1, roughly 42% of theoretical accessory losses have been eliminated associated with the applied anytime technologies.

- Add road load reductions (Aero2, LRRT2) and 5% mass reduction

These technologies reduce braking/inertia, aerodynamic and rolling resistance loads, with a minor degradation in indicated efficiency (because the engine is running at lower overall loads). Combined with the technologies previously added in 1), the sum of these technologies is shown below in Table 1.5-2 and provides a total of 24.5% reduction in GHG compared to an unimproved vehicle.

Table 1.5-2

	Braking / Inertia	Aero Load	Rolling Load	Trans Losses	Access Losses	Friction Losses	Pumping Losses	Ind Eff Losses	Second Law
% of tractive energy	23%	37%	40%						
Baseline % of fuel	3.9%	6.4%	6.9%	3.9%	1.1%	8.3%	5.6%	34.0%	30.0%
Reduction	**8%**	**17%**	**18%**	0%	42%	22%	20%		n/a
% of NEW fuel	3.6%	5.3%	5.6%	4.3%	0.6%	6.2%	4.3%	35.3%	30%

	Indicated Efficiency	Mech Efficiency	Brake Efficiency	Drivetrain Efficiency	Cycle Efficiency	Fuel Efficiency	Road Loads		
2008 Baseline	36.0%	58.4%	21.0%	81.6%	100.0%	17.1%	100.0%	75.5%	Fuel Consumption
New	34.7%	67.9%	23.6%	81.6%	100.0%	19.2%	84.8%	**24.5%**	**GHG reduction**

- Add high efficiency gearbox

The high efficiency gearbox reduces transmission (driveline) losses due to the mechanical improvements as described in Section 3.4.2.4 of the Joint TSD. Combined with the technologies previously added, the sum of these technologies is shown below in Table 1.5-3 and provides a total of 28.5% reduction in GHG compared to an unimproved vehicle.

Table 1.5-3

	Braking / Inertia	Aero Load	Rolling Load	Trans Losses	Access Losses	Friction Losses	Pumping Losses	Ind Eff Losses	Second Law
% of tractive energy	23%	37%	40%						
Baseline % of fuel	3.9%	6.4%	6.9%	3.9%	1.1%	8.3%	5.6%	34.0%	30.0%
Reduction	8%	17%	18%	**25%**	42%	22%	20%		n/a
% of NEW fuel	3.6%	5.3%	5.6%	3.3%	0.6%	6.2%	4.3%	35.3%	30%

	Indicated Efficiency	Mech Efficiency	Brake Efficiency	Drivetrain Efficiency	Cycle Efficiency	Fuel Efficiency	Road Loads		
2008 Baseline	36.0%	58.4%	21.0%	81.6%	100.0%	17.1%	100.0%	71.5%	Fuel Consumption
New	34.7%	67.9%	23.6%	86.2%	100.0%	20.3%	84.8%	**28.5%**	**GHG reduction**

- Add dual cam phasing

Dual cam phasing provides significant pumping loss reductions at the expense of increased mechanical friction due to the more complex valvetrain demands (as a result, the "friction loss" reduction value below is actually reduced). Combined with the technologies previously added, the sum of these technologies is shown below in Table 1.5-4 and provides a total of 31.4% reduction in GHG compared to an unimproved vehicle.

Table 1.5-4

	Braking / Inertia	Aero Load	Rolling Load	Trans Losses	Access Losses	Friction Losses	Pumping Losses	Ind Eff Losses	Second Law
% of tractive energy	23%	37%	40%						
Baseline % of fuel	3.9%	6.4%	6.9%	3.9%	1.1%	8.3%	5.6%	34.0%	30.0%
Reduction	8%	17%	18%	25%	42%	**20%**	**39%**		n/a
% of NEW fuel	3.6%	5.3%	5.6%	3.4%	0.6%	6.4%	3.3%	35.1%	30%

	Indicated Efficiency	Mech Efficiency	Brake Efficiency	Drivetrain Efficiency	Cycle Efficiency	Fuel Efficiency	Road Loads		
2008 Baseline	36.0%	58.4%	21.0%	81.6%	100.0%	17.1%	100.0%	68.6%	Fuel Consumption
New	34.9%	70.4%	24.6%	86.2%	100.0%	21.2%	84.8%	**31.4%**	**GHG reduction**

- Add stoichiometric GDI, downsized, turbocharged engine (18-bar)

An 18-bar downsized and turbocharged engine, combined with stoichiometric gasoline direct injection increases an engine's indicated efficiency, and drastically reduces pumping losses. Combined with the technologies previously added, the sum of these technologies is shown below in Table 1.5-5 and provides a total of 38.3% reduction in GHG compared to an unimproved vehicle.

Table 1.5-5

	Braking / Inertia	Aero Load	Rolling Load	Trans Losses	Access Losses	Friction Losses	Pumping Losses	Ind Eff Losses	Second Law
% of tractive energy	23%	37%	40%						
Baseline % of fuel	3.9%	6.4%	6.9%	3.9%	1.1%	8.3%	5.6%	34.0%	30.0%
Reduction	8%	17%	18%	25%	42%	20%	**67%**		n/a
% of NEW fuel	3.6%	5.3%	5.6%	3.8%	0.6%	6.7%	1.9%	33.4%	30%

	Indicated Efficiency	Mech Efficiency	Brake Efficiency	Drivetrain Efficiency	Cycle Efficiency	Fuel Efficiency	Road Loads		
2008 Baseline	36.0%	58.4%	21.0%	81.6%	100.0%	17.1%	100.0%	61.7%	Fuel Consumption
New	**36.6%**	74.7%	27.3%	86.2%	100.0%	23.6%	84.8%	**38.3%**	**GHG reduction**

- Add 8-speed wet clutch DCT

An 8-speed wet clutch DCT reduces losses in several ways. The elimination of the planetary gearset and torque converter increases the reduction in transmission losses, while engine pumping losses are further reduced with the addition of more fixed gears (allowing for more efficient engine operation). Combined with the technologies previously added, the sum of these technologies is shown below in Table 1.5-6 and provides a total of 42.6% reduction in GHG compared to an unimproved vehicle.

Table 1.5-6

	Braking / Inertia	Aero Load	Rolling Load	Trans Losses	Access Losses	Friction Losses	Pumping Losses	Ind Eff Losses	Second Law
% of tractive energy	23%	37%	40%						
Baseline % of fuel	3.9%	6.4%	6.9%	3.9%	1.1%	8.3%	5.6%	34.0%	30.0%
Reduction	8%	17%	18%	**48%**	42%	20%	**72%**		n/a
% of NEW fuel	3.6%	5.3%	5.6%	2.7%	0.6%	6.8%	1.6%	32.9%	30%

	Indicated Efficiency	Mech Efficiency	Brake Efficiency	Drivetrain Efficiency	Cycle Efficiency	Fuel Efficiency	Road Loads		
2008 Baseline	36.0%	58.4%	21.0%	81.6%	100.0%	17.1%	100.0%	57.4%	Fuel Consumption
New	**37.1%**	75.5%	28.0%	90.5%	100.0%	25.3%	84.8%	**42.6%**	**GHG reduction**

In summary, for this technology package, the mathematical combination of individual effectiveness values (added without synergies) would yield a GHG reduction value of about 50%. Based on the lumped parameter model – which is calibrated to vehicle simulation results that include synergies – this technology package would provide a GHG reduction of 42.6%. In most cases negative synergies develop between technologies addressing the same losses, and with increasing magnitude as the level of applied technology grows. This increasing disparity is shown below in Table 1.5-7.

Table 1.5-7: Comparison of LP-predicted to gross aggregate effectiveness

Technologies Added	Individual Effectiveness (for step)	Combined Effectiveness LP total	Gross Effectiveness total
EFR2, LDB, ASL2, IACC2, EPS	16.4%	14.9%	16.4%
Aero2, LRRT2, MR5	10.8%	24.5%	25.5%
HEG	5.3%	28.5%	29.4%
DCP	5.5%	31.4%	33.3%
GDI, TDS18	14.9%	38.3%	43.2%
8spDCT-wet	11.9%	42.6%	50.0%

1.5.7 Calibration of LP results to vehicle simulation results

The LP model includes a majority of the new technologies being considered as part of this final rulemaking. The results from the 2011 Ricardo vehicle simulation project (Joint TSD, Section 3.3-1) were used to successfully calibrate the predictive accuracy and the synergy calculations that occur within the LP model. When the vehicle packages Ricardo modeled are estimated in the lumped parameter model, the results are comparable. All of the baselines for each vehicle class, as predicted by the LP model, fall within 3% of the Ricardo-modeled baseline results. With a few exceptions (discussed in 1.5.8), the lumped parameter results for the MYs 2020-2025 "nominal" technology packages are within 5% of the vehicle simulation results. Shown below in Figure 1.5-4 through Figure 1.5-9 are Ricardo's vehicle simulation package results (for conventional stop-start and P2 hybrid packages[R]) compared to the lumped parameter estimates.

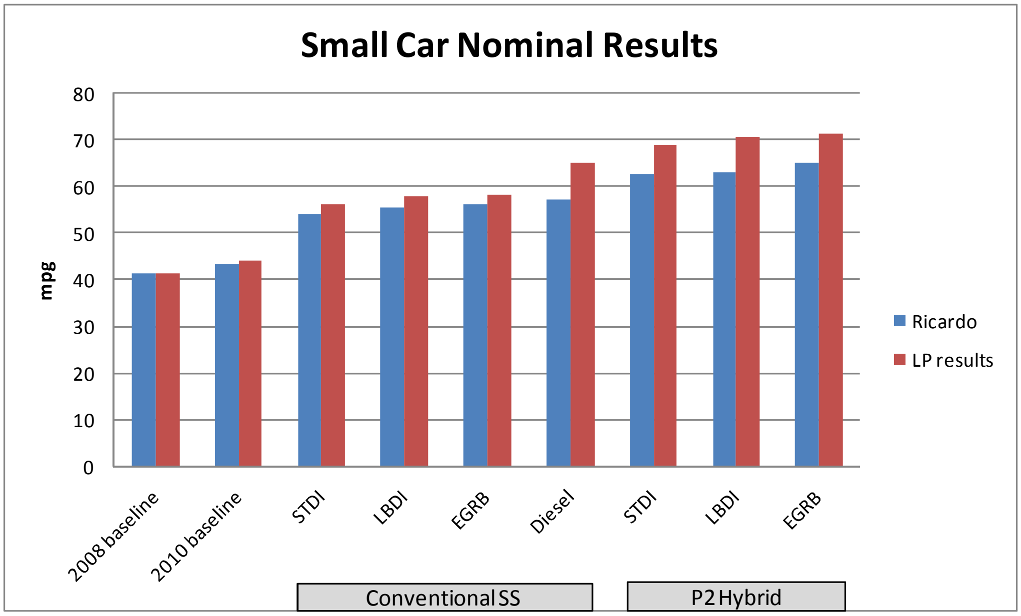

Figure 1.5-4 Comparison of LP to simulation results for Small Car class

[R] Refer to Joint TSD, Section 3.3-1 for definitions of the baselines, "conventional stop-start" and "P2 hybrid" vehicle architectures.

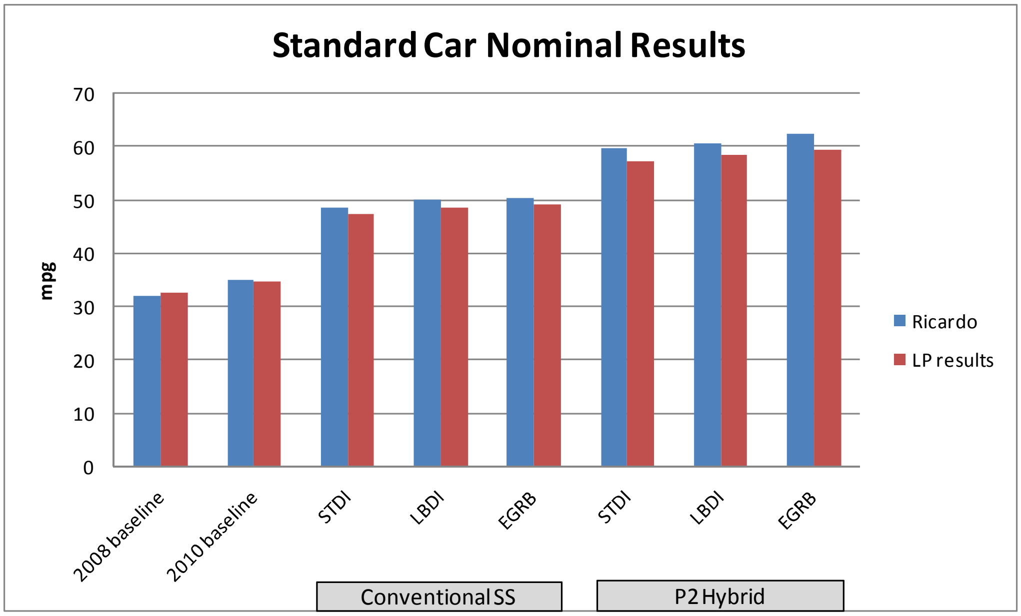

Figure 1.5-5 Comparison of LP to simulation results for Standard Car class

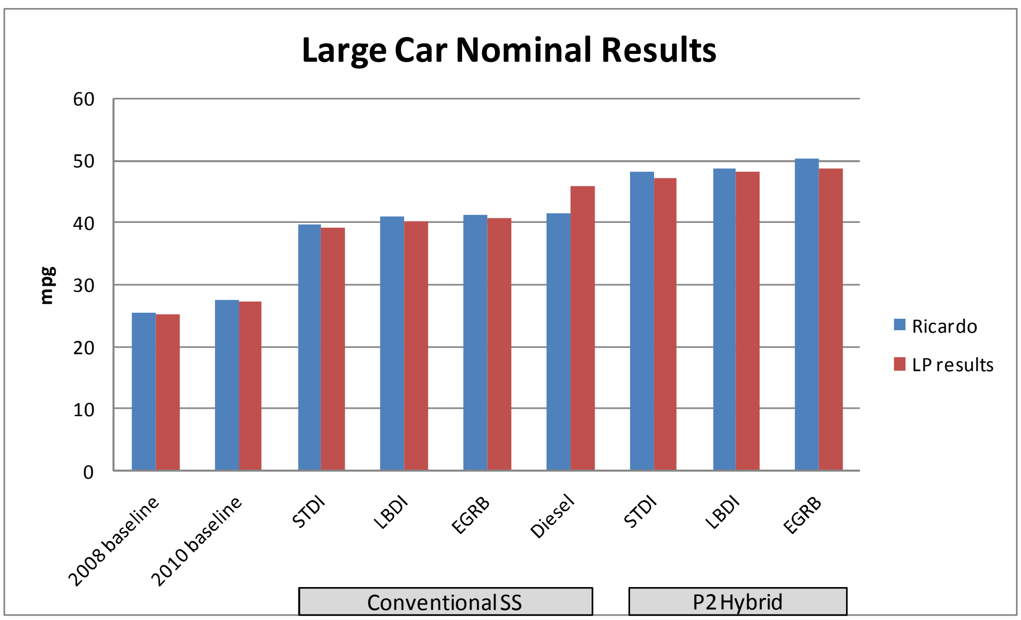

Figure 1.5-6 Comparison of LP to simulation results for Large Car class

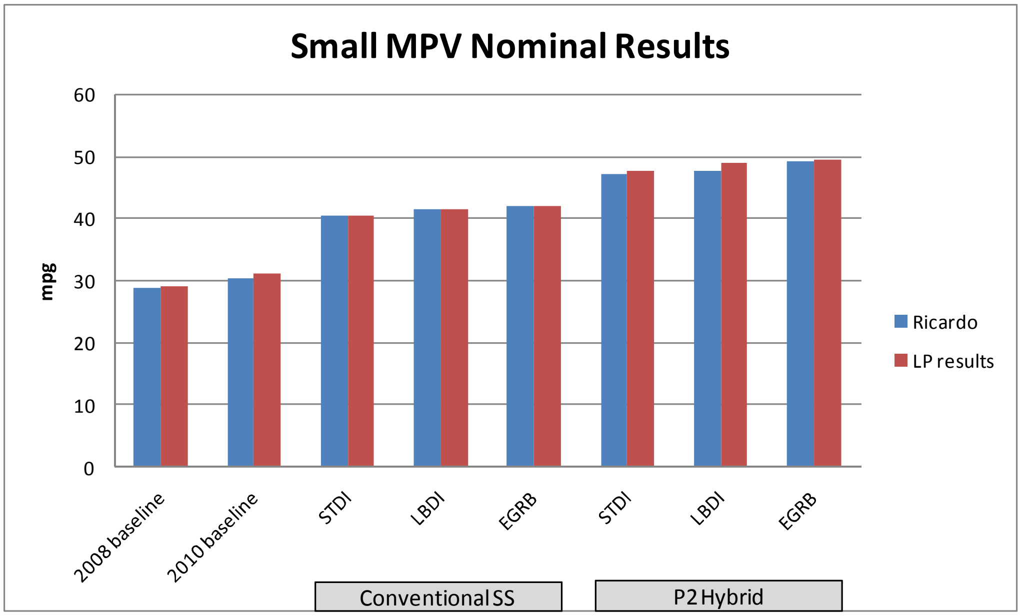

Figure 1.5-7 Comparison of LP to simulation results for Small MPV class

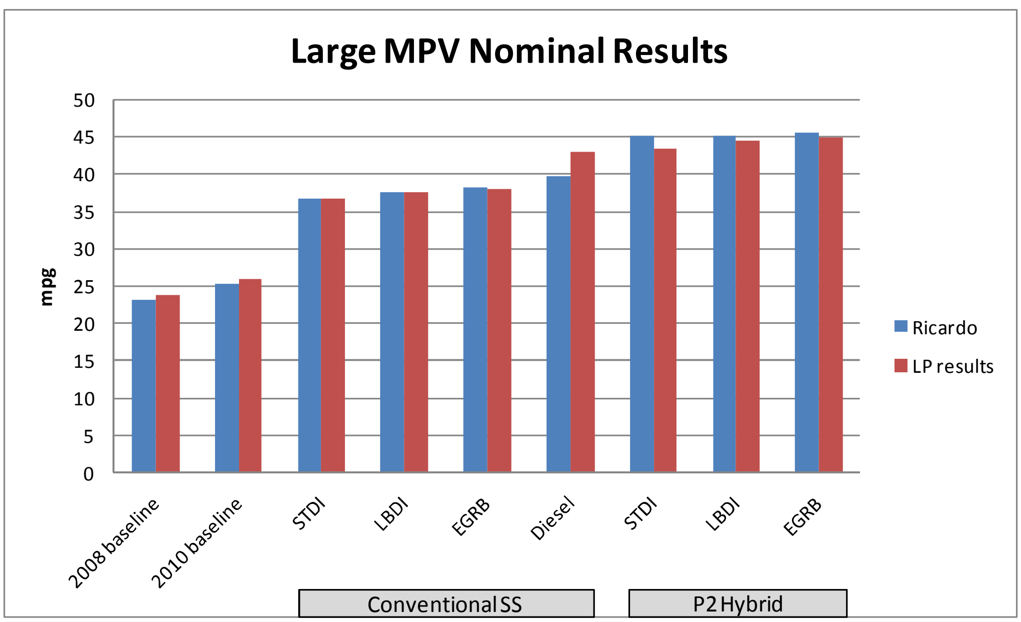

Figure 1.5-8 Comparison of LP to simulation results for Large MPV class

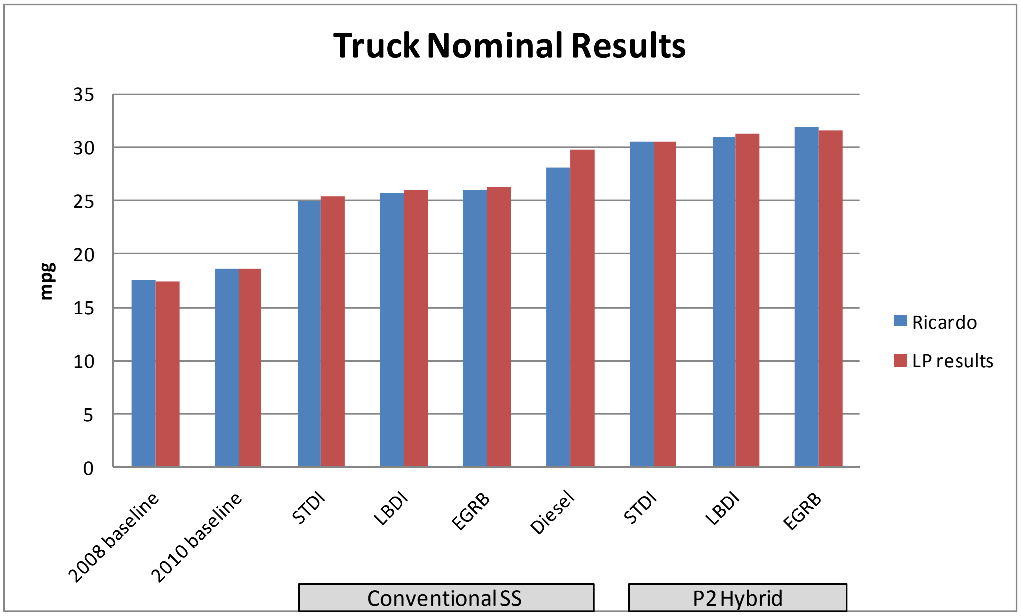

Figure 1.5-9 Comparison of LP to simulation results for Truck class

As described in Chapter 3 of the Joint TSD, NHTSA contracted Argonne National Laboratory (ANL) to supplement the existing Ricardo modeling with additional modeling work for the mild hybrid pickup trucks. The recent ANL modeling results for mild hybrids largely confirmed the effectiveness as originally predicted by the lumped parameter model, with minor differences for small cars and large trucks.[11] A comparison of the ANL results to the original lumped parameter results (for comparable vehicle classes when modeled with a nominal 15 kW motor size) is shown below in Table 1.5-1 and Table 1.5-2.

Table 1.5-1 ANL Effectiveness for Mild Hybrid

	Compact	Midsize	Small SUV	Midsize SUV	Pickup
FC reduction	11.6%	11.6%	10.2%	10.5%	8.5%

Table 1.5-2 Lumped Parameter Model Effectiveness for Mild Hybrid

	Small Car	Std Car	Small MPV	Large MPV	Truck
FC reduction	14.1%	11.8%	10.1%	10.1%	6.9%

The underlying structure of the lumped parameter model was not changed to accommodate this new information; instead, the nominal 15 kW motor sizes for small cars and pickup truck mild hybrids were slightly adjusted (to 10 kW and 18 kW, respectively) to reflect the updated effectiveness results provided by the ANL simulation work.

1.5.8 Notable differences between LP model and Ricardo results

1.5.8.1 Small car

At first glance, it would appear that the results for small cars predicted by the lumped parameter model- (especially hybrids) are too high when compared to the Ricardo vehicle simulation results. However, further investigation of the simulation results showed that the applied road load coefficients for the small car, as modeled by Ricardo, may have been higher than they should have been. Figure 1.5-10, below, shows road load power (in units of horsepower, or RLHP) plotted as a function of vehicle speed for the simulated vehicles. As expected, road load curves decrease as the vehicle class (weight and size) decreases. The road load coefficients used by Ricardo were all taken from certification test data. As shown, the modeled Yaris (small car) road load curve, in purple, is actually comparable to that for a Camry (the standard car exemplar vehicle), shown in green. By investigating the certification test data, EPA identified a second (alternate) road load curve for an alternative Yaris vehicle configuration, shown as a dashed line. Applying the mathematical equivalent of this alternate road load curve to the small car in the vehicle simulation Complex Systems tool (described in the Joint TSD, Section 3.3.1) achieved results much closer to those predicted by the LP model. While both Yaris road load curves are based on actual certification coefficients, it would make sense that the small car class should exhibit lower road loads than a standard car class.

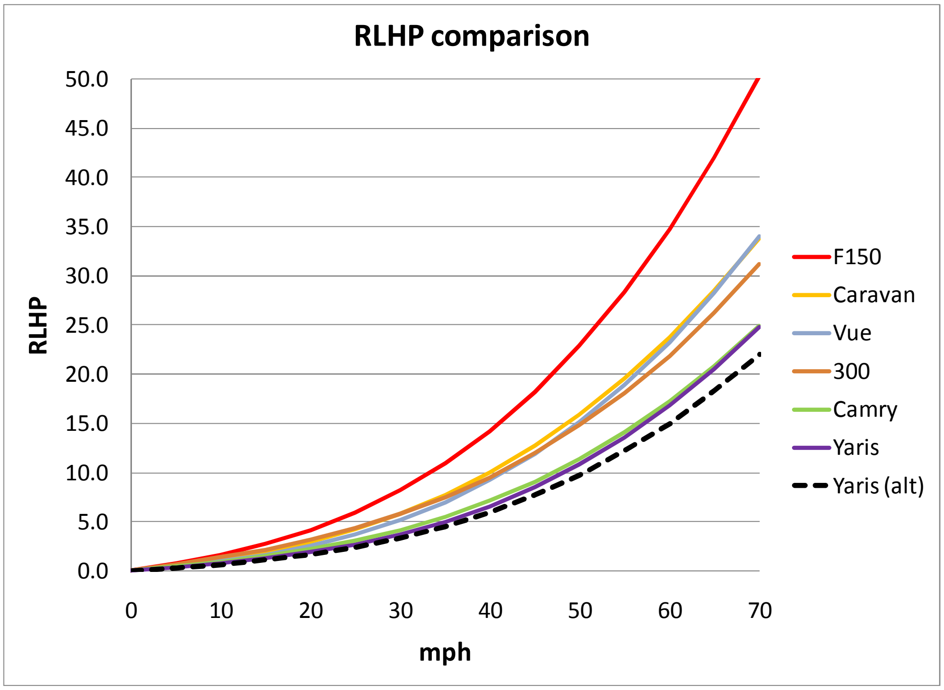

Figure 1.5-10 Road load power for modeled vehicles

The LP results for the small car P2 hybrids appear to deviate further. However, the deviation can be explained due to two main factors. Aside from the higher road load curve employed by Ricardo, the small car P2 hybrid effectiveness was understated due to a relatively undersized nominal motor/generator (30% smaller than the optimal motor size of 21 kW). The percentage of available braking energy did not match levels seen with the other vehicle classes, and fuel economy suffered slightly as a result.

For these reasons, EPA finds the LP model estimate for the small car class to be more appropriate for package effectiveness estimates.

1.5.8.2 Diesels

Detailed analysis of the diesel vehicle simulation results showed that the vehicles did not operate in the most efficient operating region, either due to a potential inconsistency in the application of the optimized shift strategy and/or due to the apparent oversizing of the nominal diesel engines. Diesel engines appeared to have been initially sized for rated power, not torque, which led to oversized displacement. This conversely reduced the average transmission efficiency realized in the model test runs. Plotting the average engine speed and load operating points for the diesel simulation data on top of the diesel engine maps showed that there was room for improvement in choice of selected gear, for example. EPA's LP estimate for the Ricardo diesel packages compare well with the simulation results when optimized shifting and early torque converter lockup (for automatic transmissions) are excluded from the LP model. Based on this comparison which is more consistent with the technology that appeared to be modeled, EPA is more comfortable with the LP diesel estimates which have slightly higher effectiveness estimates than the diesel package vehicle simulation results.

1.5.9 Comparison of results to real-world examples

To validate the lumped parameter model, representations of actual late-model production vehicles exhibiting advanced technologies were created. Shown below in Table 1.5-8 are a set of select vehicle models containing a diverse array of technologies: included are the pertinent technologies and vehicle specifications, along with actual vehicle certification fuel economy test data compared to the lumped parameter fuel economy estimates. For the vehicles and technologies shown, the predicted fuel economy is within about 3% of the actual data.

Table 1.5-8 Production vehicle certification data compared to lumped parameter predictions

Vehicle	2011 Chevy Cruze ECO	2011 Sonata Hybrid	2011 Escape Hybrid	2011 F-150 Ecoboost
Vehicle class	Small Car	Standard Car	Small MPV	Truck
Engine	1.4L I4 turbo GDI	2.4L I4 Atkinson	2.5L I4 Atkinson	3.5L V6 turbo GDI
Transmission	6 speed auto	6 speed DCT	CVT	6 speed auto
HEV motor (kW)	n/a	30	67	n/a
ETW (lbs)	3375	3750	4000	6000
City/HW FE (mpg)	**40.3**	**52.2**	**43.9**	**22.6**
LP estimate (mpg)	**40.2**	**51.7**	**44.0**	**21.9**
Key technologies applied in LP model	GDI (stoich.) turbo (30% downsize) ultra low R tires active grill shutters	P2 hybrid aero improvements	Powersplit hybrid	GDI (stoich) turbo (37% downsize)

References

[1] Woldring, D., Landenfeld, T., Christie, M.J., 2007, "DI Boost: Application of a High Performance Gasoline Direct Injection Concept." SAE Technical Paper Series No. 2007-01-1410; Kapus, P.E., Fraidl, G.K., Prevedel, K., Fuerhapter, A., 2007, "GDI Turbo – The Next Steps." JSAE Technical Paper No. 20075355; Hancock, D., Fraser, N., Jeremy, M., Sykes, R., Blaxill, H., 2008, "A New 3 Cylinder 1.2l Advanced Downsizing Technology Demonstrator Engine." SAE Technical Paper Series No. 2008-01-0611; Lumsden, G., OudeNijeweme, D., Fraser, N. Blaxill, H., 2009, "Development of a Turbocharged Direct Injection Downsizing Demonstrator Engine." SAE Technical Paper Series No. 2009-01-1503; Cruff, L., Kaiser, M., Krause, S., Harris, R., Krueger, U., Williams, M., 2010, "EBDI® - Application of a Fully Flexible High Bmep Downsized Spark Ignited Engine." SAE Technical Paper Series No. 2010-01-0587; Taylor, J., Fraser, N., Wieske, P., 2010, "Water Cooled Exhaust Manifold and Full Load EGR Technology Applied to a Downsized Direct Injection Spark Ignition Engine." SAE Technical Paper Series No. 2010-01-0356; Roth, D.B., Keller, P, Becker, M., 2010, "Requirements of External EGRSystems for Dual Cam Phaser Turbo GDI Engines." SAE Technical Paper Series No. 2010-01-0588.

[2] Spreadsheet files used to generate the values presented in this chapter can be found on a compact disk placed in Docket No. EPA-HQ-OAR-2010-0799, see "LDGHG 2017-2025 Cost Development Files."

[3] See "LDGHG 2017-2025 Cost Development Files," CD in Docket No. EPA-HQ-OAR-2010-0799.

[4] See "LDGHG 2017-2025 Cost Development Files," CD in Docket No. EPA-HQ-OAR-2010-0799.

[5] See "LDGHG 2017-2025 Cost Development Files," CD in Docket No. EPA-HQ-OAR-2010-0799.

[6] National Research Council, "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards", National Academy Press, 2002.

[7] Patton, et al. "Aggregating Technologies for reduced Fuel Consumption: A Review of the Technical Content in the 2002 National Research Council Report on CAFE". SAE 2002-01-0628. Society of Automotive Engineers, 2002.

[8] See RIA Chapter 4 in support of the MYs 2012-2016 final rule (EPA-420-R-10-009, April 2010).

[9] U.S. EPA, "Computer Simulation of Light-Duty Vehicle Technologies for Greenhouse Gas Emission Reduction in the 2020-2025 Timeframe", Contract No. EP-C-11-007, Work Assignment 0-12, Docket EPA-HQ-OAR-2010-0799, November, 2011.

[10] Heywood, J. Internal Combustion Engine Fundamentals. Figures 13-9 and 13-10, p. 723. McGraw-Hill, 1988.

[11] See FRM Joint Technical Support Document 3.2.1.3 Docket No. EPA-HQ-OAR-2010-0799

2 EPA's Vehicle Simulation Tool

2.1 Introduction

2.1.1 Background

It is well known that full-scale physics-based vehicle simulation modeling is the most sophisticated method for estimating fuel saving benefits by a package of advanced new technologies (short of actually building an actual prototype). For this reason, EPA has used full vehicle simulation results generated by Ricardo, Inc. to calibrate and validate the lumped parameter model (described in Chapter 1) to estimate technology effectiveness of many combinations of different technologies. However, EPA only has limited access to the Ricardo's model and proprietary data, so there has been a growing need for developing and running detailed vehicle simulations in-house for GHG regulatory and compliance purposes (notwithstanding that this is a very time-consuming and resource-intensive task). As a result, over the past two years, EPA has developed full vehicle simulation capabilities in order to support regulations and vehicle compliance by quantifying the effectiveness of different technologies with scientific rigor over a wide range of engine and vehicle operating conditions. This in-house vehicle simulation tool has been developed for modeling a wide variety of light-, medium- and heavy-duty vehicle applications over various driving cycles. The first application of this vehicle simulation tool was intended for medium- and heavy-duty vehicle compliance and certification. This simulation tool, the "Greenhouse gas Emissions Model" (GEM), has been peer-reviewed[12] and has also recently been published.[13] For the model years 2014 to 2017 final rule for medium- and heavy-duty trucks, GEM is used both to assess Class 2b-8 vocational vehicle and Class 7/8 combination tractor GHG emissions and to demonstrate compliance with the vocational vehicle and combination tractor standards. See 40 CFR sections 1037.520 and 1037.810 (c).

2.1.2 Objective and Scope

Unlike in the heavy-duty program, where the vehicle simulation tool is used for GHG certification since chassis-based certifications are not yet practical or feasible for most HD vehicles, we intend to use the light-duty simulation tool to help with the light-duty regulatory analysis but not for certification since it is not only feasible but also common practice to certify light-duty vehicles based on chassis-based vehicle testing. For light-duty (LD) vehicles, EPA had developed a simulation tool for non-hybrid and hybrid vehicles, which is capable of simulating a wide range of conventional and advanced engines, transmissions, and vehicle technologies over various driving cycles. It is called "Advanced Light-Duty Powertrain and Hybrid Analysis Tool" (ALPHA). The tool evaluates technology package effectiveness while taking into account synergy effects among vehicle components and estimates GHG emissions for various combinations of future technologies. This LD vehicle simulation tool, ALPHA, is capable of providing reasonably (though not absolutely) certain predictions of the fuel economy and GHG emissions of specific vehicles to be produced in the future. Currently, it is capable of simulating power-split and P2 hybrid vehicles as well as non-hybrid vehicles with a Dual-Clutch Transmission (DCT), under warmed-up conditions only. Additional simulation capabilities such as automatic transmissions, cold-start conditions, and other hybrid architectures including PHEV and electric vehicles are being developed by EPA for future use.

The ALPHA is a full vehicle simulator that uses the same physical principles as commercially available vehicle simulation tools (such as Autonomie, AVL-CRUISE, GT-Drive, Ricardo-EASY5, etc.). In order to ensure transparency of the models and free public access, EPA has developed the tool in MATLAB/Simulink environment with a completely open source code. For the 2017 to 2025 GHG rule, EPA used the simulation tool in a more limited manner: to quantify the amount of GHG emissions reduced by improvements in A/C systems and off-cycle technologies, as explained in Chapter 5 of the Joint TSD and Section III.C of the Preamble.

2.2 Descriptions of EPA's Vehicle Simulation Tool

2.2.1 Overall Architecture

Table 2.2-1 provides a high-level architecture of ALPHA, which consists of six systems: Ambient, Driver, Electric, Engine, Transmission, and Vehicle. With the exception of "Ambient" and "Driver" systems, each system consists of one or more component models which represent physical elements within the corresponding system. The definition and function of each system and their respective component models are discussed in the next section.

Table 2.2-1 High-Level Structure of Vehicle Simulator

System	Component Models
Ambient	N/A
Driver	N/A
Electric	Accessory (electrical)
Engine	Accessory (mechanical), Cylinder
Transmission	Clutch, Gear
Vehicle	Final Drive, Differential, Axle, Tire, Chassis

Figure 2.2-1 illustrates the overall streamline process of the vehicle simulation and how the current tool is designed for a user to run desired vehicle simulations. Upon execution of the main MATLAB script, it launches a Graphical User Interface (GUI) which will allow the user to choose desired inputs such as vehicle type, engine technology type, driving cycle, etc. while making the use of the tool much easier and straightforward. When the simulation is run via GUI, it first initializes all necessary vehicle model parameters including engine maps, transmission gear ratios, and vehicle road load parameters. Then, it runs the Simulink vehicle model over the desired driving cycles. Upon completing the simulation run, it automatically displays the simulation outputs in terms of fuel economy and GHG emissions. It also displays a plot of the simulated vehicle speed trace, showing how closely the simulation vehicle followed the desired speed trace. Although this first version of the vehicle simulation tool is still in an early stage, it does provide simulation capabilities for various vehicle types, engine

and transmission technologies, and driving cycles. In the future, it will undergo upgrades and improvements to include more technology choices and more simulation flexibilities.

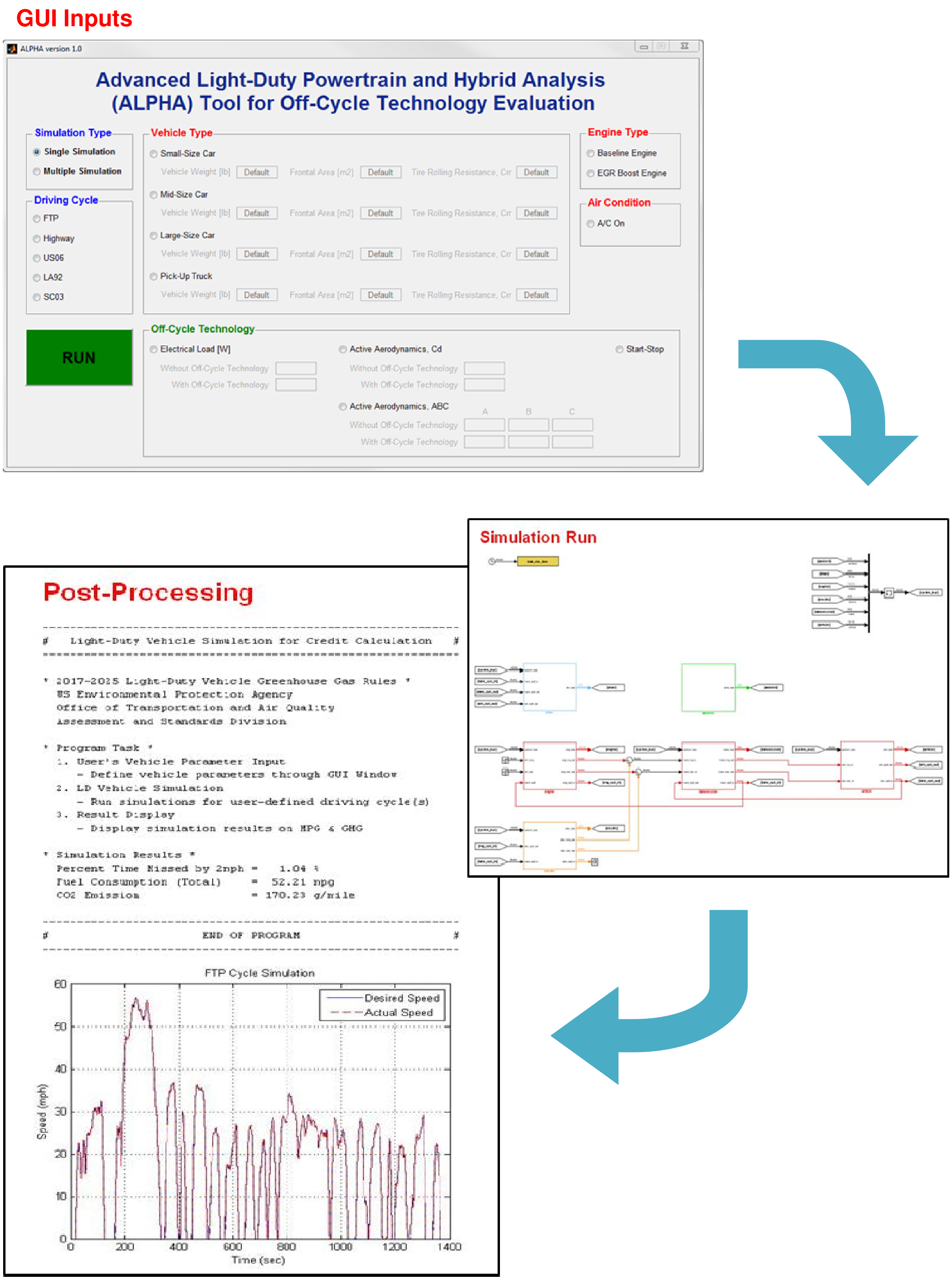

Figure 2.2-1 LD Vehicle Simulation Tool

2.2.2 System Models

In this section, detailed descriptions of the system models (Ambient, Driver, Electric, Engine, Transmission, and Vehicle) are provided. For Electric, Engine, Transmission, and Vehicle systems, the components within each of the systems will be described as well. These system models remain consistent regardless of vehicle types, engine or transmission technologies, and driving cycles.

2.2.2.1 Ambient System

This system defines surrounding environment conditions, such as pressure, temperature, and road gradient, where vehicle operations are simulated. By default, the environmental conditions defined in this system are in accordance with the standard SAE practices – air temperature of 25°C, air pressure of 101.325 kPa, and air density based on the Ideal Gas law which results in a density of 1.20 kg/m^3. The road gradient is set to 0 %, indicating a vehicle moving on a flat surface. However, these conditions are easily reconfigurable by the user.

2.2.2.2 Driver System

The driver model utilizes two control schemes to keep the simulated vehicle speed at the desired values: feedforward and feedback. It uses the targeted vehicle speed defined by a desired driving cycle to first estimate vehicle's torque requirement at the wheel at any given time. The engine power demand is then calculated based on the required wheel torque. And, the required accelerator and braking pedal positions are determined to deliver the demanded engine power which will drive the vehicle at the desired speed. If the simulated vehicle speed deviates the desired target, a speed correction logic is applied via a classical proportional-integral-derivative (PID) controller to adjust the accelerator and braking pedal positions by necessary amount in order to maintain the targeted vehicle speed at every simulation time step.

2.2.2.3 Electric System

The electric system was originally modeled as a system which consists of four individual electrical components – starter, electrical energy storage such as battery, alternator, and electrical accessory. However, for the purpose of calculating A/C credits as well as off-cycle credits, the simulation tool has modeled the electrical system as a constant power consumption devise as a function of the vehicle category. It basically represents the power loss associated with the starter, alternator, and other electrical accessories. This type of simplification was made since the purpose of the simulation was A-B comparisons only, i.e. relative difference between case A and case B on GHG emissions.

2.2.2.4 Engine System

The engine system mainly consists of two components: Mechanical Accessory and Cylinder, which represent torque loss and torque production by an engine, respectively.

2.2.2.4.1 Mechanical Accessory

This component is modeled as a simple power consumption source. Most vehicles run a number of accessories that are driven by mechanical power generated from the engine crankshaft rotation. Some of these accessories are necessary for the vehicle to run, like the coolant pump, while others are only used occasionally at the operator's discretion, such as the air conditioning compressor. For estimating the impact of A/C usage on fuel consumption, the mechanical accessory is modeled as a power consumption devise which varies with engine speed. More detailed description of the A/C compressor model is provided in the next section.

2.2.2.4.2 Cylinder

The cylinder component is modeled based on engine torque curves at wide open throttle (maximum torque) and closed throttle (minimum torque) as well as a steady-state fuel map covering a wide range of engine speed and torque conditions. The engine fuel map is represented as fueling rates pre-defined in engine speed and load conditions. This part of the model is not physics-based, therefore does not attempt to model the in-cylinder combustion and the corresponding torque production process. During the vehicle simulation, the instantaneous engine torque and speed are monitored and used to select an appropriate fueling rate based on the fuel map. This map is adjusted automatically by taking into account three different driving modes: acceleration, brake, and coast. The fuel map, torque curves, and the different driving modes are pre-programmed into the model for several different engine technologies.

2.2.2.5 Transmission System

The transmission system consists of two components: Clutch and Gear. The current version of the transmission system only models a DCT.

2.2.2.5.1 Clutch

This component represents a mechanical clutch in either a manual transmission or a DCT. For an automatic transmission, it is replaced by a torque converter component. It is modeled as an ideal clutch, where no dynamics during clutch slip is considered during clutch engaging and disengaging process.

2.2.2.5.2 Gear

This component is modeled as a simple gearbox. The number of gears and corresponding gear ratios are predefined during the preprocessing of simulation runs. Also, torque transmitting efficiency is defined for each gear to represent the losses that occur in the physical system. Like the clutch component, the gear is modeled as an ideal gear, where no dynamics is considered during gear engaging and disengaging process.

2.2.2.6 Vehicle System

The vehicle system consists of five components: Final Drive, Differential, Axle, Tire, Chassis. It basically models all components after transmission in a vehicle.

2.2.2.6.1 Final Drive and Differential

Both final drive and differential components are modeled as mechanical systems which transmit inertia and toque from an upstream component to a downstream component with a certain gear ratio and efficiency. The gear ratios for both components can be specified by the user according to the simulated vehicle. The torque transmitting efficiencies are defined by maps based on input speed and torque to the modeled component.

2.2.2.6.2 Axle

Typically, all axles are lumped together, and one axle model represents the overall behavior of vehicle axles during vehicle simulations. In ALPHA, however, the axle component is modeled to simulate the behavior of each individual axle used by the simulated vehicle. The axle is treated individually in order to properly simulate all wheel drive vehicle types.

2.2.2.6.3 Tire and Chassis

This part of the vehicle system models the body of the vehicle including tires. For the chassis component, the coefficient of aerodynamic drag, mass of vehicle, and vehicle frontal area are the key model parameters. For the tire component, the user specifies the configuration of each axle on the vehicle, including the tire diameter and its rolling resistance coefficient. However, these components will have a capability to use typical coast-down coefficients to calculate road load, instead of tire rolling resistance and aerodynamic drag.

2.3 Applications of Simulation Tool for Final Rule

As mentioned previously, EPA used the vehicle simulation tool for the final rule to quantify the amount of GHG emissions reduced by improvements in A/C system efficiency (thus fixing the maximum credit potential) and to determine the default credit value for active aerodynamics, electrical load reduction, and engine start-stop - some of the listed off-cycle technologies (off-cycle technologies for which a credit of pre-determined amount may be obtained). In this section, we discuss the specifics of these applications of the simulation tool.

2.3.1 Impact of A/C on Fuel Consumption

Among the simulation model systems described in the previous section, there are four key system elements in the light-duty vehicle simulation tool which describe the overall vehicle dynamics behavior and the corresponding fuel efficiency: electric, engine, transmission, and vehicle. The electric system model consists of parasitic electrical load and A/C blower fan, both of which were assumed to be constant. The engine system model is comprised of engine torque and fueling maps. For estimating indirect A/C impact on fuel consumption increase, two engine maps were used: baseline and EGR boost engines. These engine maps were obtained by reverse-engineering the vehicle simulation results provided by Ricardo Inc. For the transmission system, a Dual-Clutch Transmission (DCT) model was used along with the gear ratios and shifting schedules used for the earlier Ricardo simulation work. For the vehicle system, four vehicles were modeled: small, medium, large size passenger vehicles, and a light-duty pick-up truck. The transient behavior and thermodynamic properties of the A/C system was not explicitly simulated, in favor of a simpler approach of capturing the compressor load based on national average ambient conditions. We believe this simplification is justified since the goal is to capture the behavior on the average of a fleet of vehicles (not an individual make or model).

In order to properly represent average load values to the engine caused by various A/C compressors in various vehicle types, EPA has adopted the power consumption curves of A/C systems, published by an A/C equipment supplier, Delphi.[14,15] Also, in an effort to characterize an average A/C compressor load in the presence of widely varying environmental conditions in the United States, EPA has adopted data from the National Renewable Energy Laboratory (NREL) to estimate environmental conditions associated with typical vehicle A/C usage.[16,17,18] Based on the NREL data, EPA selected an A/C power consumption curve as a function of engine speed that was acquired by Delphi at 27°C and 60% relative humidity as a representative average condition. This power consumption data was taken from a fixed displacement compressor with a displacement volume of 210 cc. The curve includes the effect of compressor cycling as well as non-summer defrost/defog usage. In order to associate each vehicle type with appropriate A/C compressor displacement, EPA scaled the curve based on the displacement volume ratio. For determining indirect A/C impact on fuel consumption increase for various vehicle types, EPA estimated A/C compressor sizes of 120 cc, 140 cc, 160 cc, and 190 cc for small, medium, large passenger cars, and light-duty pick-up truck, respectively. By applying these ratios to the 210 cc power consumption curve, EPA created A/C load curves for four vehicle types, as shown in Figure 2.3-1.

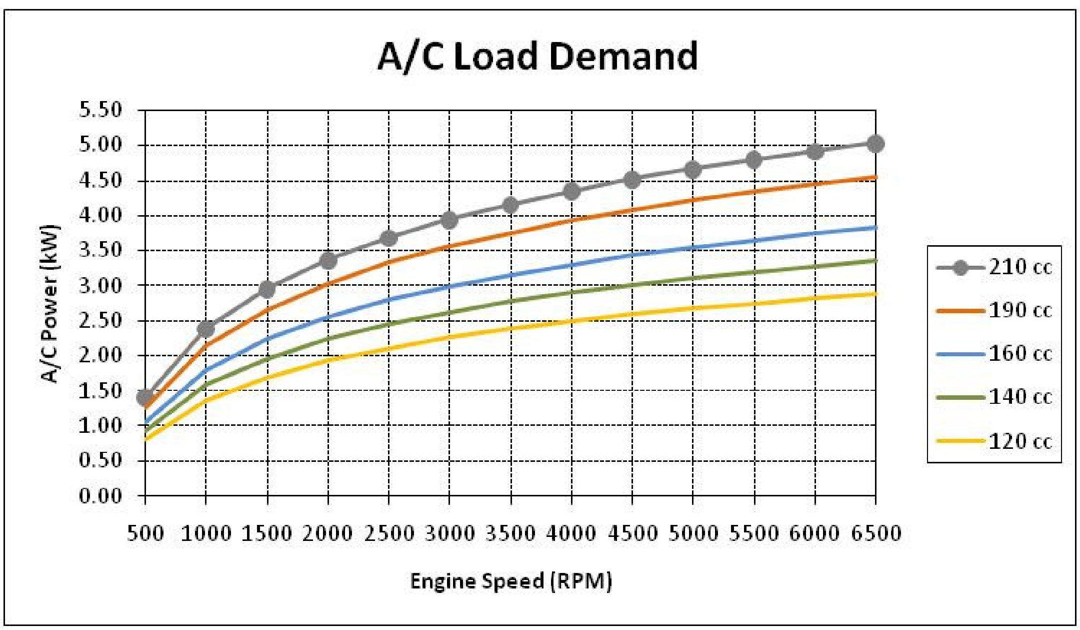

Figure 2.3-1 Representative A/C Compressor Load Curves

With these A/C compressor load curves, EPA ran full vehicle simulations based on the following matrix shown below. In this matrix, the baseline engine represents a typical Spark-Ignition (SI), Port-Fuel Injection (PFI), Naturally-Aspirated (NA) engine equipped with a Variable Value Actuation (VVA) technology. In this technology, the valve timing (both intake and exhaust) is continuously varied over a wide range of engine operating conditions in order to result in optimal engine breathing efficiency. On the other hand, the EGR boost engine uses turbocharging and cooled EGR to increase engine's Brake Mean Effective Pressure (BMEP) level while managing combustion and exhaust temperatures. This engine usually has a peak BMEP of 25 to 30 bars, which supports significant downsizing (e.g. about 50%) compared to the baseline engines. Table 2.3-1 provides simulation results over SC03 driving cycle with an EGR boost engine for various vehicle classes.

- Small, medium, large cars, and pick-up truck
- FTP, Highway, and SC03 driving cycles
- Baseline and EGR boost engines
- A/C off and A/C on

Table 2.3-1 Vehicle Simulation Results on CO_2 Emissions over SC03 Cycle with EGR Boost Engine

SC03 Cycle		Small Car	Medium Car	Large Car	Truck
CO_2 with A/C off	[g/mi]	196.4	235.7	293.7	472.4
CO_2 Increase with A/C on	[g/mi]	11.7	12.0	13.8	17.2
Total CO_2 with A/C	[g/mi]	208.1	247.7	307.5	489.6
Indirect A/C Fuel Use	[%]	5.6	4.8	4.5	3.5

EPA ran the SC03 cycle simulations instead of the FTP/Highway combined cycle simulations so that the simulation results would represent the actual A/C cycle test. EPA also assumed the EGR boost engine during vehicle simulations because the EGR boost engine better represents an engine technology more likely to be implemented in model years 2017 to 2025 and because the A/C impact on CO_2 increase in the EGR boost engine is similar to that in the baseline engine as shown in Table 2.3-1 and Table 2.3-2. Details of this analysis which showed impact of A/C usage on fuel consumption is relatively independent of engine technology are provided in the next section. Moreover, EPA assumed 62% and 38% of market penetrations for manual and automatic climate control systems, respectively. EPA also assumed 23.9% and 35.0% of A/C on-time for manual and automatic climate control systems, respectively. These are the same assumptions made for the 2012-2016 rule.[19] In order to come up with the overall impact of A/C usage on CO_2 emissions for passenger cars, the simulation results for cars shown in Table 2.3-1 were sales-weighted for each year from 2017 to 2025. For the final result, the impact of A/C usage was estimated at 11.9 CO_2 g/mile for cars and 17.2 CO_2 g/mile for trucks. This corresponds to an impact of approximately 14.0 CO_2 g/mile for the (2012) fleet, which is comparable to the 2012-2016 final rule result, but still lower than the two studies by NREL[17] and NESCCAF[18] cited above.

2.3.1.1 Effect of Engine Technology on Fuel Consumption by A/C System

In order to continue to maintain the credit levels from the 2012-2016 rule, EPA had to first demonstrate that the fuel economy and CO_2 emissions due to A/C was relatively insensitive to the engine technologies that may be expected to be used in 2012-2016 light duty vehicles . If, for example, more efficient engines are able to run the A/C system more efficiently such that the incremental increase in emissions due to A/C decreased compared to the base engines, then credits for the same A/C technologies must decrease over time as engines become more efficient. This would correspond to a decrease in credits proportional (or multiplicative) to the increase in efficiency of the engine. Conversely, if the incremental increase in emissions due to A/C remained relatively constant, then the credits available for A/C efficiency should also remain stable. This would correspond to the credits (A/C impact) being additive to the base emissions rate, thus being independent of engine efficiency. The EPA based the hypothesis on the latter assumption.

In order to prove out this hypothesis, EPA carried out vehicle simulations for several cases, including two engine technologies: baseline and EGR boost engines (a surrogate for a future advanced efficient engine). Table 2.3-2 shows the vehicle simulation results of CO_2 emissions over the SC03 driving cycle when baseline engines are used, as opposed to the advanced EGR boost engines. By comparing the values of CO_2 increase with A/C on in Table 2.3-1 and Table 2.3-2, it is evident that the impact of A/C usage on fuel consumption is not highly dependent on the engine technologies. In fact, the difference in the CO_2 increase with A/C on (2nd row in table) between the emissions from the baseline and EGR boost engines is less than 10% for all vehicle classes.

Table 2.3-2 Vehicle Simulation Results on CO2 Emissions over SC03 Cycle with Baseline Engine

SC03 Cycle		Small Car	Medium Car	Large Car	Truck
CO_2 with A/C off	[g/mi]	259.3	348.0	425.4	628.1
CO_2 Increase with A/C on	[g/mi]	11.3	11.1	12.5	16.2
Total CO_2 with A/C	[g/mi]	270.6	359.1	437.9	644.3
Indirect A/C Fuel Use	[%]	4.2	3.1	2.9	2.5

Figure 2.3-2 depicts zoomed-in BSFC maps for baseline and EGR boost engines. The circles on these maps represent average operating conditions of the engines over the FTP (city) drive cycle. The blue circle represents a simulated average operating condition without A/C while the red circle represents an average operating condition with A/C. As can be seen in the figure, the engines operate at higher load levels when the A/C is on.

For the baseline engine case, the engine efficiency improves significantly (375 g/kW-h to almost 330 g/kW-h) as it moves along the BSFC surface, whereas the improvement is much less for the EGR boost engine as it moves from approximately 250 g/kW-h to 240 g/kW-h. However, the large improvement in engine efficiency for the baseline engine is offset by the fact that the engine itself is less efficient than the EGR boost engine. Conversely, the small efficiency improvement for the EGR boost engine is compensated by the fact that the engine is much more efficient than the baseline engine. As a result, the CO_2

increase seen by both engines due to A/C usage becomes similar in two different technologies. This result allows us to approximate the A/C impact on vehicle fuel consumption as an additive effect rather than a multiplicative effect since it is independent of engine technologies. For the same reason, it also means that A/C credits for a given technology can remain constant over time, which will greatly simplify the progression of future credits.[S]

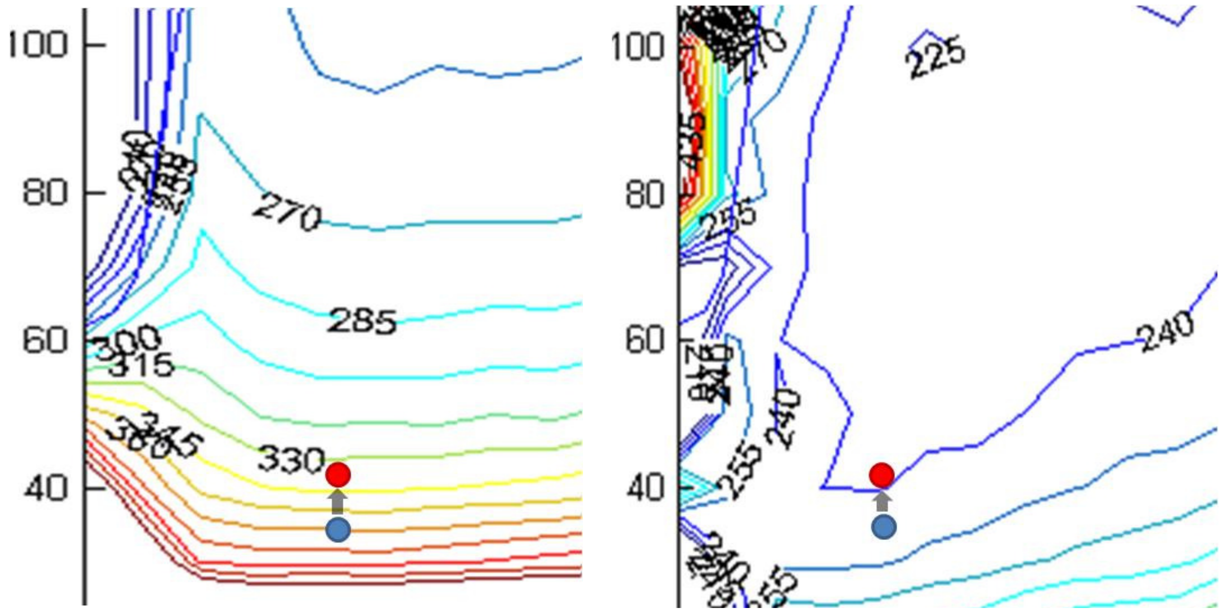

Figure 2.3-2 Average Engine Operating Conditions with A/C Off and A/C On over Fueling Maps for Baseline and EGR Boost Engines

2.3.2 Off-Cycle Credit Calculation

The aerodynamics of a vehicle plays an important role in determining fuel economy. Improving the aerodynamics of a vehicle reduces drag forces that the engine must overcome to propel the vehicle, resulting in lower fuel consumption. The aerodynamic efficiency of a vehicle is usually captured in a coast-down test that is used to determine the dynamometer parameters used during both the two-cycle and five-cycle tests. This section discusses active aerodynamic technologies that are activated only at certain speeds to improve aerodynamic efficiency while preserving other vehicle attributes or functions. Two examples of active aerodynamic technologies are active grill shutters and active ride height control. Active aerodynamic features can change the aerodynamics of the vehicle according to how the vehicle is operating, and the benefit of these vehicle attributes may not be fully captured during the EPA test cycles.

[S] It also means that the last row in the above two tables are somewhat misleading as A/C impact should not be quantified as a fraction of the total emissions, but rather an additive increment. The numbers are left onto the tables only for comparison purposes to studies in the literature that use this convention.

EPA is limiting credits to active aerodynamic systems only (not passive). The aerodynamic drag on the vehicle is highly dependent on the vehicle shape, and the vehicle shape is (in turn) highly dependent on the design characteristics for that brand and model. EPA feels that it would be inappropriate to grant off-cycle credits for vehicle aesthetic and design qualities that are passive and fundamentally inherent to the vehicle.

2.3.2.1 Performance-Based Metrics

To evaluate technologies that reduce aerodynamic drag, the EPA conducted an analysis of the reduction in emissions corresponding to a general reduction of aerodynamic drag on a vehicle. Using the EPA's full vehicle simulation tool (ALPHA) described in the previous section, the agency evaluated the change in fuel consumption for increasing reductions in aerodynamic drag for a typically configured vehicle. The results of this analysis form the basis for a consistent methodology that the EPA applied to technologies that provide active aerodynamic improvements.

Vehicle aerodynamic properties impact both the combined FTP/Highway and 5-cycle tests. However, these impacts are larger at higher speeds and have a larger impact on the 5-cycle tests. By their nature of being "active" technologies, EPA understands that active aerodynamic technologies will not be in use at all times. While deployment strategies for different active aerodynamic technologies will undoubtedly vary by individual technology, the impact of these technologies will mostly be realized at high speeds. EPA expects that the 5-cycle tests will capture the additional real-world benefits not quantifiable with the FTP/Highway test cycles due to the higher speed in the US06 cycle. Active aero may also depend on weather conditions. For example, active aerodynamics may operate less in hot weather when air cooling is required to exchange heat at the condenser. Also, active grill shutters may need to stay open during snowy conditions in order to prevent them from freezing shut (potentially causing component failure).

Using the EPA's full vehicle simulation tool, the impact of reducing aerodynamic drag was simulated on both the combined FTP/Highway cycle and the 5-cycle drive tests. In order to determine the fuel savings per amount of aerodynamic drag reduction, the fuel savings on the FTP/Highway test cycle was subtracted from the fuel savings on the 5-cycle test. This is consistent with the approach taken for other technologies. Table 2.3-3 shows the results of the vehicle simulation. Also, Figure 2.3-3 represents this GHG reduction metrics in a graphical form. These results assume that the active aerodynamics affects the coefficient of drag only, which is currently assumed to be constant over a wide range of vehicle operating speed. However, if the coefficient of aerodynamic drag is assumed to be vehicle speed dependent, then a different relationship could result.

This vehicle simulation tool was also used for estimating other off-cycle credits, such as electrical load reduction and engine start-stop credits. Details of the analysis and values of these scalable credits are described in Chapter 5 of TSD. Although this simulation tool will not be officially used for credit compliance purposes, EPA may use the tool for the alternate method demonstration process of credit approval. EPA encourages manufacturers to use this simulation tool in order to estimate the credits values of their off-cycle technologies.

Table 2.3-3 Simulated GHG Reduction Benefits of Active Aerodynamic Improvements

Reduction in Aerodynamic Drag (C_d)	GHG Reduction in Cars [g/mile]	GHG Reduction in Trucks [g/mile]
1%	0.2	0.3
2%	0.4	0.6
3%	0.6	1.0
4%	0.8	1.3
5%	0.9	1.6
10%	1.9	3.2

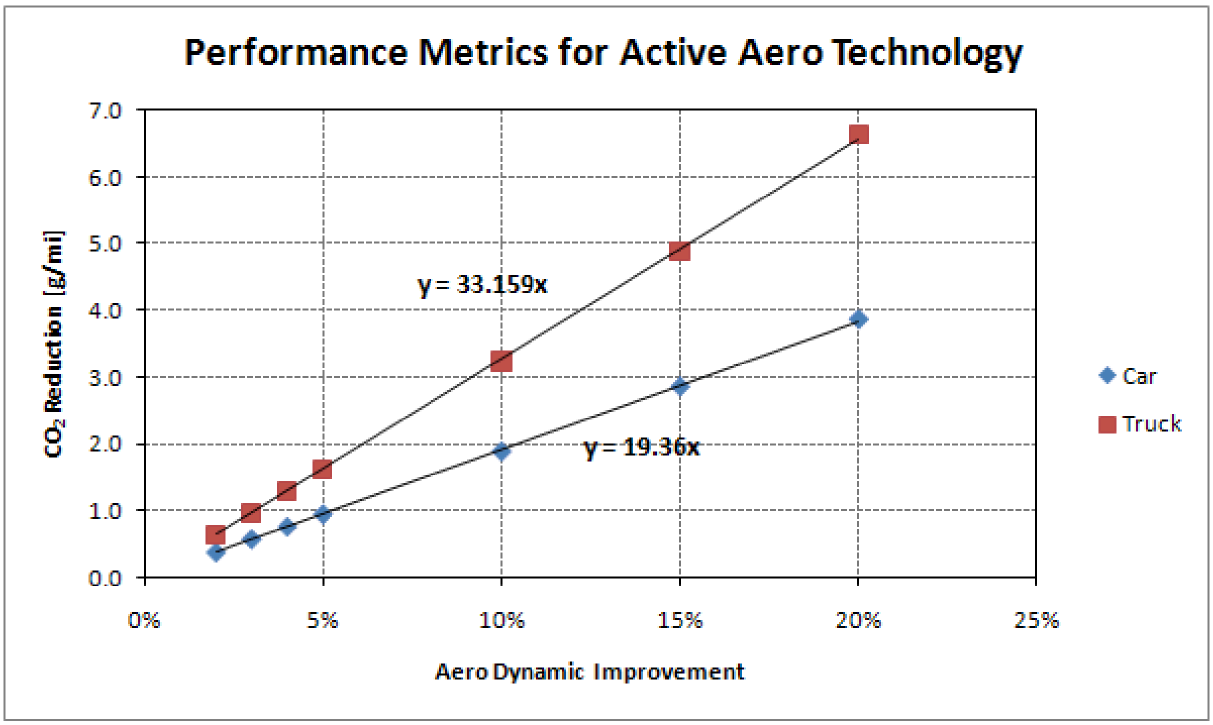

Figure 2.3-3 Simulated GHG Reduction Benefits of Active Aerodynamic Improvements

2.3.2.2 Active Aerodynamics

One of the active aerodynamic technologies is active grill shutters. This technology is a new innovation that is beginning to be installed on vehicles to improve aerodynamics at higher speeds. Nearly all vehicles allow air to pass through the front grill of the vehicle to flow over the radiator and into the engine compartment. This flow of air is important to prevent overheating of the engine (and for proper functioning of the A/C system), but it creates a significant drag on the vehicle and is not always necessary. Active grill shutters close off the area behind the front grill so that air does not pass into the engine compartment when additional cooling is not required by the engine. This reduces the drag of the vehicle, reduces CO_2 emissions, and increases fuel economy. When additional cooling is needed by the engine, the shutters open until the engine is sufficiency cooled.

Based on manufacturer data, active grill shutters provide a reduction in aerodynamic drag (C_d) from 0 to 5% when deployed. EPA expects that most other active aerodynamic technologies, such as active suspension lowering will provide a reduction of drag in the same range as active grill shutters. EPA also expects that active aerodynamic technologies may not always be available during all operating conditions. Active grill shutters, for example, may not be usable in very cold temperatures due to concerns that they could freeze in place and cause overheating. Control and calibration issues, temperature limitations, air conditioning usage, and other factors may limit the usage of grill shutters and other active aerodynamic technologies. Therefore, EPA is providing a credit for active aerodynamic technologies according to the performance metrics represented in Figure 2.3-3 and Table 2.3-3. It is conceivable that some systems can achieve better performance. Manufacturers may apply for a greater credit for better performing systems through the normal application process described in Section III.C.5.b of the preamble to the final rule.

2.4 On-Going and Future Work

2.4.1 Simulation Tool Validation

Since the EPA's full vehicle simulation tool (ALPHA) is still in an early stage, only the HEV version of the model has been validated to test data. The non-hybrid model has not been fully validated against vehicle test data yet. However, EPA has attempted to compare the EPA's simulation results to those of Ricardo's. Unfortunately, none of the Ricardo's vehicle simulation metrics exactly matched with the simulation runs performed by the EPA's simulation tool. For this reason, EPA used the lumped parameter model (described in Chapter 1) which had been calibrated and tuned with Ricardo's simulation results for a benchmark comparison.

Table 2.4-1 Comparison between EPA's Full Vehicle Simulation Tool and Lumped Parameter Model Runs

Simulation Tool	Small-Size Car [g/mile]	Mid-Size Car [g/mile]	Large-Size Car [g/mile]	Pick-up Truck [g/mile]
Vehicle Simulation	211.7	273.8	350.2	532.7
Lumped Parameter Model	220	280	359	520
Percent Difference	3.8%	2.2%	2.5%	2.4%

Using the same simulation metrics (e.g. baseline engine, DCT transmission, vehicle types) for both ALPHA and the lumped parameter model, the results were obtained as shown in Table 2.4-1. As shown in Table 2.4-1, it is evident that the EPA vehicle simulation tool provides GHG estimations which are very comparable with lumped parameter model results, and therefore with Ricardo's simulation results for various vehicle types. The differences are all within ±5% between the two simulations. Although this benchmarking result against the Ricardo's simulation does provide a certain level of confidence in the EPA's simulation tool, a full validation of the tool will be performed using actual vehicle test data in the near future. For the analysis conducted in this rule, where only a difference in CO_2 emissions or fuel economy is required, we believe that this is a sufficient level of validation.

2.4.2 Simulation Tool Upgrade

As mentioned previously, the EPA's full light-duty vehicle simulation tool (ALPHA) is still in an early stage. There are a number of improvements and new additions being planned for the simulation tool so that it will be capable of performing various different types of simulations for a number of vehicle technologies. EPA expects that the upgraded vehicle simulation tool can provide more capabilities for future EPA analysis.

First, an automatic transmission model will be added for the conventional (non-hybrid) vehicle simulation tool. Although EPA expects that DCT will be a dominant technology in transmissions in MYs 2017 to 2025, EPA must be able to simulate vehicles with automatic transmissions which give baseline vehicle performances. Also, 8-speed automatic transmissions with lock up will also require this model as a basis. Along with the automatic transmission, a transmission shifting algorithm will be developed, which will help us avoid requiring transmission shifting maps. This algorithm will automatically optimize the shifting strategy based on torque required by the vehicle and torque produced by the engine during simulation. Therefore, it should eliminate the need for having shifting maps for different combinations of powertrains and vehicles.

In addition to upgrading the non-hybrid vehicle simulation tool, EPA is planning to enhance hybrid electric vehicle (HEV) simulation capabilities. EPA has already developed and validated power-split and P2 hybrid vehicle models. We plan to add more HEV configurations, such as series hybrid, PHEV, electric vehicles, etc. For both non-hybrid and hybrid simulation tools, EPA is also planning to design a Graphical User Interface (GUI) and integrate it with the vehicle simulation tool. This GUI will allow the user to choose from different technologies and simulation options while making the use of the tool much easier and straightforward. These tools are expected to assist in further analysis for the final rule as necessary.

Reference

[12] "Peer Review of the Greenhouse gas Emissions Model (GEM) and EPA's Response to Comments," Docket EPA-HQ-OAR-2010-0162-3418, Publication Number: EPA-420-R-11-007, July 2011.

[13] Lee, S., Lee, B., Zheng, H., Sze, C., Quinones, L., and Sanchez, J., "Development of Greenhouse Gas Emissions Model for 2014-2017 Heavy- and Medium-Duty Vehicle Compliance," SAE 2011 Commercial Vehicle Engineering Congress, Chicago, September 2011, SAE Paper 2011-01-2188.

[14] Forrest, W.O., "Air Conditioning and Gas Guzzler Tax Credits," Society of Automotive Engineers, International Congress & Exposition, Detroit, Michigan, March 2002, SAE Paper 2002-01-1958.

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[17] Rugh, J.P., Hovland, V., Andersen, S.O., "Significant Fuel Savings and Emissions Reductions by Improving Vehicle Air Conditioning," Presentation at the 15th Annual Earth Technologies Forum and Mobile Air Conditioning Summit, April 15, 2004.

[18] Northeast States Center for a Clean Air Future, "Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles," September, 2004.

[19] EPA and DOT, "Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Final Rule," May 7, 2010.

3 Results of Final and Alternative Standards

3.1 Introduction

This chapter provides the methodology and results of the technical assessment of the future vehicle scenarios presented in this final rule. All methods in this chapter pertain to both the MY 2008 and MY 2010 based future fleet projection. We note the few places where the methods differ between the analyses. All results in this chapter are for the MY 2008 based future fleet projection, while those for the MY 2010 based future fleet projection are found in RIA Chapter 10. Although there are differences in the details of these cost and technology penetration estimates, the results are largely similar between the analyses conducted with each of the two baselines.

As in the analysis of the MYs 2012-2016 rulemaking and in the proposal, in this final rule, our evaluation of these scenarios included identifying potentially available technologies and assessing their effectiveness, cost, and impact on relevant aspects of vehicle performance and utility. The wide number of technologies that are available and likely to be used in combination required a method to account for their combined cost and effectiveness, as well as estimates of their availability to be applied to vehicles.

Applying these technologies efficiently to the wide range of vehicles produced by various manufacturers is a challenging task. In order to assist in this task, EPA is again using a computerized program called the Optimization Model for reducing Emissions of Greenhouse gases from Automobiles (OMEGA). Broadly, OMEGA starts with a description of the future vehicle fleet, including manufacturer, sales, base CO_2 emissions, footprint and the extent to which emission control technologies are already employed. For the purpose of this analysis, EPA uses OMEGA to analyze over 200 vehicle platforms which encompass approximately 1300 vehicle models in order to capture the important differences in vehicle and engine design and utility of future vehicle sales of roughly 15-17 million units annually in the 2017-2025 timeframe. The model is then provided with a list of technologies which are applicable to various types of vehicles, along with the technologies' cost and effectiveness and the percentage of vehicle sales which can receive each technology during the redesign cycle of interest. The model combines this information with economic parameters, such as fuel prices and a discount rate, to project how various manufacturers would apply the available technology in order to meet increasing levels of emission control. The result is a description of which technologies are added to each vehicle platform, along with the resulting cost. The model can also be set to account for various types of compliance flexibilities.[T]

EPA has described OMEGA's specific methodologies and algorithms previously in the model documentation,[20] the model is publically available on the EPA website,[21] and it has been peer reviewed.[22]

[T] While OMEGA can apply technologies which reduce CO_2 efficiency related emissions and refrigerant leakage emissions associated with air conditioner use, this task is currently handled outside of the OMEGA core model. A/C improvements are highly cost-effective, and would always be added to vehicles by the model, thus they are simply added into the results at the projected penetration levels.

No public comments were received on the use of the OMEGA model, or on the OMEGA analytic framework used in the proposal.

3.2 OMEGA model overview

The OMEGA model evaluates the relative cost and effectiveness of available technologies and applies them to a defined vehicle fleet in order to meet a specified GHG emission target. Once the regulatory target (whether the target adopted in the rule, or an alternative target) has been met, OMEGA reports out the cost and societal benefits of doing so. The model is written in the C# programming language, however both inputs to and outputs from the model are provided using spreadsheet and text files. The output files facilitate additional manipulation of the results, as discussed in the next section.

OMEGA is primarily an accounting model. It is not a vehicle simulation model, where basic information about a vehicle, such as its mass, aerodynamic drag, an engine map, etc. are used to predict fuel consumption or CO_2 emissions over a defined driving cycle.[U] Although OMEGA incorporates functions which generally minimize the cost of meeting a specified CO_2 target, it is not an economic simulation model which adjusts vehicle sales in response to the cost of the technology added to each vehicle.[V]

OMEGA can be used to model either a single vehicle model or any number of vehicle models. Vehicles can be those of specific manufacturers as in this analysis or generic fleet-average vehicles as in the 2010 Joint Technical Assessment Report supporting the MY 2017-2025 NOI. Because OMEGA is an accounting model, the vehicles can be described using a relatively few number of terms. The most important of these terms are the vehicle's baseline CO_2 emission level, the level of CO_2 reducing technology already present, and the vehicle's "type," which indicates the technology available for addition to that vehicle to reduce CO_2 emissions. Information determining the applicable CO_2 emission target for the vehicle must also be provided. This may simply be vehicle class (car or truck) or it may also include other vehicle attributes, such as footprint.[W] In the case of this rulemaking, footprint and vehicle class are the relevant attributes.

Emission control technology can be applied individually or in groups, often called technology "packages." The OMEGA user specifies the cost and effectiveness of each technology or package for a specific "vehicle type," such as midsize cars with V6 engines or minivans. The user can limit the application of a specific technology to a specified percentage of each vehicle's sales (i.e., a "maximum penetration cap"),

[U] Vehicle simulation models may be used in creating the inputs to OMEGA as discussed in Joint TSD Chapter 3 as well as Chapter 1 and 2 of the RIA.
[V] While OMEGA does not model changes in vehicle sales, RIA Chapter 8 discusses this topic.
[W] A vehicle's footprint is the product of its track width and wheelbase, usually specified in terms of square feet.

which for this rulemaking, are specified a priori by EPA and NHTSA.[X] The effectiveness, cost, application limits of each technology package can also vary over time.[Y] A list of technologies or packages is provided to OMEGA for each vehicle type, providing the connection to the specific vehicles being modeled. A description of these packages can be found in Chapter 1 of this RIA.

OMEGA is designed to apply technology in a manner similar to the way that a vehicle manufacturer might make such decisions. In general, the model considers three factors which EPA believes are important to the manufacturer: 1) the cost of the technology, 2) the value which the consumer is likely to place on improved fuel economy and 3) the degree to which the technology moves the manufacturer towards achieving its fleetwide CO_2 emission target.

Technology can be added to individual vehicles using one of three distinct ranking approaches. Within a vehicle type, the order of technology packages is set by the OMEGA user. The model then applies technology to the vehicle with the lowest Technology Application Ranking Factor (hereafter referred to as the TARF). OMEGA offers several different options for calculating TARF values. One TARF equation considers only the cost of the technology and the value of any reduced fuel consumption considered by the vehicle purchaser. The other two TARF equations consider these two factors in addition to the mass of GHG emissions reduced over the life of the vehicle. Fuel prices by calendar year, vehicle survival rates and annual vehicle miles travelled with age are provided by the user to facilitate these calculations.

For each manufacturer, OMEGA applies technology (subject to phase in constraints, as discussed in Joint TSD 3) to vehicles until the sales and VMT-weighted emission average complies with the specified standard or until all the available technologies have been applied. The standard can be a flat standard applicable to all vehicles within a vehicle class (e.g., cars, trucks or both cars and trucks). Alternatively the GHG standard can be in the form of a linear or constrained logistic function, which sets each vehicle's target as a function of vehicle footprint (vehicle track width times wheelbase). When the linear form of footprint-based standard is used, the "line" can be converted to a flat standard for footprints either above or below specified levels. This is referred to as a piece-wise linear standard, and was used in modeling the standards in this analysis.

The emission target can vary over time, but not on an individual model year basis. One of the fundamental features of the OMEGA model is that it applies

[X] See TSD 3.
[Y] "Learning" is the process whereby the cost of manufacturing a certain item tends to decrease with increased production volumes or over time due to experience. While OMEGA does not explicitly incorporate "learning" into the technology cost estimation procedure, the user can currently simulate learning by inputting lower technology costs in each subsequent redesign cycle based on anticipated production volumes or on the elapsed time.

technology to a manufacturer's fleet over a specified vehicle redesign cycle. OMEGA assumes that a manufacturer has the capability to redesign any or all of its vehicles within this redesign cycle. OMEGA does not attempt to determine exactly which vehicles will be redesigned by each manufacturer in any given model year. Instead, it focuses on a GHG emission goal several model years in the future, reflecting the manufacturers' capability to plan several model years in advance when determining the technical designs of their vehicles. Any need to further restrict the application of technology can be effected through the caps on the application of technology to each vehicle type mentioned above.

The OMEGA model is designed to estimate the cost of complying with a regulation in a given year. While the OMEGA design assumes that a manufacturer's entire fleet of vehicles can be redesigned within one redesign cycle, rarely will a manufacturer redesign exactly 20% of its vehicle sales in each of five straight model years. The base emissions and emission reductions of the vehicles being redesigned will vary. Thus, OMEGA inherently assumes the banking and borrowing of credits to enable compliance with standards in the intermediate years of a redesign cycle using the technology projected for the final year of the cycle, assuming that the intermediate standards require gradual improvement each year. However, any credit banking or borrowing outside of the redesign cycle is incumbent upon the user to estimate.[Z]

Once technology has been added so that every manufacturer meets the specified targets (or exhausts all of the available technologies), the model produces a variety of output files. These files include information about the specific technology added to each vehicle and the resulting costs and emissions. Average costs and emissions per vehicle by manufacturer and industry-wide are also determined for each vehicle class.

3.3 OMEGA Model Structure

OMEGA includes several components, including a number of pre-processors that assist users in preparing a baseline vehicle forecast,[AA] creating and ranking technology packages,[BB] and calculating the degree to which technology is present on baseline vehicles. The OMEGA core model collates this information and produces estimates of changes in vehicle cost and CO_2 emission level. Based on the OMEGA core model output, the

[Z] EPA has considered modeling credit banking as part of this analysis, but decided not to analyze the program using this approach for two reasons. First, as the GHG standards continue indefinitely, rather than expiring in 2025, EPA wants to represent the cost of bringing vehicles into compliance with the standard, rather than the reduced cost of a long term credit deficit. Second, properly modeling credit banking requires perfect knowledge of future redesign cycles. The OMEGA redesign cycle approach is specifically designed to avoid this issue, and the related uncertainty. See also Preamble Section I.C explaining the difference in the agencies' programmatic costs estimates which result from this difference in methodology.

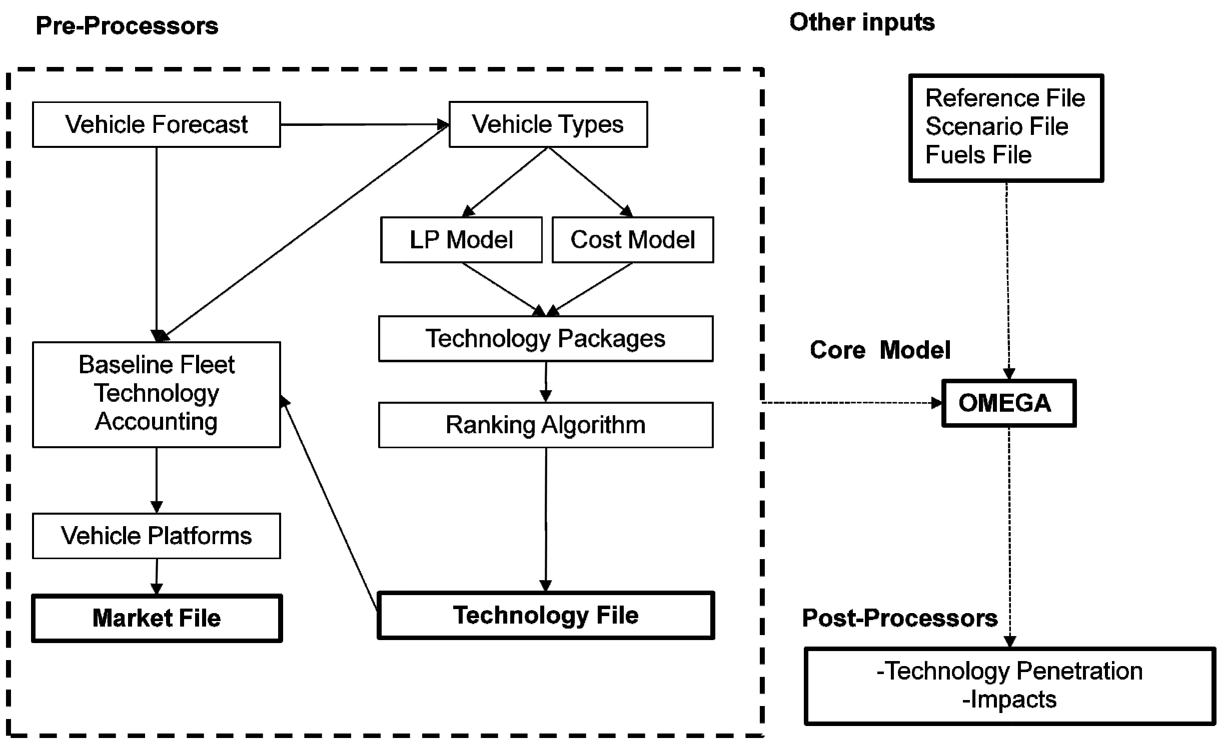
[AA] Joint TSD Chapter 1

[BB] RIA Chapter 1

technology penetration of the new vehicle mix and the scenario impacts (fuel savings, emission impacts, and other monetized benefits) are calculated via post-processors. The pre- and post- processors are Microsoft Excel spreadsheets and scripted programs (written in Visual Basic and MATLAB), while the OMEGA core model is an executable program written in the C# language.

OMEGA is designed to be flexible in a number of ways. Very few numerical values are hard-coded in the model, and consequently, the model relies heavily on its input files. The model utilizes five input files: Market, Technology, Fuels, Scenario, and Reference. Figure 3.3-1 shows the (simplified) information flow through OMEGA, and how these files interact.

Figure 3.3-1 Information Flow in the OMEGA Model



OMEGA utilizes four basic sets of input data. The first, the market file, is a description of the vehicle fleet. The key pieces of data required for each vehicle are its manufacturer, CO_2 emission level, fuel type, projected sales and footprint. The model also requires that each vehicle be assigned to one of the 19 vehicle types, which tells the model which set of technologies can be applied to that vehicle. Chapter 1 of the Joint TSD contains a description of how the market forecasts were created for modeling purposes, and includes a discussion on how EPA defined the 19 vehicle types. In addition, the degree to which each vehicle already reflects the effectiveness and cost of each available technology in the baseline fleet must be input. This prevents the model from adding technologies to vehicles already having these technologies in the baseline. It also avoids the situation, for example, where the model might try to add a basic engine improvement to a current hybrid vehicle. Section 3.4.1.2 of this Regulatory Impact Analysis (RIA) contains a detailed discussion of how EPA accounts for technology present in the baseline fleet in OMEGA.

The second type of input data, the technology file, is a description of the technologies available to manufacturers which consists primarily of their cost, effectiveness, compliance credit value, and electricity consumption. This information was described in Chapter 1 of this RIA and Chapter 3 of the Joint TSD. In all cases, the order of the technologies or technology packages for a particular vehicle type is designated by the model user in the input files prior to running the model. The ranking of the packages is described in Chapter 1 of the RIA.

The third type of input data describes vehicle operational data, such as annual scrap rates and mileage accumulation rates, and economic data, such as fuel prices and discount rates. These estimates are described in chapter 4 of the Joint TSD.

The fourth type of data describes the CO_2 emission standards being modeled. These include the MY 2016 standards and the MY 2017-2025 standards. As described in more detail in Chapter 5 of the Joint TSD and briefly in section 3.5.6 below, the application of A/C technology is evaluated in a separate analysis from those technologies which impact CO_2 emissions over the 2-cycle test procedure. For modeling purposes, EPA applies this AC credit by adjusting manufacturers' car and truck CO2 targets by an amount associated with EPA's projected use of improved A/C systems, as discussed in Section 3.5.6, below.

The input files used in this analysis, as well as the current version of the OMEGA model, are available in the docket (EPA-HQ-OAR-2010-0799). The following sections describe creation of each of the input files from the data and parameters discussed in the Joint.TSD and in this RIA.

3.4 Model Inputs

3.4.1 Market Data

3.4.1.1 Vehicle platforms

As discussed in Joint TSD Chapter 3 and in Chapter 1 of the RIA, vehicle manufacturers typically develop many different models by basing them on a smaller number of vehicle platforms. The platform typically consists of a common set of vehicle architecture and structural components. This allows for efficient use of design and manufacturing resources. In this analysis, EPA created over 200 vehicle platforms which were used to capture the important differences in vehicle and engine design and utility of future vehicle sales. The approximately sixty vehicle platforms are a result of mapping the vehicle fleet into the 19 engine based vehicle types (Table 3.4.1) and the 10 body size and structure based utility classes (Table Of **2**) by manufacturer. As not all vehicle types match to all utility types, and not all manufacturers make all vehicle and utility types, the number of vehicles is less than the multiplicative maximum of the two tables.

Table 3.4-1 Vehicle Types in the MY 2017-2025 Analysis

Vehicle Description	Vehicle Type	Vehicle Class
Auto Subcompact I3 DOHC 4v Auto Subcompact I4 SOHC/DOHC 2v/4v	1	Small car

Auto Subcompact Electric		
Auto Compact SOHC 2v Auto Compact SOHC/DOHC 4v Auto Midsize SOHC/DOHC 4v Pickup Small DOHC 4v	2	Standard car
Auto Subcompact I5 SOHC 4v Auto Subcompact V6 SOHC/DOHC 4v Auto Subcompact I4 SOHC/DOHC 4v turbo/supercharged Auto Compact Rotary Auto Compact I5 DOHC 4v Auto Compact V6 SOHC/DOHC 4v Auto Compact I4 SOHC/DOHC 4v turbo/supercharged Auto Midsize V6 SOHC/DOHC 4v Auto Midsize I4 SOHC/DOHC 4v tubo/supercharged Auto Large V6 SOHC/DOHC 4v Auto Midsize I4 SOHC 4v tubo/supercharged	3	Standard car
Auto Subcompact V6 SOHC 3v Auto Compact V6 OHV 2v Auto Midsize V6 SOHC 2v Auto Midsize V6 OHV 2v Auto Large V6 OHV 2v	4	Standard car
Auto Subcompact V8 DOHC 4v Auto Compact V10 DOHC 4v Auto Compact V8 DOHC 4v turbo/supercharged Auto Compact V8 DOHC 4v/5v Auto Compact V6 DOHC 4v Auto Compact V5 DOHC 4v turbo/supercharged Auto Midsize V12 DOHC 4v Auto Midsize V10 DOHC 4v Auto Midsize V8 DOHC 4v/5v Auto Midsize V8 SOHC 4v Auto Midsize V6 DOHC 4v Auto Midsize V7 DOHC 4v Auto Large V16 DOHC 4v turbo/supercharged Auto Large V12 SOHC 4v turbo/supercharged Auto Large V12 DOHC 4v Auto Large V10 DOHC 4v Auto Large V8 DOHC 4v turbo/supercharged Auto Large V8 DOHC 2v/4v Auto Large V8 SOHC 4v	5	Large car
Auto Subcompact V10 OHV 2v Auto Subcompact V8 SOHC 3v Auto Midsize V8 SOHC 3v turbo/supercharged Auto Midsize V8 SOHC 3v Auto Midsize V8 OHV 2v Auto Large V12 SOHC 3v turbo/supercharged Auto Large V8 SOHC 3v turbo/supercharged Auto Large V8 SOHC 2v Auto Large V8 OHV 2v/4v	6	Large car
SUV Small I4 DOHC 4v SUV Midsize SOHC/DOHC 4v SUV Large DOHC 4v Minivan I4 DOHC 4v	7	Small MPV
SUV Small I4 DOHC 4v turbo/supercharged SUV Midsize V6 SOHC/DOHC 4v	8	Large MPV

SUV Midsize I4 SOHC/DOHC 4v turbo/supercharged SUV Large V6 SOHC/DOHC 4v SUV Large I5 DOHC 2v SUV Large I4 DOHC 4v turbo/supercharged		
SUV Midsize V6 SOHC 2v SUV Large V6 SOHC 2v	9	Large MPV
SUV Small V6 OHV 2v SUV Midsize V6 OHV 2v SUV Large V6 OHV 2v Minivan V6 OHV 2v Cargo Van V6 OHV 2v	10	Large MPV
SUV Large V10 DOHC 4v turbo/supercharged SUV Large V8 DOHC 4v turbo/supercharged SUV Large V8 SOHC/DOHC 4v SUV Large V6 DOHC 4v turbo/supercharged	11	Truck
SUV Large V8 SOHC 3v turbo/supercharged SUV Large V8 SOHC 2v/3v SUV Large V8 OHV 2v Cargo Van V10 SOHC 2v Cargo Van V8 SOHC/OHV 2v	12	Truck
Pickup Large DOHC 4v	13	Small MPV
Pickup Small V6 SOHC 4v Pickup Small I5 DOHC 2v Pickup Large V6 DOHC 2v/4v Pickup Large I5 DOHC 2v	14	Large MPV
Pickup Small V6 SOHC 2v Pickup Small V6 OHV 2v Pickup Large V6 SOHC 2v Pickup Large V6 OHV 2v	15	Large MPV
Pickup Large V8 DOHC 4v	16	Truck
Pickup Large V8 SOHC 2v	17	Truck
Pickup Large V8 SOHC/DOHC 3v turbo/supercharged Pickup Large V8 SOHC 3v	18	Truck
Pickup Large V8 OHV 2v	19	Truck

[a]I4 = 4 cylinder engine, I5 = 5 cylinder engine, V6, V7, and V8 = 6, 7, and 8 cylinder engines, respectively, DOHC = Double overhead cam, SOHC = Single overhead cam, OHV = Overhead valve, v = number of valves per cylinder.

Table Of 2 Vehicle Types in the Technical Assessment Analysis

Utility Class #	Utility Class	Vehicle Use [1]	Footprint Criteria	Structure Criteria
1	Subcompact Auto	Car	Footprint <43	--
2	Compact Auto	Car	43<=Footprint<46	--
3	Mid Size Auto	Car	46<=Footprint<53	--

4	Large Auto	Car	56<=Footprint	--
5	Small SUV	SUV	43<=Footprint<46	--
6	Large SUV	SUV	46<=Footprint	--
7	Small Pickup	Pickup	Footprint < 50	--
8	Large Pickup	Pickup	50<=Footprint	--
9	Cargo Van	Van	--	Ladder Frame
10	Minivan	Van	--	Unibody

1. Vehicle use type is based upon analysis of EPA certification data.

3.4.1.2 Accounting for technology already on vehicles

As mentioned above, our modeling accounts for the fact that many baseline vehicles are already equipped with one or more of the technologies discussed in Joint TSD 3. Because of the choice to apply technologies in packages, and because vehicles are equipped with individual technologies in a wide variety of combinations, accounting for the presence of specific technologies in terms of their proportion of package cost and CO_2 effectiveness requires careful, detailed analysis.

Thus, EPA developed a method to account for the presence of the combinations of applied technologies in terms of their proportion of the technology packages. This analysis can be broken down into four steps

The first step in the process is to break down the available GHG control technologies into five groups: 1) engine-related, 2) transmission-related, 3) hybridization, 4) weight reduction and 5) other. Within each group we gave each individual technology a ranking which generally followed the degree of complexity, cost and effectiveness of the technologies within each group. More specifically, the ranking is based on the premise that a technology on a baseline vehicle with a lower ranking would be replaced by one with a higher ranking which was contained in one of the technology packages which we included in our OMEGA modeling. The corollary of this premise is that a technology on a baseline vehicle with a higher ranking would be not be replaced by one with an equal or lower ranking which was contained in one of the technology packages which we chose to include in our OMEGA modeling. This ranking scheme can be seen in an OMEGA pre-processor (the TEB/CEB calculation macro), available in the docket (EPA-HQ-OAR-2010-0799).

In the second step of the process, we used these rankings to estimate the complete list of technologies which would be present on each vehicle after the application of a technology package. In other words, this step indicates the specific technology on each vehicle after a package has been applied to it. We then used the EPA lumped parameter model to estimate the total percentage CO2 emission reduction associated with the technology present on the baseline vehicle (termed package 0), as well as the total percentage reduction after application of each package. We used a similar approach to determine the total cost of all of the technology present on the baseline vehicle and after the application of each applicable technology package.

The third step in this process is to account for the degree to which each technology package's incremental effectiveness and incremental cost is affected by the technology already present on the baseline vehicle. Termed the technology effectiveness basis (TEB) and cost effectiveness basis (CEB), respectively, the values are calculated in this step using the equations shown in RIA chapter 3. For this final rulemaking, we also account for the credit values using a factor termed other effectiveness basis (OEB).

The value of each vehicle's TEB for each applicable technology package is determined as follows:

$$TEB_i = \frac{1-\left(\dfrac{TotalEffect_{v,i-1}}{1-TotalEffect_{v,i}}\right)\times\left(\dfrac{1-TotalEffect_{p,i}}{1-TotalEffect_{p,i-1}}\right)}{\left(1-\dfrac{1-TotalEffect_{p,i}}{1-TotalEffect_{p,i-1}}\right)}$$

Where

$TotalEffect_{v,i}$ = Total effectiveness of all of the technologies present on the baseline vehicle after application of technology package i

$TotalEffect_{v,i-1}$ = Total effectiveness of all of the technologies present on the baseline vehicle after application of technology package i-1

$TotalEffect_{p,i}$ = Total effectiveness of all of the technologies included in technology package i

$TotalEffect_{p,i-1}$ = Total effectiveness of all of the technologies included in technology package i-1

Equation 3.4-1 – TEB calculation

The degree to which a technology package's incremental cost is reduced by technology already present on the baseline vehicle is termed the cost effectiveness basis, or CEB, in the OMEGA model. The value of each vehicle's CEB for each applicable technology package is determined as follows:

$$CEB_i = 1 - (TotalCost_{v,i} - TotalCost_{v,i-1}) / (TotalCost_{p,i} - TotalCost_{p,i-1})$$

Where

$TotalCost_v$ = total cost of all of the technology present on the vehicle after addition of package i or i-1 to baseline vehicle v

$TotalCost_p$ = total cost of all of the technology included in package i or i-1

i = the technology package being evaluated

i-1 = the previous technology package

Equation 3.4-2 – CEB calculation

As described above, technology packages are applied to groups of vehicles which generally represent a single vehicle platform and which are equipped with a single engine size (e.g., compact cars with four cylinder engine produced by Ford). Thus, the fourth step is to combine the fractions of the CEB and TEB of each technology package already present on the individual baseline vehicle models for each vehicle grouping. For cost, percentages of each package already present are combined using a simple sales-weighting procedure, since the cost of each package is the same for each vehicle in a grouping. For effectiveness, the individual percentages are combined by weighting them by both sales and base CO_2 emission level. This appropriately weights vehicle models with either higher sales or CO_2 emissions within a grouping. Once again, this process prevents the model from adding technology which is already present on vehicles, and thus ensures that the model does not double count technology effectiveness and cost associated with complying with the modeled standards.

The other effectiveness basis (OEB) was designed to appropriately account for credit differences between technologies actually on the vehicle and technology packages applied through the technology input file. As an example, if a baseline vehicle includes start stop technology, and the applied package does not, the model needs to account for this different in off-cycle credit. The OEB is an absolute credit value and is used directly in the model's compliance calculations. Accounting for Net Mass Reduction and Safety related Mass reduction

For this analysis, as in the proposal, EPA applied mass reduction in a manner similar to that used by NHTSA in the CAFE model analysis. In this methodology, and in contrast to the approach taken by EPA in the MYs 2012-2016 rule, more mass is taken out of heavier vehicles, and less mass is taken out of lighter vehicles. This approach allows the agency to provide costs for a technology assessment that is estimated to result in a safety neutral compliance path (i.e., no net additional fatalities attributable to the means modeled to achieve the standards) to the fleet. The agencies received several comments on the safety analysis; these comments are discussed in section II.G of the preamble to the final rule. Manufacturers may not necessarily apply mass reduction in this manner, but as shown here, EPA demonstrates that a technically feasible and economically practicable compliance path exists for manufacturers to meet their fleet standards without compromising safety. The limits on mass reduction, as applied in the OMEGA model, are dependent upon both the technology inputs discussed in TSD Chapter 3, as well as on the fatality coefficients from the 2012 Kahane report and the related adjustments for improvements in federal motor vehicle safety standards (FMVSS) as discussed in Section II.G of the Preamble, and are subject to the same caveats. Between the 2011 Kahane report, and the updated 2012 report used in this final rulemaking, several relevant coefficients were updated. As noted in the proposal, adjustments to these coefficients changes the projected amount of mass reduction projected for the fleet, and correspondingly, changes the projected amount of other technologies. Generally, the revisions to the Kahane coefficients led to less mass reduction technology being used in our modeling as compared to the proposal.

Using a spreadsheet scoping tool, EPA projected the maximum amount of mass reduction on a vehicle by vehicle basis that would result in a net fatality neutral result. Based on the Kahane 2012 coefficients used in the analysis, reducing weight from trucks above 4,594 pounds and from minivans, reduces fatalities. By contrast, the Kahane analysis states that removing weight from the other vehicle categories increases fatalities. The inputs used in the OMEGA analysis are shown below (Table 3.4-3 Fatality coefficients used in OMEGA analysis

).

Only the 1.56 percent risk increase in the lighter cars is statistically significant. There are nonsignificant increases in the heavier cars and the lighter truck-based LTVs, and nonsignificant societal benefits for mass reduction in CUVs, minivans, and the heavier truck-based LTVs. The report concludes that judicious combinations of mass reductions that maintain footprint and are proportionately higher in the heavier vehicles are likely to be safety-neutral – i.e., they are unlikely to have a societal effect large enough to be detected by statistical analyses of crash data. The primarily non-significant results are not due to a paucity of data, but because the societal effect of mass reduction while maintaining footprint, if any, is small. These coefficients are further discussed in Preamble Section II.G of the final rule.

Table 3.4-3 Fatality coefficients used in OMEGA analysis

Vehicle Category by class and weight	Kahane Coefficients [1]	Base fatalities per billion miles	adjustment for new FMVSS	Change in Fatalities per pound per mile[2]
PC below 3106	1.56%	11.091	0.904	1.6E-12
PC above 3106	0.51%	9.313	0.904	4.3E-13
LT below 4594	0.52%	13.241	0.904	6.2E-13
LT above 4594	-0.34%	13.032	0.904	-4.0E-13
Minivan	-0.37%	7.499	0.904	-2.5E-13

[1]Expressed as percent change in base fatalities per 100 pound change in vehicle weight
[2]Calculated as coefficients x base fatalities x adjustment x one billion miles / 100

The mass reduction scoping tool contains the entire fleet discussed in joint TSD 1, along with their curb weight, and their passenger car, light truck, and minivan classification according to the criteria in the 2012 Kahane report. Using this tool, EPA determined that a simulation of fatality neutrality could result by assuming that no MY 2008 baseline passenger car was had its curb weight reduced below 3,200 pounds, and no light trucks were reduced below 4,594 pounds. These values were determined iteratively, with the end product a safety neutral analysis. By contrast, in the proposal, we assumed that no MY 2008 baseline passenger car was reduced in weight below 3,000 pounds, and no light trucks were reduced below 4,594 pounds; for this final rule analysis, we reduced the maximum weight reduction for cars based on the revisions to the Kahane report.[CC] The OMEGA model could still select mass reduction for vehicles above these weight limits, with the amount constrained by these limits and the phase-in cap on mass reduction. Vehicles above these weights could have their weight reduced through mass reduction technology in the OMEGA model. The per vehicle

[CC] The MY 2010 baseline, because it has a different distribution of weight by vehicle class, required a separate analysis. Weight caps of 3,300 pounds (cars) and 4,100 pounds (trucks) were used.

limit on weight reduction for these vehicles was therefore determined by these specific weight cut points, or by the maximum phase-in caps for mass reduction of 15% in 2021, 20% in 2025.. Vehicles below these weights had no net mass reduction applied.

The term “net mass reduction” is used because EPA explicitly accounted for the mass impacts (generally increases) from converting a vehicle into a hybrid-electric, plug-in hybrid electric, or battery electric vehicle. These weight increases were included in the proposal, but were not included in the MYs 2012-2016 analysis or in the technical assessment report. A table of these weight impacts is presented in Joint TSD Chapter 3. The per-vehicle limit on weight reduction determined above is for net mass reduction, rather than the application of total mass reduction technology.

Because the limits on net mass reduction are at the individual vehicle level, they are reflected through modifications to the individual TEB and CEB values rather than the “caps” in the technology file (which are discussed in the next section). EPA assumed that there was no mass reduction technology being utilized in the baseline fleets, or in other words, that the costs for mass reduction appropriately reflected the level of mass reduction technology currently in the fleet.

To implement this schema, each vehicle in the baseline was assigned the following parameters:

- Amount of mass reduction already present in baseline vehicle (assumed to be zero in this analysis)
- Maximum amount of mass reduction allowed
- Mass penalty for adding various technologies to that vehicle

Some examples:

- A baseline vehicle is defined with a 10 percent maximum mass reduction. A vehicle package is applied containing a 15 percent mass reduction. The package mass reduction will be overridden resulting in a 10 percent cost and effectiveness applied to the vehicle.
- A baseline vehicle has a 5 percent penalty for P2HEV conversion. A vehicle package is applied containing a 10 percent mass reduction and a conversion to P2 hybrid. Due to the 5 percent penalty for conversion, the baseline vehicle will incur a cost of 15 percent mass reduction to result in an overall 10 percent reduction. The resulting effectiveness due to the mass reduction will be 10 percent.

Under this system, any amount of mass reduction already in the baseline vehicle will be subtracted from the maximum amount of mass reduction allowed. All vehicles in the baseline fleet are assumed to have no mass reduction technology applied.

3.4.2 Technology Data

Consistent with OMEGA's redesign cycle approach, the technology input file defines the technology packages which the model can add to the vehicle fleet. In brief, each of the 19 vehicle types has an associated list of technology packages, costs, credit values, and effectivenesses.[DD] For this analysis, as discussed below, we considered the off-cycle credit values for active aerodynamics and start-stop technology We also considered the full size pickup truck credits – both mild and strong. Each of the 19 lists was then ordered by how OMEGA should add them to that specific vehicle type. The order of this list is influenced by the relative cost and effectiveness of technologies as well as their market penetration cap (or maximum penetration rate). Market penetration caps of less than 100% restrict the model to that fraction of a vehicle platform.[EE] The processes to build and rank technology packages for the technology file are described in detail in Chapter 1 of the RIA.

For this analysis, a separate technology file was developed for each scenario (reference and control) and model year (2021 and 2025) for which OMEGA was run. The MY 2021 and MY 2025 costs differ due to the learning effects discussed in the Joint TSD Chapter 3, and the technology files also differ due to the different limits on maximum penetrations of technologies. MY 2016 was also run in order to evaluate stranded capital costs.

OMEGA adds technology effectiveness according to the following equation in which the subscripts t and t-1 represent the times before and after technology addition, respectively. The numerator is the effectiveness of the current technology package and the denominator serves to "back out" any effectiveness that is present in the baseline. AIE is the "average incremental effectiveness" of the technology package on a vehicle type, and TEB is the "technology effectiveness basis", which denotes the fraction of the technology present in the baseline.

For this final rulemaking, OMEGA has been modified to additionally include the cost and benefits of certain off-cycle credits start-stop and active aerodynamics) and the full size pickup mild and strong HEV credit. As a result, the model separately tracks each source of CO_2 emissions that are used in the compliance equation. For this analysis, these sources are the vehicle tailpipe and the credits associated with these technologies.

Equation 3.4-3– Calculation of New Tailpipe CO_2

$$CO2_t = \frac{CO2_{t-1} \times (1 - AIE)}{1 - AIE \times TEB}$$

[DD] Given that effectiveness is expressed in percentage terms, the absolute effectiveness differs even among vehicles of the same vehicle type, but the relative effectiveness is the same.
[EE] Penetration caps may reflect technical judgments about technology feasibility and availability, consumer acceptance, lead time, and other reasons as detailed in Chapter 3 of the Joint TSD.

The tailpipe CO_2 is adjusted for the usage of these credits in order to calculate compliance CO_2. If, for example, the applied package has 1.0 grams worth of credit associated with it, then the 1.0 gram from the credit will be subtracted from the tailpipe CO_2 to produce the CO_2 value that OMEGA uses in the compliance calculation. As the credits differ on a vehicle by vehicle, rather than vehicle type by vehicle type basis, the OEB is used in the compliance calculation rather than the credit value in the technology file.

OMEGA then adds technology cost according to the equations below, where CEB refers to the "cost effectiveness basis", or in other words, the technology cost that is present in the baseline. Cost can be calculated for the application of a package, or eventually, for the average cost of a manufacturers fleet (Equation 3.4-4, Equation 3.4-5).

Equation 3.4-4– Calculation of New Cost after applying a package

$$Cost_t = Cost_{t-1} + TechCost * (1 - CEB)$$

Equation 3.4-5 – Calculation of Average Cost for a manufacturer

$$AvgVehicleCost_{MFR} = \left[\frac{TechCost * ModelSales}{TotalFleetSales} \right]_{MFR}$$

EPA's OMEGA model calculates the new CO_2 and average vehicle cost after each technology package has been added.

Relative to the proposal, EPA modified the methodology used to generate the OMEGA technology input file relative to previous analyses.

As background, for both the MYs 2012-2016 rulemaking analysis and the Technical Assessment Report supporting the MYs 2017-2025 NOI, the technology caps generally fell into a few broad numeric categories. As an example, in the analysis supporting the MYs 2012-2016 final rulemaking, most technologies were capped at one of three levels (15%, 85%, 100%). The small number of technology caps made it relatively simple to build packages around technologies which had a shared cap. By contrast, and as discussed in Chapter 3 of the joint TSD, there are both more technologies and more technology cap levels considered in this final rule. Thus, it was more difficult to construct packages with uniform sets of caps. For the proposal, these caps were incorporated into the OMEGA modeling in one of two ways. Major engine technologies such as turbo-charging and downsizing, hybridization, electrification and dieselization were directly controlled through caps in the technology file. Maximum penetration rates of other technologies were managed through multiple runs of the TEB-CEB computation algorithm and modifications to the cost, effectiveness, and electric conversion values in the technology file.

While this "weighting" method was used in the proposal, for this final rule, we have implemented a package ranking scheme based solely upon calculated TARF values. This ranking methodology is described in RIA chapter 1. In short, a list of technically reasonable packages is fed into an algorithm which ranks the packages based on their cost-effectiveness and the availability of space under the selected caps.[23] The output is a ranked technology file. The ranked technology files and the ranking algorithm are docketed.[24]

OMEGA also tracks electrical consumption of each vehicle in kWh per mile. Each technology package is associated with an "electricity conversion percentage" which refers to the increase in the energy consumed by the electric drivetrain relative to reduction in the consumption of energy from liquid fuel. Electricity is a highly refined form of energy which can be used quite efficiently to create kinetic energy. Thus, electric motors are much more efficient than liquid fuel engines. Consequently, the electric consumption percentage input in the Technology File for plug-in vehicles is generally well below than 100%. It may be possible that this percentage could exceed 100% under certain circumstances, for example when one type of plug-in vehicle is being converted into another plug-in vehicle and electricity consumption per mile is increasing due to larger and heavier batteries, etc. However, that was not the case for any of the technologies evaluated in this analysis.

The electric consumption for each vehicle as entered into the OMEGA technology file (in this analysis) in the on-road energy consumption, calculated as

Equation 3.4-6 – Electricity Consumption considered in OMEGA

Electricity Consumption =

2 cycle energy consumption from the battery / (1-on road gap)/ (1-charging losses)

Where:

2 cycle energy consumption	=	Based on vehicle type as documented in TSD 3
On road gap for electricity	=	30%
Charging losses	=	10%

The actual input to the model is the "electric conversion percentage," which is computed as a single fraction for each vehicle type. Thus, in OMEGA's calculations, the resulting electricity consumption differs based on the starting CO_2 of the vehicle.

Equation 3.4-7 – Electrical Conversion Percentage

Electric Conversion Percentage =

$$\frac{\text{Electricity consumption}}{\left(\text{g CO2 reduction} * \frac{\text{12 gram C}}{\text{44 Grams CO2}} * \frac{\text{1 gallon fuel}}{\text{Carbon content of fuel}} * \frac{\text{3409 btu per kwh}}{\text{Energy content of gasoline (btu)}}\right)}$$

Where:
Electricity consumption = values from TSD 3 or RIA 1
Carbon content of fuel = 2433 for gasoline
Energy content of fuel = 115,000 btu/gallon

3.4.3 The Scenario File

3.4.3.1 Reference Scenario

In order to determine the technology costs associated with this final rulemaking, EPA performed three separate modeling exercises. The first was to determine the costs associated with meeting the MY 2016 GHG regulations. EPA considers the MY 2016 GHG regulations to constitute the "reference case" for calculating the costs and benefits of this GHG rule. In other words, absent any further rulemaking, this is the vehicle fleet EPA would expect to see through 2016 -- the "status quo". In order to calculate the costs and benefits of this final rule alone, EPA subtracted out any costs associated with meeting any existing standards related to GHG emissions.

EPA assumes that in the absence of the MYs 2017-2025 GHG and CAFE standards, the reference case fleet in MYs 2017-2025 would have fleetwide GHG emissions performance no better than that projected to be necessary to meet the MY 2016 standards. While it is not possible to know with certainty the future fleetwide GHG emissions performance in the absence of more stringent standards, EPA believes that this approach is the most reasonable assumption for developing the reference case fleet for MYs 2017-2025. A discussion of this topic is presented in section III.D of the preamble, and is presented below with additional figures and tables.

One critical factor supporting the final approach is that AEO2012 Early Release projects relatively stable gasoline prices over the next 13 years. The average actual price in the U.S. for the first four months of 2012 for regular gasoline was $3.68 per gallon[FF] with prices approaching $4.00 in March and April.[GG] The AEO2012 Early Release reference case projects the regular gasoline price to be $3.87 per gallon in 2025, only slightly higher than the price for the first four months of 2012.[HH] Accordingly, the reference fleet for MYs 2017-2025 reflects constant GHG emission standards (i.e. the MY 2016 standards continuing to apply in each of those model years), and gasoline prices only slightly higher than today's gasoline prices.

As discussed at proposal, these are reasonable assumptions to make for a reference case. See 76 FR 75030-31. Based on these fuel price projections, the reference fleet for MYs 2017-2025 should correspond to a time period where there is a stable, unchanging GHG standard, and essentially stable gasoline prices.

[FF] In 2012 dollars. As 2012 is not yet complete, we are not relating this value to 2010 dollars. See RIA 1 for additional details on the conversion between dollar years.
[GG] http://www.eia.gov/petroleum/gasdiesel/ and click on "full history" for weekly regular gasoline prices through May 7, 2012, last accessed on May 8, 2012.
[HH] http://www.eia.gov/forecasts/aeo/er/ last accessed on May 8, 2012.

EPA reviewed the historical record for similar periods when we had stable fuel economy standards and stable gasoline prices. EPA maintains, and publishes every year, the authoritative reference on new light-duty vehicle CO_2 emissions and fuel economy.[II] This report contains very detailed data from MYs 1975-2010. There was an extended 18-year period from 1986 through 2003 during which CAFE standards were essentially unchanged,[JJ] and gasoline prices were relatively stable and remained below $1.50 per gallon for almost the entire period. The 1975-1985 and 2004-2010 timeframes are not relevant in this regard due to either rising gasoline prices, rising CAFE standards, or both. Thus, the 1986-2003 time frame is an excellent analogue to the period out to MY 2025 during which AEO projects relatively stable gasoline prices. EPA analyzed the Fuel Economy Trends data from the 1986-2003 timeframe (during which CAFE standards were universal rather than attribute-based),shown in Table 3.4-4 and Table 3.4-5 and has drawn three conclusions: 1) there was a small, industry-wide, average over-compliance with CAFE on the order of 1-2 mpg or 3-4%, 2) almost all of this industry-wide over-compliance was from 3 companies (Toyota, Honda, and Nissan) that routinely over-complied with the universal CAFE standards simply because they produced smaller and lighter vehicles relative to the industry average, and 3) full line car and truck manufacturers, such as General Motors, Ford, and Chrysler, which produced larger and heavier vehicles relative to the industry average and which were constrained by the universal CAFE standards, rarely over-complied during the entire 18-year period.

[20] Previous OMEGA documentation for versions used in MYs 2012-2016 Final Rule (EPA-420-B-09-035), Interim Joint TAR (EPA-420-B-10-042). Docket Nos. EPA-HQ-OAR-2010-0799-1108 and EPA-HQ-OAR-2010-0799-1109. The documentation for OMEGA 1.4.1 is also in the docket.

[21] http://www.epa.gov/oms/climate/models.htm

[22] EPA-420-R-09-016, September 2009. (Docket No. EPA-HQ-OAR-2010-0799-1135)

[23] OMEGA model ranking algorithm. Available in the docket on the DVD ""FRM OMEGA model, OMEGA inputs and outputs & GREET 2011 (DVD)"

[24] OMEGA model inputs and outputs. These are available on a DVD in the docket (Docket No. EPA-HQ-OAR-2010-0799). "FRM OMEGA model, OMEGA inputs and outputs & GREET 2011 (DVD)"

[II] Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 through 2010, November 2010, available at www.epa.gov/otaq/fetrends.htm.
[JJ] There are no EPA LD GHG emissions regulations prior to MY 2012.

Table 3.4-4 Fuel Economy Data for Selected Manufacturers, 1986-2003—Cars

Year	Standard	GM	Ford	Chrysler	Sales-Weighted average	Delta	Vehicle Weight		Toyota	Honda	Nissan	Sales-Weighted average	Delta	Vehicle Weight		Vehicle Weight delta
1986	27.5	27.0	26.7	28.6	27.1	-0.4	3145		32.3	33.6	29.9	32.0	4.5	2706		439
1987	27.5	27.2	26.5	27.7	27.1	-0.4	3149		32.9	32.8	29.3	31.5	4.0	2782		368
1988	27.5	28.1	27.0	28.5	27.8	0.3	3157		32.7	31.8	30.6	31.8	4.3	2779		378
1989	27.5	27.4	26.9	28.0	27.3	-0.2	3207		31.8	31.3	30.2	31.2	3.7	2822		385
1990	27.5	27.3	26.3	27.4	27.0	-0.5	3298		30.4	30.4	28.4	29.9	2.4	2943		355
1991	27.5	27.2	27.2	27.5	27.2	-0.3	3252		30.6	30.3	29.0	30.1	2.6	2950		303
1992	27.5	26.7	26.7	27.7	26.8	-0.7	3329		28.9	30.9	29.9	29.9	2.4	3051		279
1993	27.5	27.3	27.8	27.9	27.6	0.1	3269		29.0	32.2	29.1	30.1	2.6	3071		198
1994	27.5	27.5	27.1	26.2	27.2	-0.3	3334		29.1	32.1	29.8	30.3	2.8	3084		250
1995	27.5	27.3	27.6	28.2	27.6	0.1	3330		30.0	32.8	29.2	30.8	3.3	3102		228
1996	27.5	27.9	26.3	27.2	27.3	-0.2	3388		29.5	31.8	30.2	30.5	3.0	3126		262
1997	27.5	28.2	26.9	27.2	27.6	0.1	3353		29.8	32.1	29.6	30.6	3.1	3122		230
1998	27.5	27.6	27.3	28.3	27.6	0.1	3347		30.2	32.0	30.2	30.9	3.4	3249		98
1999	27.5	27.4	27.2	27.0	27.3	-0.2	3429		30.4	30.9	29.6	30.4	2.9	3280		148
2000	27.5	27.6	27.1	27.6	27.4	-0.1	3448		30.5	31.0	28.0	30.2	2.7	3258		190
2001	27.5	28.1	26.8	27.6	27.6	0.1	3463		31.3	32.2	28.3	31.0	3.5	3233		230
2002	27.5	28.5	27.1	27.0	27.8	0.3	3442		30.7	32.0	28.9	30.8	3.3	3303		140
2003	27.5	28.6	26.7	28.5	27.9	0.4	3506		32.4	32.7	27.9	31.5	4.0	3276		230
Average 1986-2003						-0.1							3.3			262

Table 3.4-5 Fuel Economy Data for Selected Manufacturers, 1986-2003—Trucks

Year	Standard	GM	Ford	Chrysler	Sales-Weighted average	Delta	Vehicle Weight		Toyota	Honda	Nissan	Sales-Weighted average	Delta	Vehicle Weight		Vehicle Weight delta
1986	20.0	20.2	20.3	20.7	20.3	0.3	3917		26.1		24.7	25.5	5.5	3240		677
1987	20.5	20.5	20.5	21.3	20.7	0.2	3876		25.9		23.5	24.9	4.4	3259		617
1988	20.5	20.2	20.6	21.4	20.6	0.1	3961		24.4		22.7	23.8	3.3	3352		609
1989	20.5	20.4	20.1	21.0	20.5	0.0	4016		23.2		23.7	23.3	2.8	3420		596
1990	20.0	19.8	20.2	21.4	20.3	0.3	4102		21.8		25.3	23.2	3.2	3528		574
1991	20.2	21.2	20.5	21.1	20.9	0.7	4026		22.4		24.8	23.1	2.9	3628		397
1992	20.2	20.3	20.2	21.3	20.5	0.3	4132		21.9		24.0	22.5	2.3	3620		512
1993	20.4	20.3	20.8	21.2	20.7	0.3	4141		22.1		23.7	22.7	2.3	3637		505
1994	20.5	20.2	20.8	20.5	20.5	0.0	4204		22.0	20.2	22.9	22.3	1.8	3711		494
1995	20.6	20.1	20.6	20.1	20.3	-0.3	4248		21.2	25.5	22.4	22.0	1.4	3797		452
1996	20.7	20.8	20.8	20.2	20.6	-0.1	4295		23.1	22.2	22.9	23.0	2.3	3678		617
1997	20.7	20.4	20.2	20.2	20.3	-0.4	4445		22.6	24.7	22.3	22.8	2.1	3734		711
1998	20.7	21.2	20.2	20.0	20.5	-0.2	4376		23.4	25.5	22.3	23.5	2.8	3762		614
1999	20.7	20.3	19.8	19.9	20.0	-0.7	4508		23.0	25.2	21.2	23.1	2.4	3943		564
2000	20.7	20.7	20.0	20.4	20.4	-0.3	4456		22.0	25.0	20.8	22.2	1.5	4098		359
2001	20.7	20.4	20.1	19.5	20.0	-0.7	4591		22.3	24.7	20.7	22.3	1.6	4125		465
2002	20.7	19.8	20.2	20.0	20.0	-0.7	4686		22.2	25.3	20.7	22.5	1.8	4149		537
2003	20.7	20.2	20.0	20.9	20.3	-0.4	4738		22.0	24.8	21.9	22.9	2.2	4195		544
Average 1986-2003						-0.1							2.6			547

Since the MYs 2012-2016 standards are footprint-based, every major manufacturer is expected to be constrained by those standards in MY 2016 and manufacturers of small vehicles will not routinely over-comply as they had with the past universal standards.[KK] Thus, the historical evidence and the footprint-based design of the MY 2016 GHG emissions and CAFE standards strongly support the use of a reference case fleet where there are no further fuel economy improvements beyond those required by the MY 2016 standards. While it is possible that one or two companies may over-comply, any voluntary over-compliance by one company would generate credits that could be sold to other companies to substitute for their more expensive compliance technologies; this ability to buy and sell credits could eliminate any over-compliance for the overall fleet.[25]

Figure 3.4-1 shows that, over the 1986-2003 period discussed above, overall average fleetwide fuel economy decreased by about 3 mpg, even with stable car CAFE standards and very slightly increasing truck CAFE standards, as the market shifted from a market dominated by cars in the 1980s to one split between cars and trucks in 2003.[LL] All projections of actual GHG emissions and fuel economy performance in MY 2016 or any other future model year are projections, of course, and it is plausible that actual GHG emissions and fuel economy performance in MYs 2017-2025, absent more stringent standards, could be lower (or higher) than projected if there are shifts in car and truck market share to truck market share, or to higher footprint levels.

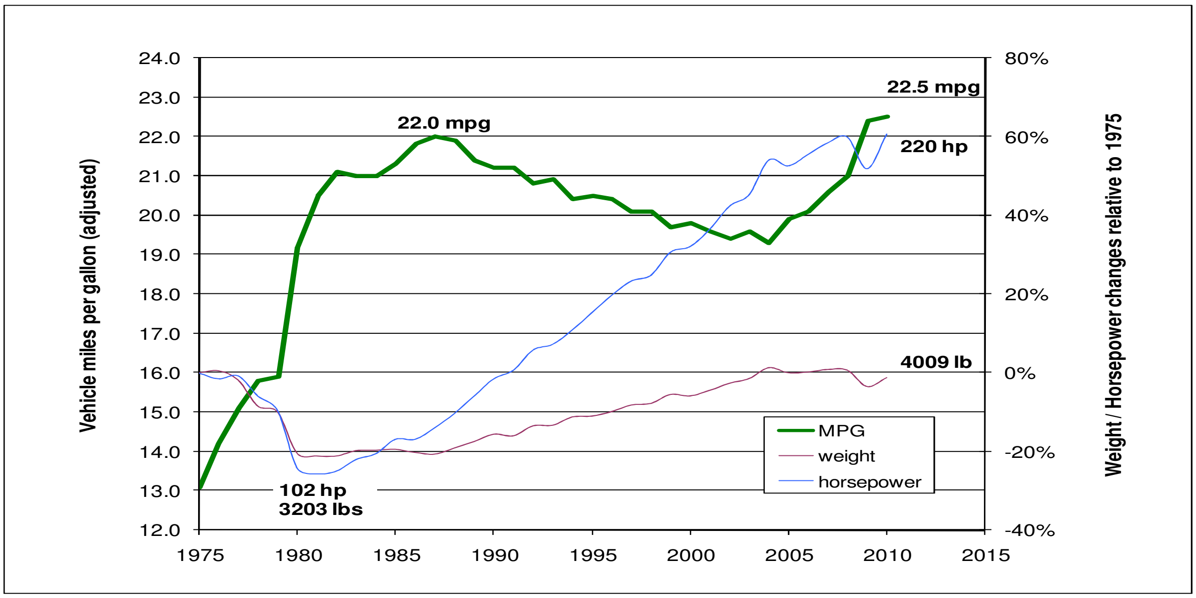
Based on the historical data discussed above, EPA believes that there is a very low likelihood that any manufacturers will voluntarily achieve higher fuel economy than their footprint-based targets relative to the projected fleet average 35.5 mpg level of MY 2016 standards in MYs 2017-2025, in the absence of more stringent standards. There are several reasons for this: gasoline prices through MY 2025 are projected to be only slightly higher than today's levels, footprint-based standards are constraining for all manufacturers, and manufacturers may use future technology to support other vehicle attributes preferred by consumers such as power and utility. In addition, even if some individual manufacturers were to voluntarily over comply, it is possible that they would sell their GHG credits to other manufacturers who might find that it is more cost-effective to purchase credits than to continue to meet the 35.5 mpg level. EPA is aware of several automakers that have already purchased, or are in the process of negotiating to purchase, credits for MY 2012. In this scenario, if all credits were sold to other manufacturers, there would be no meaningful impact on the agency's projected costs and benefits. But, the agency recognizes that it is possible that, under certain circumstances, there might be some industry-wide over compliance. For example, oil prices much higher than projected by AEO 2012 early release could lead to a higher baseline due to industry-wide over compliance. But, under this higher baseline, costs and benefits would both be lower and it is impossible to know whether net consumer and societal benefits would be higher or lower. Both agencies assume no fuel economy

[KK] With the notable exception of manufacturers who only market electric vehicles or other limited product lines.
[LL] Note that the mpg values in this one figure are consumer label values, not the CAFE/compliance values shown throughout this preamble. Consumer label values are typically about 20% lower than compliance values. The trends are the same.

improvement in their primary analyses, but we note that NHTSA chose to analyze an alternative market-driven baseline as a sensitivity case in their RIA.

Figure 3.4-1 Average Fleetwide Light-Duty Vehicle Fuel Economy, Horsepower, and Weight, 1975-2010

(fuel economy data is consumer label values, about 20% lower than compliance values)



Consistent with this discussion, for the reference case, EPA configured the OMEGA model to determine the cost to comply with the MY 2016 standards and did not allow access to the post-MY 2016 technology levels. This reflects the belief that manufacturers will (a) need to comply in MY 2016, and so will not add additional technology to their vehicles afterwards to comply with GHG standards (b) will use that new technology for attributes other than fuel economy, since their vehicles are already compliant, (c) in the absence of additional regulation beyond the MYs 2012-2016 rule would not develop many of the technologies become available under the control case runs. Similarly, the air conditioning technology usage was capped at the MY 2016 projections, as manufacturers that were already compliant would have no need to add additional air conditioning technology (especially as the cost of alternative refrigerants is significantly higher than the present refrigerant).

EPA ran the OMEGA model three times with the same MY 2016 technology input but with the market data file configured to MY 2016, MY 2021, and MY 2025 sales. The model was run three times because car/truck sales mix shifts between MYs 2016 and 2025 require some manufacturers to add minimal additional technology to their vehicles in order to remain in compliance. While slight additional amounts of technology are added or removed, the compliance cost for the MY 2016 rule declines over time as a result of the learning effects discussed in the RIA Chapter 1. To reflect this learning progression, but also that the technology choices were made during MY 2016, OMEGA was run with MY 2016 costs, which were then post-processed to the proper cost-year.

Consistent with the proposal and the MYs 2012-2016 rule analysis, EPA did not allow EVs and PHEVs (maximum penetration caps of zero) in the reference case. While the penetration of EVs and PHEVs in MY 2016 will likely be non-zero, as they are being sold in MY 2011, EPA chose not to include these technologies in the reference case assessment due to their cost-distorting effects on the smallest companies (Table 3.4-6). In the OMEGA projections, the vast majority of companies do not use EVs or PHEVs to comply with the MY 2016 standards. Six companies, some of which are intermediate or smaller volume, under the technology restrictions set forth in this analysis, cannot comply with the MY 2016 standards.[MM] This finding is consistent with the MY 2012-2016 rule analysis; these companies are BMW, Daimler, Geely-Volvo, Volkswagen, Porsche and Tata (which is comprised of Jaguar and Land Rover vehicles in the U.S. fleet).[26]

As shown below, these manufacturers (other than Porsche) could comply with the MY 2016 standards by including electric vehicles and plug-in hybrids in their fleet. As reflected in the MY 2012-2016 rule, EPA believes that it is unlikely that these manufacturers will convert up to 10% of their fleet EVs and PHEVs by MY 2016. As an alternative to this choice, these companies could exceed our assumed technology caps on other technologies (such as mass reduction), make use of carry-forward credits, carry-back credits, or purchase credits from another manufacturer. Alternatively, they could use a vehicle compliance strategy not considered here, as discussed in section III.D of the MYs 2012-2016 rule. Thus the compliance cost for these vehicles for the 2016 rule could potentially be greater than presented in this analysis, which would decrease the incremental cost of the later MY standards.[NN] Moreover the companies would eventually achieve the 2016 targets in the reference case (Table 3.5-1 & Table 3.5-2).

For these manufacturers, the MY 2016 reference case results presented are those with the fully allowable application of technology available in EPA's OMEGA modeling analysis and not for the technology projected to enable compliance with the final MY 2016 standards. Again, this analytic choice increases the incremental costs of the MY 2017-MY 2025 program for these companies.

[MM] While OMEGA model results are presented assuming that all manufacturers must comply with the program as proposed (to the extent that they can), some manufacturers, such as small volume manufacturers may be eligible for additional options (and alternative standards) which have not been considered here. Under the final rule, small volume manufacturers with U.S. sales of less than 5,000 vehicles would be able to petition EPA for an alternative standard for MY 2017 and later. Manufacturers currently meeting the 5,000 vehicle cut point include Lotus, Aston Martin, and McLaren. Under the MY 2016 program, the TLAAS program – which provides additional lead time to certain intermediate sized manufacturers which meet alternative standards would also be available, and is not modeled here.

[NN] Of course, any manufacturer could, in theory, also find more cost-effective methods to comply than those shown in this analysis.

Table 3.4-6 – MY 2016 EV+PHEV Penetrations, and additional potential additional costs in MY 2016[1,2]

Manufacturer	MY 2016 Shortfall without EV/PHEV (g/mile)	MY 2016 Shortfall with EV/PHEV (g/mile)	Reference Cost Delta added by including EVs ($)	EV+PHEV (% of MY 2016 Sales if added)
BMW	3	-	-$89	3%
Daimler	19	-	$1,447	7%
Geely-Volvo	20	-	$1,846	8%
Porsche[OO]	46	18	$2,195	11%
Tata/ JLR	25	-	$2,215	9%
Volkswagen	14	-	$803	6%

[1]Please note that these are MY 2016 costs, and would be significantly lower in later MYs as a result of learning. See RIA 1 for more details
[2] For BMW, the few number of EVs that they would produce in the reference case would be more cost effective than other technologies that they would need to use to comply, resulting in a negative cost delta.

The MY 2016 coefficients are found in 75 FR at 25409. When input to OMEGA, these coefficients were adjusted vertically upward by 10.2 grams (cars) and 11.4 grams (trucks) to account for external calculations relating to air conditioning costs.

No additional compliance flexibilities were explicitly modeled for the MY 2016 standards. The EPA flexible fueled vehicle credit expires before MY 2016.[PP] The Temporary Leadtime Allowance Alternative Standards (TLAAS), as analyzed in RIA chapter 5 of the MY 2012-2016 rule, is projected to have an impact of approximately 0.1 g/mile in MY 2016, and expire afterwards.[QQ] While this may have a more significant impact on specific companies, as a result of the overall magnitude, no incentive credits are projected to be available in the reference case modeled here. In a change from the proposal modeling, under the reference case standards, manufacturers are allowed access to the off-cycle credit "menu." As a result, the off-cycle credits modeled here lower costs relative to the proposal.

[OO] EPA analyzed Porsche and VW as separate fleets for the Final Rule. However, on August 1, 2012, VW completed its acquisition of Porsche and thus EPA expects that the Porsche fleet will be combined with the VW fleet for purposes of compliance with the MY 2017-2025 standards.
[PP] The credit available for producing FFVs will have expired, although the real world usage credits will be available.
[QQ] In this final rulemaking, EPA is providing additional lead time to meet the initial model year standards for certain intermediate volume manufacturers, as described in Preamble section III.B.8. The discussion in the text above, however, concerns how the reference fleet is modeled in OMEGA, and in the reference fleet case, the TLAAS ends with MY 2016.

With respect to car-truck trading, the OMEGA model facilitates the trading of car-truck credits on a total lifetime CO_2 emission basis, consistent with the provisions of the final rule and the MY 2016 rule. For example, if a manufacturer over-complies with its applicable CO_2 standard for cars by 10 g/mi, sells 1,000,000 cars, and cars have a lifetime VMT of 195,264 miles, it generates 1,952,640 metric tons of CO_2 credits. If these credits are used to compensate for under-compliance towards the truck CO_2 standard and truck sales are 500,000, with a lifetime truck VMT of 225,865 miles, the manufacturer's truck CO_2 emission level could be as much as 17.3 g/mi CO_2 above the standard. Car-truck trading was allowed in the OMEGA runs without limit consistent with the trading provisions of the MYs 2012-2016 and MYs 2017-2025 GHG rules.

3.4.3.2 Control Scenarios

Similar to the reference scenario, OMEGA runs were conducted for MYs 2021 and 2025 for the standards adopted in the final rule and for alternative scenarios. The standards for these scenarios were derived from the coefficients discussed in Section III.B of the preamble. The joint EPA/NHTSA development of these target curve coefficients is discussed in Joint TSD Chapter 2. As in MYs 2012-2016, these curves were adjusted for air conditioning through a negative additive offset based on the estimated year over year penetrations of air conditioning shown in preamble III.C.1 and below. For the OMEGA cost analysis, as we analyzed air conditioning costs outside of the model, we re-adjusted the model input curves to remove this projected penetration of air conditioning technology. For the MY 2021 and MY 2025 OMEGA runs, air conditioning credits were projected at 18.8 g/mi for cars and 24.4 g/mi for light trucks.

EPA's final rule incorporates several additional compliance flexibilities. See generally Preamble section III.C for an extended discussion of these credits. EVs and PHEVs were modeled with zero g/mile in all cases. As discussed in Section III.B of the preamble, the cap for EVs and PHEVs at zero g/mile (i.e. the production cap relating to when upstream emissions associated with increased electricity use is considered for compliance purposes) is related to the standard level being finalized. As in the proposal, for purposes of this cost modeling, we assume that this cap is never reached. The PH/EV multipliers (a regulatory incentive, as explained in Preamble section III.C.2) were not modeled in this cost analysis, but would reduce compliance costs in MY 2021 and earlier. The multiplier is included in EPA's benefits analysis, as discussed in RIA chapter 4. A discussion of the potential impacts of these credits can be found in preamble section III.B.2 and RIA chapter 4. Costs beyond MY 2025 assume no technology changes on the vehicles, and implicitly assume that the compliance values for EVs remains at zero gram/mile.[RR]

As discussed previously, in a difference from the proposal, the credit for mild and strong HEV full size pickups was modeled in this final rule analysis. Two off-cycle credits, those for start-stop technology and active aerodynamics were also included. In a change from

[RR] The costs for PHEVs and EVs in this rule reflect those costs discussed in Joint TSD Chapter 3, and do not reflect any tax incentives, as the availability of those tax incentives in this time frame is uncertain.

the proposal modeling, the impact of the off-cycle credits for start-stop technology and active aerodynamics were modeled. This change lowers costs relative to the proposal.

Like the reference case, car-truck trading was allowed without limit.

3.4.4 Fuels and reference data

Fuels data was based on AEO fuel prices, as documented in Chapter 4 of the Joint TSD. Estimates of carbon and energy content per gallon of liquid fuel are consistent with the MYs 2012-2016 rule analysis.

The VMT schedules used in the TARF calculation were chosen for consistency with the EPA credit trading regulations, and is 195,264 for cars and 225,685 for trucks. It is important to use the same VMT schedules in the numerator and denominator of the TARF equation, or unintended errors can be introduced to the OMEGA model calculations.

Using the data and equations discussed above, the OMEGA model begins by determining the specific CO_2 emission standard applicable for each manufacturer and its vehicle class (i.e., car or truck). As the reference case, the final rule, and all alternatives allow for averaging across a manufacturer's car and truck fleets, the model determines the CO_2 emission standard applicable to each manufacturer's car and truck sales from the two sets of coefficients describing the piecewise linear standard functions for cars and trucks (i.e. the respective car and truck curves) in the inputs, and creates a combined car-truck standard. This combined standard considers the difference in lifetime VMT of cars and trucks, as indicated in the regulations which govern credit trading between these two vehicle classes.

The model then works with one manufacturer at a time to add technologies until that manufacturer meets its applicable standard. The OMEGA model can utilize several approaches to determining the order in which vehicles receive technologies. For this analysis, EPA used a "manufacturer-based net cost-effectiveness factor" to rank the technology packages in the order in which a manufacturer is likely to apply them. Conceptually, this approach estimates the cost of adding the technology from the manufacturer's perspective and divides it by the mass of CO_2 the technology will reduce. One component of the cost of adding a technology is its production cost, as discussed above. However, it is expected that new vehicle purchaser's value improved fuel economy since it reduces the cost of operating the vehicle. Typical vehicle purchasers are assumed to value the fuel savings accrued over the period of time which they will own the vehicle, which is estimated to be approximately five years.[SS] It is also assumed that consumers discount these savings at the same rate as that used in the rest of the analysis (3 or 7 percent).[TT] Any residual value of the additional technology which might remain when the vehicle is sold is not considered for this analysis.

[SS] For a fuller discussion of this topic see Section III.H

[TT] While our costs and benefits are discounted at 3% or 7%, the decision algorithm (TARF) used in OMEGA was run at a discount rate of 3%. Given that manufacturers must comply with the standard regardless of the discount rate used in the TARF, this has little impact on the technology projections shown here. Further, the fuel savings aspect of the TARF are only directly relevant when two different fuels are being compared, because the fuel saving/delta CO_2 ratio is a constant for any given vehicle on a single fuel in a single model year.

The CO_2 emission reduction is the change in CO_2 emissions multiplied by the percentage of vehicles surviving after each year of use multiplied by the annual miles travelled by age.

Given this definition, the higher priority technologies are those with the lowest manufacturer-based net cost-effectiveness value (relatively low technology cost or high fuel savings leads to lower values).[UU] Because the order of technology application is set for each vehicle, the model uses the manufacturer-based net cost-effectiveness primarily to decide which vehicle receives the next technology addition. Initially, technology package #1 is the only one available to any particular vehicle. However, as soon as a vehicle receives technology package #1, the model considers the manufacturer-based net cost-effectiveness of technology package #2 for that vehicle and so on. In general terms, the equation describing the calculation of manufacturer-based cost effectiveness is as follows:

Equation 3.4-8 – Calculation of Manufacturer-Based Cost Effectiveness

$$CostEffManuf_t = \frac{\Delta TechCost - \Delta FS}{\Delta CO_2 x\, VMT_{regulatory}}$$

Where:

$CostEffManuf_t$= Manufacturer-Based Cost Effectiveness (in dollars per kilogram CO_2),
TechCost = Marked up cost of the technology (dollars),
FS = Difference in fuel consumption due to the addition of technology times fuel price and discounted over the payback period, or the number of years of vehicle use over which consumers value fuel savings when evaluating the value of a new vehicle at time of purchase
dCO_2 = Difference in CO_2 emissions (g/mile) due to the addition of technology
$VMT_{regulatory}$ = the statutorily defined VMT

EPA describes the technology ranking methodology and manufacturer-based cost effectiveness metric in greater detail in the OMEGA documentation.[27] Please note that the TARF equation does not consider attributes other than cost effectiveness, credit values, and relative fuel savings. This distinction is significant when considering the technology penetrations presented later in this chapter. An electric vehicle, which is approximately the same cost as a plug-hybrid but is significantly more effective over the certification cycles, will generally be chosen by OMEGA before the plug-in hybrid. The current TARF does not reflect potential consumer concerns with the range limits of the electric vehicle (reflecting our assumption that purchasers of these vehicles are aware of the vehicles' limited range)..[VV] As a result of EVs greater cost-effectiveness, relatively more (although still few in an absolute sense) are shown in the projected technology penetrations. When calculating the fuel savings in the TARF equation, the full retail price of fuel, including taxes is used. While taxes are not generally included when calculating the cost or benefits of a regulation, the net cost

[UU] To ensure a consistent approach to technology ranking, the credit value is modeled as producing fuel savings. While credits will not actually provide fuel savings to a consumer, an increase in the denominator (increased CO2 savings) without a corresponding change in the numerator (increased fuel savings) can provide a perverse situation where adding credits makes a technology less desirable.

[VV] As the general form of the TARF is net cost change/net CO2 change, the electric vehicle attributes could be assigned a value and incorporated into the TARF.

component of the manufacturer-based net cost-effectiveness equation is not a measure of the social cost of this rule, but a measure of the private cost, (i.e., a measure of the vehicle purchaser's willingness to pay more for a vehicle with higher fuel efficiency). Since vehicle operators pay the full price of fuel, including taxes, they value fuel costs or savings at this level, and the manufacturers will consider this when choosing among the technology options.[WW]

The values of manufacturer-based net cost-effectiveness for specific technologies will vary from vehicle to vehicle, often substantially. This occurs for three reasons. First, both the cost and fuel-saving component cost, ownership fuel-savings, and lifetime CO_2 effectiveness of a specific technology all vary by the type of vehicle or engine to which it is being applied (e.g., small car versus large truck, or 4-cylinder versus 8-cylinder engine). Second, the effectiveness of a specific technology often depends on the presence of other technologies already being used on the vehicle (i.e., the dis-synergies). Third, the absolute fuel savings and CO_2 reduction of a percentage an incremental reduction in fuel consumption depends on the CO_2 level of the vehicle prior to adding the technology. Chapter 1 of EPA's RIA contains further detail on the values of manufacturer-based net cost-effectiveness for the various technology packages.

3.5 Analysis Results

3.5.1 Targets and Achieved Values

3.5.1.1 Reference Case

Table 3.5-1 Reference Case Targets and Projected Shortfall in MY 2021

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	222	--	222	222	346	--	123
BMW	228	285	243	245	237	287	6
Chrysler/Fiat	230	295	259	261	227	297	0
Daimler	234	301	250	252	253	324	21
Ferrari	235	0	235	235	399	0	165
Ford	230	305	256	258	232	302	0

[WW] This definition of manufacturer-based net cost-effectiveness ignores any change in the residual value of the vehicle due to the additional technology when the vehicle is five years old. Based on historic used car pricing, applicable sales taxes, and insurance, vehicles are worth roughly 23% of their original cost after five years, discounted to year of vehicle purchase at 7% per annum. It is reasonable to estimate that the added technology to improve CO2 level and fuel economy will retain this same percentage of value when the vehicle is five years old. However, it is less clear whether first purchasers, and thus, manufacturers consider this residual value when ranking technologies and making vehicle purchases, respectively. For this final rule, this factor was not included in our determination of manufacturer-based net cost-effectiveness in the analyses.

Geely	232	280	247	248	247	306	19
General Motors	226	308	267	270	225	309	0
Honda	223	283	241	243	222	285	0
Hyundai	223	280	234	236	223	279	0
Kia	218	291	235	237	223	279	0
Lotus	206	--	206	206	240	--	34
Mazda	220	276	230	231	224	262	0
Mitsubishi	219	270	237	238	223	261	0
Nissan	226	294	247	249	222	302	0
Porsche[XX]	206	287	225	227	250	335	45
Spyker	219	280	227	229	248	319	31
Subaru	211	258	222	224	221	231	0
Suzuki	208	272	219	221	209	265	0
Tata	250	273	261	262	248	330	30
Tesla	206	--	206	206	0	--	0
Toyota	221	294	250	252	216	300	0
Volkswagen	217	296	233	235	225	329	14
Fleet	224	296	250	252	224	300	1

[XX] EPA analyzed Porsche and VW as separate fleets for the Final Rule. However, on August 1, 2012, VW completed its acquisition of Porsche and thus EPA expects that the Porsche fleet will be combined with the VW fleet for purposes of compliance with the MY 2017-2025 standards.

Table 3.5-2 Reference Case Targets and Projected Shortfall in MY 2025

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	222	-	222	222	346	-	123
BMW	228	286	243	245	237	289	7
Chrysler/Fiat	229	294	257	259	227	296	-
Daimler	234	302	249	251	254	324	21
Ferrari	235	-	235	235	399	-	165
Ford	230	303	253	255	232	299	-
Geely	232	280	246	248	247	306	19
General Motors	226	307	264	267	225	307	-
Honda	223	283	240	242	221	285	-
Hyundai	223	280	234	235	223	279	-
Kia	218	292	234	236	222	278	-
Lotus	206	-	206	206	240	-	34
Mazda	220	277	230	231	223	263	-
Mitsubishi	219	270	236	238	223	261	-
Nissan	227	292	246	248	222	301	-
Porsche	206	287	224	226	250	335	45
Spyker	219	280	227	228	248	319	30
Subaru	211	258	222	223	220	230	-
Suzuki	208	272	219	220	209	265	-
Tata	250	273	261	261	248	330	28
Tesla	206	-	206	206	-	-	-
Toyota	221	293	247	250	215	302	-
Volkswagen	217	296	233	235	225	329	13
Fleet	224	295	248	250	224	299	1

3.5.1.1 Final rule and Alternatives

Table 3.5-3 Final rule Targets and Projected Shortfall in MY 2021

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	171	-	171	171	192	-	21
BMW	175	236	191	193	180	225	-
Chrysler/Fiat	176	246	208	211	183	239	-
Daimler	180	253	198	200	176	262	-
Ferrari	181	-	181	181	227	-	46
Ford	177	261	205	208	189	240	-
Geely	178	231	195	196	174	237	-
General Motors	174	262	217	221	187	249	-
Honda	171	234	190	192	177	221	-
Hyundai	171	231	183	184	175	215	-
Kia	167	243	184	186	177	214	-
Lotus	157	-	157	157	156	-	-
Mazda	169	227	179	180	176	198	-
Mitsubishi	168	220	186	188	182	197	-
Nissan	174	248	197	199	179	238	-
Porsche	157	238	176	178	148	263	-
Spyker	168	230	177	178	163	257	-
Subaru	161	207	172	174	175	167	-
Suzuki	158	222	170	171	164	199	-
Tata	193	223	208	209	153	256	-
Tesla	157	-	157	157	-	-	-
Toyota	170	247	200	202	172	242	-
Volkswagen	166	248	183	185	163	259	-
Fleet	172	250	199	202	178	239	-

Table 3.5-4 Final rule Targets and Projected Shortfall in MY 2025

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	142	-	142	142	142	-	-
BMW	146	194	159	160	144	199	-
Chrysler/Fiat	146	201	170	172	154	191	-
Daimler	150	208	163	165	140	233	-
Ferrari	150	-	150	150	168	-	17
Ford	147	212	167	169	157	192	-
Geely	148	189	160	162	138	207	-
General Motors	144	213	177	180	156	202	-
Honda	142	191	156	158	145	183	-
Hyundai	142	188	151	152	146	172	-
Kia	139	199	152	153	145	177	-
Lotus	131	-	131	131	130	-	-
Mazda	140	186	148	149	145	163	-
Mitsubishi	139	180	153	154	146	166	-
Nissan	145	202	162	163	149	191	-
Porsche	131	195	144	146	118	231	-
Spyker	139	188	146	147	132	231	-
Subaru	134	169	142	143	145	138	-
Suzuki	132	181	140	141	133	174	-
Tata	161	182	171	171	114	228	-
Tesla	131	-	131	131	-	-	-
Toyota	141	201	163	165	146	193	-
Volkswagen	138	203	151	152	131	228	-
Fleet	143	203	163	165	147	194	-

Table 3.5-5 Alternative 1- (Trucks +20) Targets and Projected Shortfall in MY 2021

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	171	-	171	171	192	-	21
BMW	175	256	197	199	188	225	-
Chrysler/Fiat	176	267	217	221	195	248	-
Daimler	180	273	203	206	184	263	-
Ferrari	181	-	181	181	227	-	46
Ford	177	282	213	216	196	249	-
Geely	178	250	201	203	184	237	-
General Motors	174	283	228	232	198	260	-
Honda	171	253	196	199	182	231	-
Hyundai	171	250	187	189	181	215	-
Kia	167	263	189	191	181	222	-
Lotus	157	-	157	157	156	-	-
Mazda	169	245	182	184	179	204	-
Mitsubishi	168	238	192	195	185	209	-
Nissan	174	267	203	206	186	244	-
Porsche	157	258	181	184	155	263	-
Spyker	168	249	179	181	166	257	-
Subaru	161	225	176	178	177	180	-
Suzuki	158	241	173	175	169	199	-
Tata	193	242	217	219	171	260	-
Tesla	157	-	157	157	-	-	-
Toyota	170	266	207	211	180	251	-
Volkswagen	166	268	187	189	169	259	-
Fleet	172	270	206	210	185	247	-

Table 3.5-6 Alternative 2- (Trucks -20) Targets and Projected Shortfall in MY 2021

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	171	-	171	171	192	-	21
BMW	175	217	186	188	172	224	-
Chrysler/Fiat	176	227	199	201	178	225	-
Daimler	180	232	193	194	168	262	-
Ferrari	181	-	181	181	227	-	46
Ford	177	240	198	200	183	229	-
Geely	178	212	189	190	165	236	-
General Motors	174	241	207	209	177	237	-
Honda	171	215	184	186	171	216	-
Hyundai	171	212	179	180	170	210	-
Kia	167	223	180	181	170	214	-
Lotus	157	-	157	157	156	-	-
Mazda	169	208	176	177	172	193	-
Mitsubishi	168	202	180	181	172	195	-
Nissan	174	228	191	192	171	232	-
Porsche	157	219	172	173	142	262	-
Spyker	168	212	174	175	159	257	-
Subaru	161	190	168	169	170	167	-
Suzuki	158	204	167	168	160	199	-
Tata	193	205	199	199	134	256	-
Tesla	157	-	157	157	-	-	-
Toyota	170	227	192	194	170	226	-
Volkswagen	166	228	179	180	157	259	-
Fleet	172	229	192	194	172	229	-

Table 3.5-7 Alternative 3- (Cars +20) Targets and Projected Shortfall in MY 2021

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	190	-	190	190	192	-	1
BMW	196	236	206	208	200	226	-
Chrysler/Fiat	197	246	219	221	195	248	-
Daimler	201	253	214	215	196	263	-
Ferrari	202	-	202	202	227	-	25
Ford	197	261	219	221	201	255	-
Geely	199	231	209	210	194	237	-
General Motors	194	262	227	230	198	258	-
Honda	190	234	204	205	187	240	-
Hyundai	190	231	199	200	191	228	-
Kia	187	243	199	201	188	240	-
Lotus	176	-	176	176	175	-	-
Mazda	188	227	195	196	191	216	-
Mitsubishi	187	220	199	200	190	216	-
Nissan	194	248	211	212	191	254	-
Porsche	176	238	190	192	166	264	-
Spyker	187	230	193	194	181	257	-
Subaru	180	207	187	187	187	187	-
Suzuki	177	222	185	186	179	215	-
Tata	215	223	219	219	171	260	-
Tesla	176	-	176	176	-	-	-
Toyota	189	247	212	214	180	258	-
Volkswagen	185	248	198	200	182	260	-
Fleet	192	250	212	214	190	251	-

Table 3.5-8 Alternative 4- (Cars -20) Targets and Projected Shortfall in MY 2021

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	151	-	151	151	192	-	41
BMW	155	236	177	179	160	224	-
Chrysler/Fiat	156	246	197	200	178	223	-
Daimler	159	253	182	185	154	262	-
Ferrari	160	-	160	160	227	-	67
Ford	157	261	192	195	177	227	-
Geely	158	231	180	183	155	236	-
General Motors	154	262	207	211	178	239	-
Honda	151	234	177	179	163	211	-
Hyundai	151	231	167	169	162	193	-
Kia	148	243	169	172	161	204	-
Lotus	139	-	139	139	139	-	-
Mazda	149	227	163	165	160	183	-
Mitsubishi	148	220	173	176	165	192	-
Nissan	154	248	183	186	166	224	-
Porsche	139	238	162	165	139	258	5
Spyker	148	230	160	161	143	255	-
Subaru	142	207	158	160	159	159	-
Suzuki	140	222	155	156	146	198	-
Tata	171	223	197	199	132	256	-
Tesla	139	-	139	139	-	-	-
Toyota	150	247	188	191	166	225	-
Volkswagen	147	248	167	170	144	257	-
Fleet	152	250	186	190	166	227	-

Table 3.5-9 Alternative 1- (Trucks +20) Targets and Projected Shortfall in MY 2025

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	142	-	142	142	142	-	-
BMW	146	213	164	166	152	199	-
Chrysler/Fiat	146	221	179	181	163	202	-
Daimler	150	228	168	170	148	233	-
Ferrari	150	-	150	150	168	-	17
Ford	147	232	173	176	162	202	-
Geely	148	207	166	168	149	207	-
General Motors	144	234	187	190	163	216	-
Honda	142	210	162	164	149	194	-
Hyundai	142	207	155	156	149	177	-
Kia	139	218	156	158	148	187	-
Lotus	131	-	131	131	130	-	-
Mazda	140	204	151	152	149	163	-
Mitsubishi	139	198	159	161	154	171	-
Nissan	145	221	167	170	153	204	-
Porsche	131	214	149	151	125	231	-
Spyker	139	207	148	149	135	231	-
Subaru	134	186	146	147	149	142	-
Suzuki	132	200	143	145	138	174	-
Tata	161	200	179	181	128	231	-
Tesla	131	-	131	131	-	-	-
Toyota	141	221	170	173	152	204	-
Volkswagen	138	223	155	157	137	228	-
Fleet	143	223	170	172	153	205	-

Table 3.5-10 Alternative 2- (Trucks -20) Targets and Projected Shortfall in MY 2025

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	142	-	142	142	142	-	-
BMW	146	174	153	154	136	199	-
Chrysler/Fiat	146	181	161	163	143	185	-
Daimler	150	187	158	159	134	233	-
Ferrari	150	-	150	150	168	-	17
Ford	147	191	161	162	148	189	-
Geely	148	170	155	155	130	207	-
General Motors	144	192	167	169	142	193	-
Honda	142	172	151	152	140	176	-
Hyundai	142	170	147	148	142	168	-
Kia	139	179	147	148	141	171	-
Lotus	131	-	131	131	130	-	-
Mazda	140	167	145	145	142	161	-
Mitsubishi	139	162	147	148	137	166	-
Nissan	145	182	156	157	141	190	-
Porsche	131	175	140	141	113	231	-
Spyker	139	170	143	144	129	231	-
Subaru	134	152	138	139	139	138	-
Suzuki	132	163	137	138	129	172	-
Tata	161	164	162	162	97	226	-
Tesla	131	-	131	131	-	-	-
Toyota	141	181	156	157	139	184	-
Volkswagen	138	183	147	148	125	228	-
Fleet	143	183	156	158	139	188	-

Table 3.5-11 Alternative 3- (Cars +20) Targets and Projected Shortfall in MY 2025

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	162	-	162	162	162	-	-
BMW	166	194	173	174	163	199	-
Chrysler/Fiat	166	201	181	183	163	206	-
Daimler	171	208	179	180	161	233	-
Ferrari	171	-	171	171	171	-	-
Ford	168	212	181	183	168	209	-
Geely	169	189	175	175	159	207	-
General Motors	164	213	188	189	163	214	-
Honda	162	191	170	171	158	196	-
Hyundai	162	188	167	168	159	194	-
Kia	158	199	167	168	160	193	-
Lotus	149	-	149	149	149	-	-
Mazda	160	186	164	165	161	180	-
Mitsubishi	159	180	166	166	162	175	-
Nissan	165	202	176	177	159	211	-
Porsche	149	195	159	160	137	231	-
Spyker	159	188	163	163	151	231	-
Subaru	153	169	156	157	157	156	-
Suzuki	150	181	155	156	152	175	-
Tata	183	182	183	183	134	231	-
Tesla	149	-	149	149	-	-	-
Toyota	161	201	175	177	156	207	-
Volkswagen	157	203	166	168	150	228	-
Fleet	163	203	176	178	160	207	-

Table 3.5-12 Alternative 4- (Cars -20) Targets and Projected Shortfall in MY 2025

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	122	-	122	122	139	-	17
BMW	126	194	144	146	123	199	-
Chrysler/Fiat	126	201	158	161	141	184	-
Daimler	129	208	147	149	120	233	-
Ferrari	130	-	130	130	168	-	38
Ford	127	212	153	156	139	188	-
Geely	128	189	146	148	119	207	-
General Motors	124	213	167	170	146	193	-
Honda	122	191	143	145	133	168	-
Hyundai	122	188	135	137	129	165	-
Kia	120	199	136	138	129	167	-
Lotus	112	-	112	112	111	-	-
Mazda	121	186	131	133	127	156	-
Mitsubishi	120	180	140	142	128	166	-
Nissan	125	202	147	150	132	186	-
Porsche	112	195	130	132	103	224	-
Spyker	120	188	129	130	112	231	-
Subaru	115	169	127	129	130	126	-
Suzuki	113	181	125	126	114	172	-
Tata	139	182	159	160	97	223	-
Tesla	112	-	112	112	-	-	-
Toyota	121	201	150	153	137	178	-
Volkswagen	119	203	135	137	112	228	-
Fleet	123	203	150	152	133	185	-

3.5.2 Penetration of Selected Technologies

On the following pages, we present OMEGA model projected penetrations of selected technologies by manufacturer, model year, and car/truck class. These tables show results of the reference case, the final standards, and the four alternatives which EPA examined. In addition, we note that although the agencies have adopted technology phase-in caps for purposes of their respective modeling analyses, no manufacturer is actually restricted by the technology caps modeled in this analysis. However, a smaller manufacturer with only a few vehicle platforms may only be able to pursue a single technology path. As an example, a manufacturer with a single platform is unlikely to produce diesel, electric, and hybrid electric vehicles, but is more likely to focus on a selected engine technology. Thus in reality, manufacturers can use a greater (or lesser) degree of technology than we model.

Moreover, although OMEGA model results are presented assuming that all manufacturers must comply with the base program as finalized (to the extent that they can), some manufacturers, such as small volume manufacturers may be eligible for additional options (including alternative case-by-case standards)which have not been considered here. As described in the preamble, small volume manufacturers with U.S. sales of less than 5,000 vehicles would be able to petition EPA for an alternative standard for MY 2017 and later. Manufacturers currently meeting the 5,000 vehicle sales cut point include Lotus, Aston Martin, and McLaren. Intermediate volume manufacturers may be eligible for additional lead time in the early model years of the program, this is a flexibility also not considered here. As described in Preamble Section III.B.6, EPA is finalizing provisions to allow additional lead time for intermediate volume manufacturers that sell less than 50,000 vehicles per year, for the first four years of the program (MY 2017-2020).

The technology penetrations presented here are absolute, and include baseline technologies. The analyses shown here illustrate just one single path towards compliance, although there are many. As an example, please see the September 2010 Technical Assessment report, where we describe technology feasibility through several different potential compliance paths.

Table 3.5-13 Technology abbreviations

Abbreviation	Meaning
Mass Tech Applied	Mass Technology Applied, expressed as a negative number
True Mass	Net Mass Reduced
Mass Penalty	Mass increase due to technology
TDS18/24/27	turbocharged & downsized at 18/24/27 bar BMEP
AT6/8	Automatic transmission
DCT6/8	Dual Clutch Transmission
MT	Manual transmission
HEG	High Efficiency Gearbox
EGR	Cooled exhaust gas recirculation
HEV	Hybrid electric vehicle
EV	Full electric vehicle
PHEV	Plug-in HEV
SS	12V stop-start
LRRT2	Lower rolling resistance tires level 2
IACC2	Improved Accesssories level 2
EFR2	Engine friction reduction level 2
DI	Stoichiometric gasoline direct injection
DSL	Advanced diesel

[25] Oates, Wallace E., Paul R. Portney, and Albert M. McGartland. “The Net Benefits of Incentive-Based Regulation: A Case Study of Environmental Standard Setting." American Economic Review 79(5) (December 1989): 1233-1242. (Docket No. EPA-HQ-OAR-2010-0799-0833)

[26] See 75 FR at 25457.

[27] See OMEGA documentation at http://www.epa.gov/otaq/climate/models.htm.

3.5.3 Projected Technology Penetrations in Reference Case

Table 3.5-14 Reference Car Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-8%	-8%	1%	40%	15%	0%	0%	0%	60%	24%	16%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
BMW	-6%	-6%	1%	45%	15%	0%	12%	0%	48%	26%	13%	0%	15%	15%	0%	0%	55%	0%	30%	0%	75%	15%	0%
Chrysler/Fiat	-5%	-5%	0%	56%	14%	0%	5%	1%	52%	28%	3%	0%	2%	0%	0%	0%	0%	0%	30%	0%	70%	0%	0%
Daimler	-7%	-6%	1%	40%	15%	0%	0%	38%	28%	30%	0%	0%	15%	15%	0%	0%	55%	0%	30%	0%	69%	16%	0%
Ferrari	-4%	-3%	1%	40%	15%	0%	14%	0%	52%	28%	5%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
Ford	-5%	-5%	0%	64%	15%	0%	22%	9%	36%	19%	7%	0%	10%	2%	0%	0%	0%	0%	30%	0%	79%	0%	0%
Geely	-6%	-6%	1%	52%	15%	0%	13%	4%	46%	25%	3%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%	0%
General Motors	-5%	-5%	0%	47%	11%	0%	6%	2%	52%	26%	6%	0%	2%	0%	0%	0%	0%	0%	30%	0%	59%	0%	0%
Honda	-1%	-1%	0%	0%	0%	0%	0%	0%	50%	22%	12%	0%	0%	3%	0%	0%	0%	0%	2%	0%	0%	0%	0%
Hyundai	-2%	-2%	0%	28%	0%	0%	14%	7%	37%	20%	7%	0%	0%	0%	0%	0%	0%	0%	8%	0%	28%	0%	0%
Kia	-1%	-1%	0%	7%	0%	0%	5%	2%	46%	25%	9%	0%	0%	0%	0%	0%	0%	0%	2%	0%	7%	0%	0%
Lotus	-1%	0%	1%	52%	15%	0%	0%	0%	15%	0%	85%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
Mazda	-3%	-3%	0%	47%	12%	0%	13%	5%	37%	20%	17%	0%	3%	0%	0%	0%	0%	0%	30%	0%	59%	0%	0%
Mitsubishi	-5%	-4%	0%	71%	15%	0%	14%	5%	42%	22%	8%	0%	15%	0%	0%	0%	12%	0%	30%	0%	85%	0%	11%
Nissan	-2%	-2%	0%	22%	8%	0%	3%	1%	49%	27%	5%	0%	1%	1%	0%	0%	0%	0%	30%	0%	30%	0%	0%
Porsche	-2%	-2%	1%	43%	15%	0%	0%	0%	28%	10%	56%	0%	15%	15%	0%	0%	55%	0%	30%	0%	73%	15%	0%
Spyker	-8%	-8%	1%	55%	15%	0%	2%	0%	49%	26%	13%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
Subaru	-3%	-3%	0%	72%	15%	0%	2%	0%	42%	22%	25%	0%	15%	0%	0%	0%	0%	0%	30%	0%	85%	0%	2%
Suzuki	0%	0%	0%	70%	15%	0%	4%	2%	45%	25%	12%	0%	15%	0%	0%	0%	0%	0%	30%	0%	85%	0%	0%
Tata	-8%	-8%	1%	40%	15%	0%	14%	0%	55%	30%	0%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-1%	-1%	0%	3%	0%	0%	5%	3%	50%	11%	7%	0%	0%	15%	0%	0%	0%	0%	1%	0%	8%	0%	0%
Volkswagen	-4%	-4%	1%	46%	15%	0%	9%	0%	51%	25%	14%	0%	15%	15%	0%	0%	55%	0%	30%	0%	84%	15%	0%
Fleet	-3%	-3%	0%	32%	8%	0%	8%	4%	46%	21%	8%	0%	4%	6%	0%	0%	8%	0%	19%	0%	43%	2%	0%

Table 3.5-15 Reference Truck Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-8%	-7%	1%	67%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	65%	0%	30%	0%	83%	5%	0%
Chrysler/Fiat	-6%	-6%	0%	22%	15%	0%	65%	28%	2%	1%	3%	0%	15%	0%	0%	0%	0%	0%	30%	0%	37%	0%	0%
Daimler	-9%	-8%	1%	56%	13%	0%	0%	100%	0%	0%	0%	0%	13%	15%	0%	0%	62%	0%	30%	0%	69%	19%	0%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-6%	-6%	0%	66%	15%	0%	59%	26%	4%	2%	3%	0%	15%	2%	0%	0%	2%	0%	29%	0%	81%	0%	0%
Geely	-9%	-8%	1%	68%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	68%	0%	30%	0%	83%	2%	0%
General Motors	-7%	-7%	0%	33%	15%	0%	66%	29%	1%	0%	0%	0%	15%	0%	0%	0%	0%	0%	30%	0%	48%	0%	0%
Honda	-3%	-3%	0%	62%	0%	0%	39%	22%	15%	8%	0%	0%	0%	0%	0%	0%	0%	0%	11%	0%	62%	0%	0%
Hyundai	-4%	-4%	0%	85%	0%	0%	59%	30%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	15%	0%	85%	0%	0%
Kia	-4%	-4%	0%	84%	0%	0%	54%	30%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	15%	0%	84%	0%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-8%	-8%	0%	64%	15%	0%	47%	20%	17%	9%	2%	0%	11%	0%	0%	0%	0%	0%	30%	0%	79%	0%	0%
Mitsubishi	-9%	-8%	0%	70%	15%	0%	51%	26%	7%	4%	0%	0%	15%	0%	0%	0%	61%	0%	30%	0%	85%	0%	15%
Nissan	-4%	-4%	0%	65%	12%	0%	44%	24%	11%	6%	2%	0%	12%	0%	0%	0%	0%	0%	30%	0%	77%	0%	0%
Porsche	-8%	-8%	1%	64%	15%	0%	69%	30%	0%	0%	1%	0%	15%	15%	0%	0%	62%	0%	30%	0%	92%	8%	0%
Spyker	-3%	-2%	1%	70%	15%	0%	61%	30%	0%	0%	0%	0%	15%	9%	0%	0%	70%	0%	30%	0%	85%	0%	6%
Subaru	-9%	-8%	0%	70%	15%	0%	17%	9%	33%	18%	8%	0%	15%	0%	0%	0%	21%	0%	30%	0%	85%	0%	4%
Suzuki	-7%	-7%	0%	70%	15%	0%	55%	30%	0%	0%	0%	0%	15%	0%	0%	0%	82%	0%	30%	0%	85%	0%	0%
Tata	-6%	-5%	1%	63%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	60%	0%	30%	0%	75%	10%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-2%	-2%	0%	47%	0%	0%	47%	25%	5%	3%	3%	0%	0%	5%	0%	0%	0%	0%	12%	0%	48%	0%	0%
Volkswagen	-8%	-8%	1%	67%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	67%	0%	30%	0%	96%	4%	0%
Fleet	-5%	-5%	0%	50%	9%	0%	55%	28%	5%	3%	2%	0%	9%	3%	0%	0%	7%	0%	23%	0%	61%	1%	0%

Table 3.5-16 Reference Fleet (Sales-Weighted) Technology Penetration in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-8%	-8%	1%	40%	15%	0%	0%	0%	60%	24%	16%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
BMW	-7%	-6%	1%	51%	15%	0%	27%	8%	35%	19%	9%	0%	15%	15%	0%	0%	57%	0%	30%	0%	77%	12%	0%
Chrysler/Fiat	-6%	-6%	0%	41%	15%	0%	32%	13%	29%	16%	3%	0%	8%	0%	0%	0%	0%	0%	30%	0%	55%	0%	0%
Daimler	-8%	-7%	1%	44%	14%	0%	0%	54%	21%	22%	0%	0%	14%	15%	0%	0%	57%	0%	30%	0%	69%	17%	0%
Ferrari	-4%	-3%	1%	40%	15%	0%	14%	0%	52%	28%	5%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
Ford	-6%	-6%	0%	65%	15%	0%	35%	15%	25%	13%	6%	0%	11%	2%	0%	0%	1%	0%	29%	0%	79%	0%	0%
Geely	-7%	-6%	1%	57%	15%	0%	31%	12%	32%	17%	2%	0%	15%	15%	0%	0%	61%	0%	30%	0%	76%	9%	0%
General Motors	-6%	-6%	0%	40%	13%	0%	36%	16%	27%	14%	3%	0%	8%	0%	0%	0%	0%	0%	30%	0%	53%	0%	0%
Honda	-2%	-2%	0%	19%	0%	0%	12%	7%	39%	18%	8%	0%	0%	2%	0%	0%	0%	0%	5%	0%	19%	0%	0%
Hyundai	-2%	-2%	0%	40%	0%	0%	23%	12%	30%	16%	6%	0%	0%	0%	0%	0%	0%	0%	9%	0%	40%	0%	0%
Kia	-2%	-2%	0%	24%	0%	0%	16%	9%	35%	19%	7%	0%	0%	0%	0%	0%	0%	0%	5%	0%	24%	0%	0%
Lotus	-1%	0%	1%	52%	15%	0%	0%	0%	15%	0%	85%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
Mazda	-4%	-4%	0%	50%	13%	0%	19%	7%	33%	18%	14%	0%	4%	0%	0%	0%	0%	0%	30%	0%	62%	0%	0%
Mitsubishi	-6%	-6%	0%	70%	15%	0%	27%	12%	30%	16%	5%	0%	15%	0%	0%	0%	29%	0%	30%	0%	85%	0%	12%
Nissan	-3%	-3%	0%	35%	9%	0%	15%	8%	37%	20%	4%	0%	4%	1%	0%	0%	0%	0%	30%	0%	45%	0%	0%
Porsche	-4%	-3%	1%	48%	15%	0%	16%	7%	22%	8%	43%	0%	15%	15%	0%	0%	57%	0%	30%	0%	77%	13%	0%
Spyker	-8%	-7%	1%	57%	15%	0%	10%	4%	42%	22%	11%	0%	15%	14%	0%	0%	57%	0%	30%	0%	72%	13%	1%
Subaru	-5%	-5%	0%	72%	15%	0%	6%	2%	40%	21%	21%	0%	15%	0%	0%	0%	5%	0%	30%	0%	85%	0%	3%
Suzuki	-1%	-1%	0%	70%	15%	0%	13%	7%	37%	20%	10%	0%	15%	0%	0%	0%	15%	0%	30%	0%	85%	0%	0%
Tata	-7%	-6%	1%	51%	15%	0%	42%	15%	28%	15%	0%	0%	15%	15%	0%	0%	58%	0%	30%	0%	73%	12%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-2%	-2%	0%	20%	0%	0%	21%	12%	32%	8%	5%	0%	0%	12%	0%	0%	0%	0%	5%	0%	24%	0%	0%
Volkswagen	-5%	-4%	1%	50%	15%	0%	22%	6%	40%	20%	11%	0%	15%	15%	0%	0%	57%	0%	30%	0%	86%	13%	0%
Fleet	-4%	-4%	0%	39%	8%	0%	24%	12%	32%	15%	6%	0%	6%	5%	0%	0%	7%	0%	21%	0%	49%	2%	0%

Table 3.5-17 Reference Car Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-8%	-8%	1%	40%	15%	0%	0%	0%	60%	24%	16%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
BMW	-6%	-6%	1%	45%	15%	0%	12%	0%	48%	26%	13%	0%	15%	15%	0%	0%	55%	0%	30%	0%	75%	15%	0%
Chrysler/Fiat	-5%	-5%	0%	51%	14%	0%	4%	1%	52%	28%	3%	0%	1%	0%	0%	0%	0%	0%	30%	0%	65%	0%	0%
Daimler	-7%	-7%	1%	40%	15%	0%	0%	39%	28%	30%	0%	0%	15%	15%	0%	0%	55%	0%	30%	0%	69%	16%	0%
Ferrari	-4%	-3%	1%	40%	15%	0%	14%	0%	52%	28%	5%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
Ford	-5%	-5%	0%	64%	15%	0%	23%	9%	35%	19%	7%	0%	11%	1%	0%	0%	0%	0%	30%	0%	79%	0%	0%
Geely	-6%	-6%	1%	51%	15%	0%	13%	4%	46%	25%	3%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%	0%
General Motors	-5%	-5%	0%	47%	11%	0%	5%	2%	52%	26%	6%	0%	2%	0%	0%	0%	0%	0%	30%	0%	59%	0%	0%
Honda	-1%	-1%	0%	0%	0%	0%	0%	0%	50%	22%	12%	0%	0%	3%	0%	0%	0%	0%	2%	0%	0%	0%	0%
Hyundai	-2%	-2%	0%	28%	0%	0%	13%	7%	38%	21%	7%	0%	0%	0%	0%	0%	0%	0%	6%	0%	28%	0%	0%
Kia	-1%	-1%	0%	6%	0%	0%	4%	2%	52%	19%	9%	0%	0%	0%	0%	0%	0%	0%	2%	0%	6%	0%	0%
Lotus	-1%	0%	1%	52%	15%	0%	0%	0%	15%	0%	85%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
Mazda	-3%	-3%	0%	46%	12%	0%	13%	4%	37%	20%	18%	0%	3%	0%	0%	0%	0%	0%	30%	0%	58%	0%	0%
Mitsubishi	-4%	-4%	0%	71%	15%	0%	13%	5%	42%	22%	8%	0%	15%	0%	0%	0%	11%	0%	30%	0%	85%	0%	11%
Nissan	-2%	-2%	0%	22%	8%	0%	3%	1%	49%	27%	5%	0%	1%	1%	0%	0%	0%	0%	30%	0%	31%	0%	0%
Porsche	-2%	-2%	1%	43%	15%	0%	0%	0%	28%	10%	56%	0%	15%	15%	0%	0%	55%	0%	30%	0%	73%	15%	0%
Spyker	-8%	-8%	1%	55%	15%	0%	2%	0%	49%	26%	13%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
Subaru	-4%	-3%	0%	72%	15%	0%	2%	0%	42%	22%	25%	0%	15%	0%	0%	0%	0%	0%	30%	0%	85%	0%	5%
Suzuki	0%	0%	0%	70%	15%	0%	3%	2%	45%	25%	12%	0%	15%	0%	0%	0%	0%	0%	30%	0%	85%	0%	0%
Tata	-9%	-8%	1%	40%	15%	0%	14%	0%	55%	30%	0%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-1%	-1%	0%	3%	0%	0%	5%	3%	50%	11%	7%	0%	0%	16%	0%	0%	0%	0%	1%	0%	8%	0%	0%
Volkswagen	-4%	-4%	1%	46%	15%	0%	9%	0%	51%	25%	14%	0%	15%	15%	0%	0%	55%	0%	30%	0%	84%	15%	0%
Fleet	-3%	-3%	0%	32%	8%	0%	8%	4%	46%	21%	8%	0%	5%	6%	0%	0%	8%	0%	19%	0%	43%	2%	0%

Table 3.5-18 Reference Truck Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-8%	-7%	1%	67%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	64%	0%	30%	0%	83%	6%	0%
Chrysler/Fiat	-6%	-6%	0%	23%	15%	0%	65%	28%	2%	1%	3%	0%	15%	0%	0%	0%	0%	0%	30%	0%	38%	0%	0%
Daimler	-9%	-8%	1%	56%	13%	0%	0%	100%	0%	0%	0%	0%	13%	15%	0%	0%	62%	0%	30%	0%	69%	19%	0%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-6%	-6%	0%	66%	15%	0%	59%	26%	4%	2%	3%	0%	15%	3%	0%	0%	4%	0%	29%	0%	81%	0%	1%
Geely	-8%	-8%	1%	68%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	68%	0%	30%	0%	83%	2%	0%
General Motors	-7%	-7%	0%	36%	15%	0%	66%	29%	1%	0%	0%	0%	15%	0%	0%	0%	0%	0%	30%	0%	51%	0%	0%
Honda	-3%	-3%	0%	61%	0%	0%	39%	21%	16%	8%	0%	0%	0%	0%	0%	0%	0%	0%	11%	0%	61%	0%	0%
Hyundai	-4%	-4%	0%	85%	0%	0%	59%	30%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	15%	0%	85%	0%	0%
Kia	-4%	-4%	0%	84%	0%	0%	54%	30%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	15%	0%	84%	0%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-8%	-8%	0%	65%	15%	0%	48%	21%	15%	8%	2%	0%	11%	0%	0%	0%	0%	0%	30%	0%	80%	0%	0%
Mitsubishi	-9%	-8%	0%	70%	15%	0%	51%	26%	7%	4%	0%	0%	15%	0%	0%	0%	61%	0%	30%	0%	85%	0%	15%
Nissan	-4%	-4%	0%	65%	12%	0%	44%	24%	10%	6%	2%	0%	12%	0%	0%	0%	0%	0%	30%	0%	77%	0%	0%
Porsche	-8%	-8%	1%	64%	15%	0%	69%	30%	0%	0%	1%	0%	15%	15%	0%	0%	62%	0%	30%	0%	92%	8%	0%
Spyker	-3%	-2%	1%	70%	15%	0%	61%	30%	0%	0%	0%	0%	15%	9%	0%	0%	70%	0%	30%	0%	85%	0%	6%
Subaru	-9%	-8%	0%	70%	15%	0%	17%	10%	33%	18%	8%	0%	15%	0%	0%	0%	23%	0%	30%	0%	85%	0%	5%
Suzuki	-7%	-7%	0%	70%	15%	0%	55%	30%	0%	0%	0%	0%	15%	0%	0%	0%	82%	0%	30%	0%	85%	0%	0%
Tata	-6%	-5%	1%	63%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	60%	0%	30%	0%	75%	10%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-2%	-2%	0%	38%	0%	0%	47%	25%	5%	3%	3%	0%	0%	6%	0%	0%	0%	0%	11%	0%	41%	0%	0%
Volkswagen	-8%	-8%	1%	67%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	67%	0%	30%	0%	96%	4%	0%
Fleet	-5%	-5%	0%	50%	9%	0%	55%	28%	5%	3%	1%	0%	9%	3%	0%	0%	7%	0%	23%	0%	60%	1%	0%

Table 3.5-19 Reference Fleet (Sales-Weighted) Technology Penetration in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-8%	-8%	1%	40%	15%	0%	0%	0%	60%	24%	16%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
BMW	-7%	-6%	1%	51%	15%	0%	28%	8%	35%	19%	9%	0%	15%	15%	0%	0%	57%	0%	30%	0%	77%	13%	0%
Chrysler/Fiat	-5%	-5%	0%	39%	14%	0%	31%	13%	30%	16%	3%	0%	7%	0%	0%	0%	0%	0%	30%	0%	53%	0%	0%
Daimler	-8%	-7%	1%	43%	14%	0%	0%	53%	22%	23%	0%	0%	14%	15%	0%	0%	57%	0%	30%	0%	69%	17%	0%
Ferrari	-4%	-3%	1%	40%	15%	0%	14%	0%	52%	28%	5%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
Ford	-6%	-6%	0%	65%	15%	0%	34%	14%	26%	13%	6%	0%	12%	2%	0%	0%	1%	0%	29%	0%	80%	0%	1%
Geely	-7%	-6%	1%	56%	15%	0%	30%	12%	33%	18%	2%	0%	15%	15%	0%	0%	60%	0%	30%	0%	75%	10%	0%
General Motors	-6%	-6%	0%	42%	13%	0%	34%	15%	28%	14%	3%	0%	8%	0%	0%	0%	0%	0%	30%	0%	55%	0%	0%
Honda	-2%	-2%	0%	18%	0%	0%	12%	6%	40%	18%	8%	0%	0%	2%	0%	0%	0%	0%	5%	0%	18%	0%	0%
Hyundai	-2%	-2%	0%	39%	0%	0%	22%	12%	30%	16%	6%	0%	0%	0%	0%	0%	0%	0%	8%	0%	39%	0%	0%
Kia	-2%	-2%	0%	23%	0%	0%	15%	8%	41%	15%	7%	0%	0%	0%	0%	0%	0%	0%	5%	0%	23%	0%	0%
Lotus	-1%	0%	1%	52%	15%	0%	0%	0%	15%	0%	85%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
Mazda	-4%	-4%	0%	49%	13%	0%	19%	7%	34%	18%	15%	0%	4%	0%	0%	0%	0%	0%	30%	0%	62%	0%	0%
Mitsubishi	-6%	-5%	0%	70%	15%	0%	25%	12%	31%	16%	5%	0%	15%	0%	0%	0%	28%	0%	30%	0%	85%	0%	12%
Nissan	-3%	-3%	0%	35%	9%	0%	15%	8%	38%	21%	4%	0%	4%	1%	0%	0%	0%	0%	30%	0%	44%	0%	0%
Porsche	-4%	-3%	1%	47%	15%	0%	15%	6%	22%	8%	44%	0%	15%	15%	0%	0%	56%	0%	30%	0%	77%	14%	0%
Spyker	-8%	-7%	1%	57%	15%	0%	10%	4%	43%	22%	11%	0%	15%	14%	0%	0%	57%	0%	30%	0%	72%	13%	1%
Subaru	-5%	-5%	0%	72%	15%	0%	5%	2%	40%	21%	21%	0%	15%	0%	0%	0%	5%	0%	30%	0%	85%	0%	5%
Suzuki	-1%	-1%	0%	70%	15%	0%	12%	7%	37%	20%	10%	0%	15%	0%	0%	0%	14%	0%	30%	0%	85%	0%	0%
Tata	-7%	-7%	1%	50%	15%	0%	40%	14%	29%	16%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	72%	13%	0%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-2%	-2%	0%	15%	0%	0%	20%	11%	34%	8%	5%	0%	0%	12%	0%	0%	0%	0%	5%	0%	20%	0%	0%
Volkswagen	-5%	-4%	1%	50%	15%	0%	21%	6%	41%	20%	11%	0%	15%	15%	0%	0%	57%	0%	30%	0%	86%	13%	0%
Fleet	-4%	-4%	0%	38%	8%	0%	23%	12%	33%	15%	6%	0%	6%	5%	0%	0%	8%	0%	20%	0%	49%	2%	0%

3.5.4 Projected Technology Penetrations in Final rule case

Table 3.5-20 Final rule Car Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-16%	-11%	6%	7%	22%	15%	0%	0%	4%	73%	7%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
BMW	-10%	-9%	1%	52%	28%	6%	0%	0%	14%	72%	10%	60%	30%	9%	4%	0%	36%	75%	57%	60%	96%	0%	21%
Chrysler/Fiat	-6%	-6%	0%	67%	21%	1%	1%	4%	21%	72%	2%	55%	9%	0%	0%	0%	0%	75%	79%	54%	89%	0%	0%
Daimler	-12%	-11%	1%	41%	29%	12%	0%	7%	6%	78%	0%	58%	30%	7%	9%	0%	41%	75%	54%	60%	89%	1%	22%
Ferrari	-8%	-3%	5%	6%	22%	15%	0%	0%	4%	78%	2%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
Ford	-6%	-6%	0%	74%	17%	1%	6%	23%	14%	49%	7%	45%	14%	2%	0%	0%	4%	74%	72%	47%	92%	0%	6%
Geely	-11%	-10%	1%	36%	30%	13%	3%	11%	9%	66%	2%	59%	30%	13%	9%	0%	46%	75%	49%	60%	91%	0%	17%
General Motors	-6%	-6%	0%	48%	15%	1%	1%	5%	22%	66%	6%	48%	9%	0%	0%	0%	0%	75%	79%	28%	63%	0%	0%
Honda	-2%	-2%	0%	15%	5%	0%	0%	0%	21%	64%	12%	10%	0%	3%	0%	0%	0%	73%	77%	5%	20%	0%	0%
Hyundai	-3%	-3%	0%	41%	14%	0%	5%	20%	17%	51%	7%	44%	2%	0%	0%	0%	0%	75%	75%	21%	56%	0%	1%
Kia	-3%	-3%	0%	17%	5%	0%	2%	7%	21%	62%	9%	17%	0%	0%	0%	0%	0%	75%	78%	9%	23%	0%	0%
Lotus	-3%	0%	3%	15%	29%	13%	0%	0%	0%	39%	49%	58%	30%	22%	12%	9%	38%	75%	45%	57%	88%	0%	8%
Mazda	-4%	-4%	0%	72%	28%	0%	3%	13%	14%	54%	16%	55%	28%	0%	0%	0%	3%	75%	76%	55%	100%	0%	4%
Mitsubishi	-6%	-6%	0%	71%	29%	0%	3%	14%	16%	59%	8%	58%	29%	0%	0%	0%	7%	75%	75%	58%	100%	0%	6%
Nissan	-3%	-3%	0%	42%	19%	0%	1%	4%	21%	69%	5%	48%	9%	1%	0%	0%	0%	74%	78%	32%	61%	0%	0%
Porsche	-6%	-2%	4%	4%	28%	15%	0%	0%	3%	56%	29%	59%	30%	25%	12%	15%	34%	75%	36%	59%	88%	0%	5%
Spyker	-14%	-12%	2%	20%	30%	15%	0%	0%	8%	72%	8%	58%	30%	22%	12%	2%	46%	75%	49%	59%	88%	0%	8%
Subaru	-6%	-5%	1%	71%	29%	0%	0%	0%	15%	64%	20%	60%	29%	0%	0%	0%	5%	75%	74%	58%	100%	0%	19%
Suzuki	-1%	0%	1%	70%	30%	0%	1%	5%	16%	68%	9%	60%	30%	0%	0%	0%	9%	75%	73%	60%	100%	0%	25%
Tata	-16%	-13%	3%	13%	30%	15%	0%	0%	10%	77%	0%	57%	30%	25%	13%	4%	35%	75%	40%	57%	87%	0%	5%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-3%	-3%	0%	23%	0%	0%	1%	4%	18%	55%	7%	4%	0%	15%	0%	0%	0%	63%	63%	0%	24%	0%	0%
Volkswagen	-7%	-5%	1%	49%	30%	12%	0%	0%	11%	71%	10%	59%	30%	1%	8%	0%	49%	75%	56%	60%	92%	0%	29%
Fleet	-5%	-5%	0%	43%	14%	2%	2%	7%	17%	61%	8%	36%	11%	4%	1%	0%	7%	72%	71%	29%	60%	0%	5%

Table 3.5-21 Final rule Truck Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-13%	-12%	1%	65%	30%	5%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	57%	60%	100%	0%	30%
Chrysler/Fiat	-7%	-6%	0%	24%	19%	3%	19%	75%	1%	3%	3%	60%	21%	0%	0%	0%	5%	75%	72%	36%	46%	0%	11%
Daimler	-15%	-14%	1%	51%	28%	10%	11%	89%	0%	0%	0%	60%	29%	0%	0%	0%	65%	75%	61%	60%	89%	11%	30%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-8%	-7%	1%	54%	21%	6%	18%	71%	1%	5%	2%	59%	28%	2%	0%	0%	7%	73%	58%	43%	81%	0%	21%
Geely	-15%	-14%	1%	64%	30%	6%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	52%	60%	100%	0%	30%
General Motors	-8%	-8%	0%	35%	15%	5%	20%	78%	0%	1%	0%	59%	20%	0%	0%	0%	8%	75%	66%	25%	55%	0%	10%
Honda	-7%	-7%	0%	61%	18%	0%	14%	57%	7%	21%	0%	60%	3%	0%	0%	0%	0%	75%	66%	27%	79%	0%	4%
Hyundai	-9%	-9%	0%	75%	25%	0%	20%	80%	0%	0%	0%	60%	5%	0%	0%	0%	0%	75%	60%	20%	100%	0%	5%
Kia	-8%	-8%	0%	75%	25%	0%	20%	79%	0%	0%	1%	60%	5%	0%	0%	0%	0%	75%	60%	20%	100%	0%	5%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-13%	-12%	0%	72%	28%	0%	14%	54%	8%	23%	2%	60%	28%	0%	0%	0%	26%	75%	66%	54%	100%	0%	14%
Mitsubishi	-14%	-13%	1%	67%	30%	0%	17%	69%	3%	11%	0%	60%	30%	3%	0%	0%	56%	75%	53%	60%	100%	0%	26%
Nissan	-5%	-5%	0%	79%	17%	3%	16%	64%	5%	14%	1%	60%	16%	0%	0%	0%	7%	75%	68%	27%	100%	0%	15%
Porsche	-15%	-14%	1%	59%	30%	11%	20%	79%	0%	0%	1%	60%	30%	2%	0%	0%	65%	75%	61%	60%	100%	0%	28%
Spyker	-3%	-2%	1%	61%	30%	9%	20%	80%	0%	0%	0%	60%	30%	2%	0%	0%	61%	75%	56%	60%	100%	0%	28%
Subaru	-15%	-13%	1%	50%	30%	0%	6%	25%	12%	51%	6%	60%	30%	20%	0%	0%	24%	75%	60%	60%	100%	0%	10%
Suzuki	-11%	-11%	1%	70%	30%	0%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	50%	60%	100%	0%	30%
Tata	-10%	-9%	1%	58%	30%	12%	20%	80%	0%	0%	0%	60%	30%	22%	0%	0%	65%	75%	63%	60%	100%	0%	8%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-4%	-4%	0%	61%	2%	3%	17%	66%	2%	7%	3%	50%	3%	5%	0%	0%	0%	71%	63%	2%	66%	0%	0%
Volkswagen	-14%	-13%	1%	63%	30%	7%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	54%	60%	100%	0%	30%
Fleet	-7%	-7%	0%	53%	16%	4%	18%	71%	2%	7%	1%	57%	16%	2%	0%	0%	11%	74%	64%	27%	73%	0%	11%

Table 3.5-22 Final rule Fleet Technology Penetration in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-16%	-11%	6%	7%	22%	15%	0%	0%	4%	73%	7%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
BMW	-11%	-10%	1%	55%	29%	6%	5%	21%	10%	53%	7%	60%	30%	7%	3%	0%	43%	75%	57%	60%	97%	0%	23%
Chrysler/Fiat	-6%	-6%	0%	48%	20%	2%	9%	36%	12%	41%	3%	57%	15%	0%	0%	0%	2%	75%	76%	46%	69%	0%	5%
Daimler	-13%	-12%	1%	44%	29%	11%	3%	27%	4%	58%	0%	58%	29%	5%	7%	0%	47%	75%	55%	60%	89%	3%	24%
Ferrari	-8%	-3%	5%	6%	22%	15%	0%	0%	4%	78%	2%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
Ford	-7%	-7%	0%	67%	19%	3%	10%	39%	10%	34%	5%	50%	19%	2%	0%	0%	5%	74%	67%	46%	89%	0%	11%
Geely	-12%	-11%	1%	45%	30%	11%	8%	32%	6%	46%	1%	59%	30%	9%	6%	0%	52%	75%	50%	60%	94%	0%	21%
General Motors	-7%	-7%	0%	41%	15%	3%	10%	41%	11%	34%	3%	53%	14%	0%	0%	0%	4%	75%	72%	27%	59%	0%	5%
Honda	-4%	-4%	0%	29%	9%	0%	4%	18%	17%	51%	8%	25%	1%	2%	0%	0%	0%	73%	74%	12%	38%	0%	1%
Hyundai	-5%	-4%	0%	48%	17%	0%	8%	32%	13%	41%	6%	48%	2%	0%	0%	0%	0%	75%	72%	21%	65%	0%	2%
Kia	-4%	-4%	0%	30%	10%	0%	6%	23%	16%	48%	7%	26%	1%	0%	0%	0%	0%	75%	74%	11%	40%	0%	1%
Lotus	-3%	0%	3%	15%	29%	13%	0%	0%	0%	39%	49%	58%	30%	22%	12%	9%	38%	75%	45%	57%	88%	0%	8%
Mazda	-5%	-5%	0%	72%	28%	0%	5%	20%	13%	49%	13%	56%	28%	0%	0%	0%	7%	75%	74%	55%	100%	0%	6%
Mitsubishi	-9%	-9%	0%	70%	29%	0%	8%	33%	11%	42%	5%	59%	29%	1%	0%	0%	24%	75%	68%	59%	100%	0%	13%
Nissan	-3%	-3%	0%	54%	18%	1%	6%	22%	16%	52%	4%	52%	11%	1%	0%	0%	2%	75%	75%	31%	73%	0%	5%
Porsche	-8%	-5%	3%	17%	29%	14%	5%	19%	2%	43%	22%	59%	30%	20%	9%	11%	42%	75%	42%	59%	91%	0%	10%
Spyker	-13%	-10%	2%	26%	30%	14%	3%	11%	7%	62%	7%	59%	30%	19%	10%	2%	48%	75%	50%	60%	90%	0%	11%
Subaru	-8%	-7%	1%	66%	30%	0%	2%	6%	14%	61%	17%	60%	30%	5%	0%	0%	10%	75%	71%	59%	100%	0%	17%
Suzuki	-3%	-2%	1%	70%	30%	0%	5%	18%	13%	56%	7%	60%	30%	0%	0%	0%	19%	75%	69%	60%	100%	0%	26%
Tata	-13%	-11%	2%	36%	30%	13%	10%	40%	5%	39%	0%	58%	30%	23%	7%	2%	50%	75%	52%	58%	93%	0%	7%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-3%	-3%	0%	38%	1%	1%	7%	28%	12%	36%	5%	22%	1%	12%	0%	0%	0%	66%	63%	1%	41%	0%	0%
Volkswagen	-8%	-7%	1%	52%	30%	11%	4%	16%	8%	57%	8%	59%	30%	1%	6%	0%	52%	75%	56%	60%	94%	0%	29%
Fleet	-6%	-5%	0%	46%	15%	3%	7%	30%	12%	42%	5%	44%	12%	4%	1%	0%	8%	73%	68%	29%	65%	0%	7%

Table 3.5-23 Final rule Car Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-20%	-12%	8%	0%	0%	29%	0%	0%	0%	76%	1%	77%	29%	27%	23%	22%	5%	100%	5%	77%	77%	0%	23%
BMW	-11%	-10%	2%	6%	60%	20%	0%	0%	0%	82%	6%	88%	75%	1%	12%	0%	33%	100%	38%	88%	88%	0%	49%
Chrysler/Fiat	-8%	-7%	1%	24%	72%	3%	0%	4%	0%	94%	2%	100%	75%	0%	0%	0%	2%	100%	73%	100%	99%	0%	27%
Daimler	-15%	-13%	2%	6%	60%	12%	0%	0%	0%	83%	0%	83%	72%	4%	17%	0%	33%	100%	33%	83%	82%	1%	46%
Ferrari	-10%	-3%	8%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	5%	77%	77%	0%	0%
Ford	-10%	-9%	1%	21%	70%	4%	0%	29%	0%	63%	4%	97%	73%	1%	2%	0%	15%	99%	61%	97%	94%	0%	35%
Geely	-14%	-11%	3%	5%	46%	26%	0%	13%	0%	71%	1%	85%	72%	5%	15%	4%	32%	100%	32%	85%	85%	0%	45%
General Motors	-8%	-7%	1%	23%	72%	3%	0%	6%	0%	89%	5%	100%	74%	0%	0%	0%	0%	100%	78%	100%	97%	0%	22%
Honda	-3%	-3%	0%	24%	73%	0%	0%	0%	0%	85%	12%	97%	73%	3%	0%	0%	0%	97%	97%	97%	97%	0%	0%
Hyundai	-5%	-4%	0%	25%	75%	0%	0%	24%	0%	69%	7%	100%	75%	0%	0%	0%	0%	100%	90%	100%	100%	0%	10%
Kia	-3%	-3%	0%	43%	57%	0%	0%	7%	0%	84%	9%	100%	57%	0%	0%	0%	0%	100%	98%	100%	100%	0%	2%
Lotus	-3%	0%	3%	7%	56%	0%	0%	0%	0%	55%	25%	80%	56%	11%	20%	5%	25%	100%	25%	80%	80%	0%	39%
Mazda	-6%	-5%	1%	20%	75%	0%	0%	15%	0%	74%	10%	98%	75%	3%	2%	0%	7%	100%	56%	98%	98%	0%	39%
Mitsubishi	-9%	-7%	2%	19%	74%	0%	0%	16%	0%	76%	4%	96%	74%	3%	4%	0%	11%	100%	46%	96%	96%	0%	47%
Nissan	-4%	-3%	1%	25%	74%	0%	0%	5%	0%	91%	3%	99%	74%	1%	0%	0%	2%	99%	77%	99%	99%	0%	22%
Porsche	-7%	-2%	4%	2%	56%	9%	0%	0%	0%	65%	12%	77%	65%	2%	23%	9%	18%	100%	18%	77%	77%	0%	48%
Spyker	-16%	-13%	3%	8%	60%	8%	0%	0%	0%	74%	4%	79%	69%	2%	21%	0%	29%	100%	29%	79%	79%	0%	48%
Subaru	-9%	-8%	1%	10%	75%	0%	0%	0%	0%	78%	16%	95%	75%	10%	5%	0%	0%	100%	68%	95%	95%	0%	17%
Suzuki	-1%	0%	1%	2%	75%	0%	0%	6%	0%	79%	7%	93%	75%	16%	7%	0%	3%	100%	62%	93%	93%	0%	15%
Tata	-19%	-14%	5%	0%	21%	37%	0%	0%	0%	77%	0%	77%	58%	13%	23%	6%	21%	100%	21%	77%	77%	0%	37%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-3%	-3%	0%	48%	34%	1%	0%	4%	0%	74%	7%	84%	31%	16%	0%	0%	0%	84%	84%	84%	83%	0%	0%
Volkswagen	-8%	-6%	2%	9%	73%	2%	0%	0%	0%	79%	6%	85%	75%	0%	15%	0%	35%	100%	35%	85%	85%	0%	49%
Fleet	-6%	-6%	1%	25%	63%	3%	0%	8%	0%	79%	6%	93%	65%	4%	3%	0%	7%	96%	73%	93%	93%	0%	20%

Table 3.5-24 Final rule Truck Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-17%	-16%	1%	15%	65%	19%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Chrysler/Fiat	-10%	-8%	1%	20%	69%	8%	0%	95%	0%	4%	1%	100%	75%	2%	0%	0%	48%	100%	51%	100%	97%	0%	47%
Daimler	-20%	-18%	2%	12%	58%	23%	0%	100%	0%	0%	0%	100%	67%	0%	0%	0%	50%	100%	50%	100%	92%	8%	50%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-11%	-9%	2%	14%	64%	20%	0%	88%	0%	9%	1%	99%	74%	28%	0%	0%	45%	99%	49%	99%	99%	0%	23%
Geely	-20%	-19%	2%	22%	72%	6%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
General Motors	-11%	-10%	1%	17%	61%	15%	0%	98%	0%	2%	0%	100%	75%	0%	0%	0%	49%	100%	50%	100%	93%	0%	50%
Honda	-11%	-10%	1%	25%	75%	0%	0%	72%	0%	28%	0%	100%	75%	0%	0%	0%	3%	100%	64%	100%	100%	0%	36%
Hyundai	-14%	-12%	2%	25%	75%	0%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Kia	-12%	-10%	1%	25%	75%	0%	0%	99%	0%	0%	1%	100%	75%	0%	0%	0%	0%	100%	51%	100%	100%	0%	49%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-19%	-17%	1%	18%	75%	0%	0%	70%	0%	26%	1%	98%	75%	5%	2%	0%	35%	100%	56%	98%	98%	0%	37%
Mitsubishi	-20%	-18%	2%	22%	70%	0%	0%	86%	0%	11%	0%	98%	70%	7%	2%	0%	43%	100%	48%	98%	98%	0%	43%
Nissan	-9%	-7%	2%	15%	70%	9%	0%	80%	0%	18%	1%	98%	75%	13%	2%	0%	41%	100%	48%	98%	98%	0%	37%
Porsche	-20%	-18%	1%	11%	61%	28%	0%	99%	0%	0%	1%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Spyker	-4%	-2%	1%	15%	65%	19%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Subaru	-19%	-17%	2%	8%	75%	0%	0%	32%	0%	60%	4%	95%	75%	12%	5%	0%	16%	100%	45%	95%	95%	0%	38%
Suzuki	-15%	-14%	1%	25%	75%	0%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Tata	-13%	-11%	2%	9%	59%	33%	0%	100%	0%	0%	0%	100%	75%	16%	0%	0%	50%	100%	50%	100%	100%	0%	34%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-8%	-7%	1%	21%	68%	8%	0%	86%	0%	10%	1%	97%	72%	3%	0%	0%	0%	97%	68%	97%	97%	0%	29%
Volkswagen	-18%	-17%	2%	19%	69%	11%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Fleet	-11%	-10%	1%	19%	67%	11%	0%	89%	0%	9%	1%	99%	74%	5%	0%	0%	32%	99%	55%	99%	97%	0%	39%

Table 3.5-25 Final rule Fleet Technology Penetration in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-20%	-12%	8%	0%	0%	29%	0%	0%	0%	76%	1%	77%	29%	27%	23%	22%	5%	100%	5%	77%	77%	0%	23%
BMW	-13%	-11%	2%	8%	62%	20%	0%	26%	0%	60%	4%	91%	75%	1%	9%	0%	37%	100%	41%	91%	91%	0%	49%
Chrysler/Fiat	-9%	-8%	1%	22%	71%	5%	0%	43%	0%	55%	1%	100%	75%	1%	0%	0%	22%	100%	63%	100%	98%	0%	36%
Daimler	-16%	-14%	2%	7%	60%	14%	0%	23%	0%	64%	0%	87%	71%	3%	13%	0%	37%	100%	37%	87%	85%	2%	47%
Ferrari	-10%	-3%	8%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	5%	77%	77%	0%	0%
Ford	-10%	-9%	1%	19%	68%	9%	0%	48%	0%	46%	4%	97%	73%	10%	1%	0%	24%	99%	57%	97%	96%	0%	32%
Geely	-16%	-13%	3%	10%	54%	20%	0%	39%	0%	50%	1%	90%	73%	3%	10%	3%	37%	100%	37%	90%	90%	0%	47%
General Motors	-9%	-8%	1%	20%	66%	9%	0%	50%	0%	47%	3%	100%	74%	0%	0%	0%	23%	100%	65%	100%	95%	0%	35%
Honda	-5%	-5%	0%	24%	73%	0%	0%	21%	0%	68%	8%	98%	73%	2%	0%	0%	1%	98%	87%	98%	98%	0%	11%
Hyundai	-7%	-6%	1%	25%	75%	0%	0%	39%	0%	55%	6%	100%	75%	0%	0%	0%	10%	100%	82%	100%	100%	0%	18%
Kia	-5%	-5%	0%	39%	61%	0%	0%	27%	0%	66%	7%	100%	61%	0%	0%	0%	0%	100%	88%	100%	100%	0%	12%
Lotus	-3%	0%	3%	7%	56%	0%	0%	0%	0%	55%	25%	80%	56%	11%	20%	5%	25%	100%	25%	80%	80%	0%	39%
Mazda	-8%	-7%	1%	20%	75%	0%	0%	24%	0%	66%	8%	98%	75%	3%	2%	0%	12%	100%	56%	98%	98%	0%	39%
Mitsubishi	-13%	-11%	2%	20%	73%	0%	0%	39%	0%	55%	3%	97%	73%	4%	3%	0%	22%	100%	47%	97%	97%	0%	46%
Nissan	-5%	-5%	1%	22%	73%	3%	0%	27%	0%	69%	3%	99%	75%	4%	0%	0%	14%	100%	69%	99%	99%	0%	27%
Porsche	-10%	-6%	4%	4%	57%	13%	0%	21%	0%	51%	9%	82%	67%	1%	18%	7%	25%	100%	25%	82%	82%	0%	49%
Spyker	-14%	-11%	3%	9%	61%	10%	0%	13%	0%	65%	4%	81%	70%	1%	19%	0%	31%	100%	31%	81%	81%	0%	49%
Subaru	-11%	-10%	1%	9%	75%	0%	0%	7%	0%	74%	13%	95%	75%	10%	5%	0%	4%	100%	63%	95%	95%	0%	22%
Suzuki	-4%	-2%	1%	6%	75%	0%	0%	22%	0%	66%	6%	94%	75%	13%	6%	0%	11%	100%	60%	94%	94%	0%	21%
Tata	-16%	-13%	3%	4%	38%	35%	0%	46%	0%	41%	0%	88%	66%	15%	12%	3%	34%	100%	34%	88%	88%	0%	35%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-5%	-5%	0%	38%	46%	4%	0%	34%	0%	51%	5%	89%	46%	11%	0%	0%	0%	89%	78%	89%	88%	0%	11%
Volkswagen	-10%	-8%	2%	11%	72%	4%	0%	20%	0%	63%	5%	88%	75%	0%	12%	0%	38%	100%	38%	88%	88%	0%	49%
Fleet	-8%	-7%	1%	23%	64%	6%	0%	35%	0%	56%	4%	95%	68%	5%	2%	0%	15%	97%	67%	95%	94%	0%	26%

3.5.5 Projected Technology Penetrations in Alternative Cases

Table 3.5-26 Alternative 1- (Trucks +20) Car Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-16%	-11%	6%	7%	22%	15%	0%	0%	4%	73%	7%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
BMW	-10%	-9%	1%	58%	30%	6%	0%	0%	17%	71%	10%	58%	30%	4%	2%	0%	33%	75%	60%	60%	98%	0%	26%
Chrysler/Fiat	-6%	-6%	0%	36%	11%	1%	1%	4%	23%	70%	3%	38%	1%	0%	0%	0%	0%	75%	79%	17%	48%	0%	0%
Daimler	-12%	-11%	1%	52%	28%	5%	0%	8%	7%	79%	0%	59%	29%	7%	6%	0%	38%	75%	57%	60%	93%	1%	22%
Ferrari	-8%	-3%	5%	6%	22%	15%	0%	0%	4%	78%	2%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
Ford	-6%	-6%	0%	52%	16%	1%	6%	23%	15%	48%	7%	45%	9%	2%	0%	0%	0%	74%	73%	29%	69%	0%	1%
Geely	-11%	-10%	1%	49%	27%	11%	3%	11%	13%	66%	2%	60%	30%	8%	6%	0%	43%	75%	52%	59%	94%	0%	22%
General Motors	-5%	-5%	0%	37%	1%	0%	1%	5%	22%	66%	6%	12%	0%	0%	0%	0%	0%	75%	79%	1%	38%	0%	0%
Honda	-2%	-2%	0%	15%	0%	0%	0%	0%	21%	64%	12%	0%	0%	3%	0%	0%	0%	73%	43%	0%	15%	0%	0%
Hyundai	-3%	-3%	0%	27%	8%	0%	5%	20%	17%	51%	7%	23%	0%	0%	0%	0%	0%	75%	75%	10%	35%	0%	0%
Kia	-2%	-2%	0%	19%	0%	0%	2%	7%	21%	62%	9%	5%	0%	0%	0%	0%	0%	75%	63%	0%	19%	0%	0%
Lotus	-3%	0%	3%	15%	29%	13%	0%	0%	0%	39%	49%	58%	30%	22%	12%	9%	38%	75%	45%	57%	88%	0%	8%
Mazda	-4%	-4%	0%	82%	18%	0%	3%	13%	16%	51%	17%	53%	5%	0%	0%	0%	3%	75%	77%	54%	100%	0%	3%
Mitsubishi	-5%	-5%	0%	74%	26%	0%	3%	14%	16%	58%	9%	58%	26%	0%	0%	0%	3%	75%	77%	51%	100%	0%	1%
Nissan	-3%	-3%	0%	36%	6%	0%	1%	4%	22%	67%	5%	33%	0%	1%	0%	0%	0%	74%	78%	7%	42%	0%	0%
Porsche	-5%	-2%	3%	10%	30%	15%	0%	0%	3%	55%	30%	58%	30%	21%	12%	12%	36%	75%	39%	59%	88%	0%	9%
Spyker	-14%	-12%	2%	30%	30%	15%	0%	0%	9%	72%	8%	59%	30%	12%	11%	2%	45%	75%	50%	59%	89%	0%	19%
Subaru	-6%	-5%	1%	73%	27%	0%	0%	0%	17%	61%	21%	57%	27%	0%	0%	0%	0%	75%	78%	58%	100%	0%	16%
Suzuki	0%	0%	0%	75%	25%	0%	1%	5%	21%	63%	10%	47%	25%	0%	0%	0%	4%	75%	78%	60%	100%	0%	12%
Tata	-15%	-14%	1%	34%	24%	15%	0%	0%	14%	78%	0%	60%	30%	19%	8%	0%	38%	75%	49%	58%	92%	0%	11%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-2%	-2%	0%	23%	0%	0%	1%	4%	18%	55%	7%	0%	0%	15%	0%	0%	0%	63%	2%	0%	24%	0%	0%
Volkswagen	-6%	-5%	1%	61%	27%	4%	0%	0%	12%	72%	11%	60%	30%	1%	6%	0%	43%	75%	59%	60%	94%	0%	29%
Fleet	-4%	-4%	0%	38%	9%	1%	2%	7%	18%	61%	8%	25%	7%	4%	1%	0%	6%	72%	56%	18%	49%	0%	4%

Table 3.5-27 Alternative 1- (Trucks +20) Truck Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-13%	-12%	1%	65%	30%	5%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	57%	60%	100%	0%	30%
Chrysler/Fiat	-7%	-7%	0%	22%	9%	3%	19%	75%	1%	3%	3%	60%	6%	0%	0%	0%	0%	75%	74%	30%	34%	0%	2%
Daimler	-15%	-14%	1%	51%	28%	10%	11%	89%	0%	0%	0%	60%	29%	0%	0%	0%	65%	75%	61%	60%	89%	11%	30%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-7%	-7%	0%	37%	16%	6%	18%	71%	1%	5%	2%	59%	18%	2%	0%	0%	3%	73%	60%	26%	59%	0%	16%
Geely	-15%	-14%	1%	64%	30%	6%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	52%	60%	100%	0%	30%
General Motors	-7%	-7%	0%	34%	11%	1%	20%	78%	0%	1%	0%	59%	3%	0%	0%	0%	0%	75%	71%	21%	46%	0%	2%
Honda	-6%	-6%	0%	61%	8%	0%	14%	57%	7%	21%	0%	43%	0%	0%	0%	0%	0%	75%	67%	8%	68%	0%	0%
Hyundai	-9%	-9%	0%	75%	25%	0%	20%	80%	0%	0%	0%	60%	5%	0%	0%	0%	0%	75%	60%	20%	100%	0%	5%
Kia	-7%	-7%	0%	94%	0%	0%	20%	79%	0%	0%	1%	60%	0%	0%	0%	0%	0%	75%	60%	0%	94%	0%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-11%	-10%	0%	82%	18%	0%	14%	54%	8%	23%	2%	60%	18%	0%	0%	0%	13%	75%	66%	31%	100%	0%	13%
Mitsubishi	-11%	-10%	1%	75%	25%	0%	17%	69%	3%	10%	0%	60%	25%	0%	0%	0%	17%	75%	63%	36%	100%	0%	17%
Nissan	-5%	-5%	0%	66%	17%	3%	16%	64%	5%	14%	1%	60%	9%	0%	0%	0%	0%	75%	68%	25%	86%	0%	9%
Porsche	-15%	-14%	1%	59%	30%	11%	20%	79%	0%	0%	1%	60%	30%	2%	0%	0%	65%	75%	61%	60%	100%	0%	28%
Spyker	-3%	-2%	1%	61%	30%	9%	20%	80%	0%	0%	0%	60%	30%	2%	0%	0%	61%	75%	56%	60%	100%	0%	28%
Subaru	-12%	-12%	0%	73%	27%	0%	6%	25%	15%	46%	8%	60%	27%	0%	0%	0%	21%	75%	70%	50%	100%	0%	10%
Suzuki	-11%	-11%	1%	70%	30%	0%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	50%	60%	100%	0%	30%
Tata	-10%	-9%	1%	58%	30%	12%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	63%	60%	100%	0%	30%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-3%	-3%	0%	63%	0%	3%	17%	66%	2%	7%	3%	11%	3%	5%	0%	0%	0%	71%	24%	0%	66%	0%	0%
Volkswagen	-14%	-13%	1%	63%	30%	7%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	54%	60%	100%	0%	30%
Fleet	-7%	-6%	0%	50%	12%	3%	18%	71%	2%	6%	1%	47%	8%	1%	0%	0%	7%	74%	57%	21%	65%	0%	7%

Table 3.5-28 Alternative 1- (Trucks +20) Fleet Technology Penetration in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-16%	-11%	6%	7%	22%	15%	0%	0%	4%	73%	7%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
BMW	-11%	-10%	1%	60%	30%	6%	5%	21%	13%	52%	8%	59%	30%	3%	1%	0%	41%	75%	59%	60%	99%	0%	27%
Chrysler/Fiat	-6%	-6%	0%	30%	10%	1%	9%	36%	13%	39%	3%	47%	4%	0%	0%	0%	0%	75%	77%	23%	41%	0%	1%
Daimler	-13%	-12%	1%	52%	28%	6%	3%	28%	5%	60%	0%	60%	29%	5%	5%	0%	44%	75%	58%	60%	92%	3%	24%
Ferrari	-8%	-3%	5%	6%	22%	15%	0%	0%	4%	78%	2%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
Ford	-6%	-6%	0%	47%	16%	3%	10%	39%	10%	34%	6%	49%	12%	2%	0%	0%	1%	74%	69%	28%	65%	0%	6%
Geely	-12%	-11%	1%	53%	28%	9%	8%	32%	9%	45%	2%	60%	30%	5%	4%	0%	49%	75%	52%	59%	96%	0%	25%
General Motors	-6%	-6%	0%	36%	6%	1%	10%	41%	11%	34%	3%	35%	2%	0%	0%	0%	0%	75%	75%	11%	42%	0%	1%
Honda	-3%	-3%	0%	29%	2%	0%	4%	18%	17%	51%	8%	13%	0%	2%	0%	0%	0%	73%	50%	2%	32%	0%	0%
Hyundai	-4%	-4%	0%	36%	11%	0%	8%	32%	13%	41%	6%	30%	1%	0%	0%	0%	0%	75%	72%	12%	48%	0%	1%
Kia	-3%	-3%	0%	36%	0%	0%	6%	23%	16%	48%	7%	17%	0%	0%	0%	0%	0%	75%	63%	0%	36%	0%	0%
Lotus	-3%	0%	3%	15%	29%	13%	0%	0%	0%	39%	49%	58%	30%	22%	12%	9%	38%	75%	45%	57%	88%	0%	8%
Mazda	-5%	-5%	0%	82%	18%	0%	5%	20%	15%	46%	14%	54%	8%	0%	0%	0%	5%	75%	75%	50%	100%	0%	5%
Mitsubishi	-7%	-7%	0%	74%	26%	0%	8%	33%	11%	41%	6%	59%	26%	0%	0%	0%	8%	75%	72%	46%	100%	0%	7%
Nissan	-3%	-3%	0%	46%	9%	1%	6%	22%	17%	51%	4%	42%	3%	1%	0%	0%	0%	75%	75%	13%	56%	0%	3%
Porsche	-8%	-5%	3%	22%	30%	14%	5%	19%	3%	42%	23%	59%	30%	16%	9%	9%	43%	75%	44%	60%	91%	0%	14%
Spyker	-13%	-11%	2%	35%	30%	14%	3%	11%	7%	62%	7%	59%	30%	10%	9%	2%	47%	75%	51%	59%	91%	0%	20%
Subaru	-7%	-7%	0%	73%	27%	0%	2%	6%	17%	58%	18%	58%	27%	0%	0%	0%	5%	75%	76%	56%	100%	0%	14%
Suzuki	-2%	-2%	0%	74%	26%	0%	5%	18%	17%	52%	9%	49%	26%	0%	0%	0%	15%	75%	73%	60%	100%	0%	15%
Tata	-13%	-12%	1%	46%	27%	13%	10%	40%	7%	39%	0%	60%	30%	10%	4%	0%	52%	75%	56%	59%	96%	0%	20%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-2%	-2%	0%	39%	0%	1%	7%	28%	12%	36%	5%	4%	1%	12%	0%	0%	0%	66%	11%	0%	40%	0%	0%
Volkswagen	-8%	-7%	1%	62%	28%	5%	4%	16%	10%	57%	8%	60%	30%	1%	5%	0%	47%	75%	58%	60%	95%	0%	29%
Fleet	-5%	-5%	0%	42%	10%	2%	7%	30%	13%	42%	6%	33%	7%	3%	1%	0%	6%	73%	56%	19%	54%	0%	5%

Table 3.5-29 Alternative 2- (Trucks -20) Car Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-16%	-11%	6%	7%	22%	15%	0%	0%	4%	73%	7%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
BMW	-10%	-8%	1%	47%	28%	6%	0%	0%	12%	71%	9%	60%	30%	12%	7%	0%	40%	75%	54%	59%	93%	0%	18%
Chrysler/Fiat	-6%	-6%	0%	68%	28%	1%	1%	4%	19%	74%	2%	59%	29%	0%	0%	0%	1%	75%	78%	58%	98%	0%	3%
Daimler	-12%	-10%	2%	27%	30%	13%	0%	6%	5%	79%	0%	59%	30%	16%	10%	3%	44%	75%	49%	59%	89%	1%	14%
Ferrari	-8%	-3%	5%	6%	22%	15%	0%	0%	4%	78%	2%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
Ford	-8%	-7%	0%	65%	26%	1%	6%	23%	14%	50%	6%	53%	27%	2%	0%	0%	10%	74%	70%	56%	93%	0%	12%
Geely	-12%	-9%	2%	22%	30%	14%	3%	11%	8%	66%	2%	59%	30%	21%	10%	4%	42%	75%	44%	59%	90%	0%	9%
General Motors	-7%	-7%	0%	68%	25%	1%	1%	5%	19%	70%	5%	57%	26%	0%	0%	0%	1%	75%	79%	55%	95%	0%	2%
Honda	-2%	-2%	0%	36%	10%	0%	0%	0%	21%	64%	12%	28%	5%	3%	0%	0%	0%	73%	77%	32%	46%	0%	0%
Hyundai	-3%	-3%	0%	62%	17%	0%	5%	20%	17%	51%	7%	45%	4%	0%	0%	0%	0%	75%	75%	37%	78%	0%	1%
Kia	-3%	-3%	0%	36%	12%	0%	2%	7%	21%	62%	9%	43%	0%	0%	0%	0%	0%	75%	78%	15%	48%	0%	0%
Lotus	-3%	0%	3%	15%	29%	13%	0%	0%	0%	39%	49%	58%	30%	22%	12%	9%	38%	75%	45%	57%	88%	0%	8%
Mazda	-5%	-4%	0%	70%	30%	0%	3%	13%	14%	55%	15%	60%	30%	0%	0%	0%	10%	75%	74%	59%	100%	0%	11%
Mitsubishi	-7%	-6%	1%	66%	30%	0%	3%	14%	14%	61%	6%	60%	30%	3%	0%	0%	21%	75%	57%	60%	100%	0%	26%
Nissan	-3%	-3%	0%	78%	21%	0%	1%	4%	20%	70%	5%	49%	10%	1%	0%	0%	1%	74%	78%	56%	99%	0%	0%
Porsche	-6%	-2%	4%	1%	28%	15%	0%	0%	3%	55%	26%	56%	30%	25%	15%	15%	31%	75%	33%	56%	85%	0%	5%
Spyker	-14%	-11%	3%	17%	30%	15%	0%	0%	8%	72%	8%	58%	30%	22%	12%	5%	44%	75%	47%	59%	88%	0%	8%
Subaru	-6%	-5%	1%	57%	29%	0%	0%	0%	15%	66%	19%	60%	29%	14%	0%	0%	8%	75%	68%	58%	100%	0%	15%
Suzuki	-1%	0%	1%	51%	30%	0%	1%	5%	16%	68%	9%	60%	30%	19%	0%	0%	9%	75%	73%	60%	100%	0%	7%
Tata	-16%	-11%	5%	5%	25%	15%	0%	0%	5%	79%	0%	58%	27%	26%	16%	14%	35%	75%	28%	59%	84%	0%	4%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-3%	-3%	0%	22%	4%	0%	1%	4%	18%	55%	7%	15%	1%	15%	0%	0%	0%	63%	67%	3%	27%	0%	0%
Volkswagen	-7%	-5%	1%	43%	30%	15%	0%	0%	8%	71%	10%	59%	30%	1%	11%	0%	49%	75%	54%	59%	89%	0%	29%
Fleet	-5%	-5%	0%	50%	19%	2%	2%	7%	16%	62%	7%	44%	17%	5%	2%	0%	8%	72%	70%	42%	74%	0%	6%

Table 3.5-30 Alternative 2- (Trucks -20) Truck Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-13%	-13%	1%	61%	30%	9%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	57%	60%	100%	0%	30%
Chrysler/Fiat	-9%	-8%	1%	36%	27%	3%	19%	75%	1%	3%	2%	60%	29%	0%	0%	0%	45%	75%	63%	47%	66%	0%	21%
Daimler	-15%	-14%	1%	51%	28%	10%	11%	89%	0%	0%	0%	60%	29%	0%	0%	0%	65%	75%	61%	60%	89%	11%	30%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-9%	-8%	1%	61%	29%	6%	18%	71%	1%	5%	2%	59%	29%	2%	0%	0%	48%	73%	54%	58%	97%	0%	27%
Geely	-15%	-14%	1%	64%	30%	6%	20%	80%	0%	0%	0%	60%	30%	4%	0%	0%	65%	75%	52%	60%	100%	0%	26%
General Motors	-9%	-9%	1%	39%	24%	5%	20%	78%	0%	1%	0%	59%	29%	0%	0%	0%	24%	75%	60%	49%	68%	0%	23%
Honda	-8%	-8%	0%	82%	18%	0%	14%	57%	7%	21%	0%	60%	10%	0%	0%	0%	6%	75%	66%	22%	100%	0%	6%
Hyundai	-10%	-10%	0%	75%	25%	0%	20%	80%	0%	0%	0%	60%	23%	0%	0%	0%	18%	75%	60%	20%	100%	0%	5%
Kia	-8%	-8%	0%	75%	25%	0%	20%	79%	0%	0%	1%	60%	5%	0%	0%	0%	0%	75%	60%	20%	100%	0%	5%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-13%	-12%	1%	71%	29%	0%	14%	54%	7%	23%	2%	60%	29%	1%	0%	0%	44%	75%	59%	56%	100%	0%	21%
Mitsubishi	-14%	-13%	1%	65%	30%	0%	17%	69%	3%	10%	0%	59%	30%	4%	1%	0%	60%	75%	51%	60%	99%	0%	26%
Nissan	-6%	-5%	0%	72%	25%	3%	16%	64%	5%	14%	1%	60%	28%	0%	0%	0%	17%	75%	66%	54%	100%	0%	18%
Porsche	-15%	-14%	1%	59%	30%	11%	20%	79%	0%	0%	1%	60%	30%	13%	0%	0%	65%	75%	61%	60%	100%	0%	17%
Spyker	-3%	-2%	1%	61%	30%	9%	20%	80%	0%	0%	0%	60%	30%	2%	0%	0%	61%	75%	56%	60%	100%	0%	28%
Subaru	-15%	-13%	1%	50%	30%	0%	6%	25%	12%	51%	6%	60%	30%	20%	0%	0%	24%	75%	60%	60%	100%	0%	10%
Suzuki	-11%	-11%	1%	70%	30%	0%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	50%	60%	100%	0%	30%
Tata	-10%	-9%	1%	58%	30%	12%	20%	80%	0%	0%	0%	60%	30%	22%	0%	0%	65%	75%	63%	60%	100%	0%	8%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-5%	-5%	0%	68%	19%	3%	17%	67%	2%	7%	3%	57%	8%	5%	0%	0%	0%	71%	62%	22%	90%	0%	8%
Volkswagen	-14%	-13%	1%	63%	30%	7%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	54%	60%	100%	0%	30%
Fleet	-8%	-8%	0%	58%	24%	4%	18%	71%	2%	7%	1%	59%	22%	2%	0%	0%	24%	74%	61%	42%	86%	0%	18%

Table 3.5-31 Alternative 2- (Trucks -20) Fleet Technology Penetration in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-16%	-11%	6%	7%	22%	15%	0%	0%	4%	73%	7%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
BMW	-11%	-10%	1%	51%	29%	7%	5%	21%	9%	53%	7%	60%	30%	9%	5%	0%	47%	75%	55%	59%	95%	0%	21%
Chrysler/Fiat	-7%	-7%	0%	54%	28%	2%	9%	36%	11%	41%	2%	59%	29%	0%	0%	0%	21%	75%	71%	53%	83%	0%	11%
Daimler	-13%	-11%	2%	33%	29%	13%	3%	26%	4%	59%	0%	60%	29%	12%	8%	2%	49%	75%	52%	60%	89%	3%	18%
Ferrari	-8%	-3%	5%	6%	22%	15%	0%	0%	4%	78%	2%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
Ford	-8%	-7%	0%	64%	27%	3%	10%	39%	10%	35%	5%	55%	28%	2%	0%	0%	23%	74%	65%	57%	94%	0%	17%
Geely	-13%	-11%	2%	35%	30%	11%	8%	32%	6%	45%	1%	59%	30%	16%	7%	3%	49%	75%	47%	59%	93%	0%	14%
General Motors	-8%	-8%	0%	54%	25%	3%	10%	41%	10%	36%	3%	58%	27%	0%	0%	0%	12%	75%	69%	52%	81%	0%	12%
Honda	-4%	-4%	0%	50%	12%	0%	4%	18%	16%	51%	8%	38%	6%	2%	0%	0%	2%	73%	74%	29%	63%	0%	2%
Hyundai	-5%	-5%	0%	64%	18%	0%	8%	32%	13%	41%	6%	48%	8%	0%	0%	0%	4%	75%	72%	34%	83%	0%	2%
Kia	-4%	-4%	0%	45%	15%	0%	6%	23%	16%	48%	7%	47%	1%	0%	0%	0%	0%	75%	74%	16%	60%	0%	1%
Lotus	-3%	0%	3%	15%	29%	13%	0%	0%	0%	39%	49%	58%	30%	22%	12%	9%	38%	75%	45%	57%	88%	0%	8%
Mazda	-6%	-6%	0%	70%	30%	0%	5%	20%	13%	49%	13%	60%	30%	0%	0%	0%	16%	75%	71%	59%	100%	0%	12%
Mitsubishi	-10%	-9%	1%	66%	30%	0%	8%	33%	10%	44%	4%	60%	30%	4%	1%	0%	35%	75%	55%	60%	99%	0%	26%
Nissan	-4%	-4%	0%	76%	22%	1%	6%	22%	15%	53%	4%	52%	16%	1%	0%	0%	6%	75%	75%	56%	99%	0%	6%
Porsche	-8%	-5%	4%	15%	29%	14%	5%	19%	2%	42%	20%	57%	30%	23%	12%	11%	39%	75%	40%	57%	88%	0%	7%
Spyker	-13%	-10%	3%	23%	30%	14%	3%	11%	7%	62%	7%	59%	30%	19%	10%	4%	46%	75%	48%	60%	90%	0%	11%
Subaru	-8%	-7%	1%	55%	30%	0%	2%	6%	14%	62%	16%	60%	30%	15%	0%	0%	12%	75%	66%	59%	100%	0%	14%
Suzuki	-3%	-2%	1%	55%	30%	0%	5%	18%	13%	56%	7%	60%	30%	15%	0%	0%	19%	75%	69%	60%	100%	0%	11%
Tata	-13%	-10%	3%	32%	27%	13%	10%	40%	3%	40%	0%	59%	29%	24%	8%	7%	50%	75%	45%	59%	92%	0%	6%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-4%	-4%	0%	40%	10%	1%	7%	29%	12%	36%	5%	32%	3%	11%	0%	0%	0%	66%	65%	10%	51%	0%	3%
Volkswagen	-8%	-7%	1%	47%	30%	13%	4%	16%	7%	57%	8%	59%	30%	1%	9%	0%	52%	75%	54%	59%	91%	0%	29%
Fleet	-6%	-6%	0%	53%	21%	3%	7%	30%	11%	43%	5%	49%	18%	4%	1%	0%	14%	73%	67%	42%	78%	0%	10%

Table 3.5-32 Alternative 3- (Cars +20) Car Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-16%	-11%	6%	7%	22%	15%	0%	0%	4%	73%	7%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
BMW	-9%	-9%	0%	70%	24%	6%	0%	0%	17%	69%	13%	58%	30%	0%	0%	0%	0%	75%	77%	60%	100%	0%	13%
Chrysler/Fiat	-6%	-6%	0%	36%	11%	1%	1%	4%	23%	70%	3%	38%	1%	0%	0%	0%	0%	75%	79%	17%	48%	0%	0%
Daimler	-12%	-11%	1%	58%	28%	4%	0%	11%	8%	79%	0%	57%	29%	7%	2%	0%	31%	75%	61%	60%	96%	1%	21%
Ferrari	-8%	-3%	5%	6%	22%	15%	0%	0%	4%	78%	2%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
Ford	-6%	-6%	0%	42%	10%	1%	6%	23%	16%	47%	7%	35%	3%	2%	0%	0%	0%	74%	73%	10%	54%	0%	1%
Geely	-11%	-10%	1%	60%	30%	8%	3%	11%	16%	66%	2%	59%	30%	0%	2%	0%	40%	75%	56%	60%	98%	0%	30%
General Motors	-5%	-5%	0%	37%	1%	0%	1%	5%	22%	66%	6%	14%	1%	0%	0%	0%	0%	75%	79%	1%	39%	0%	0%
Honda	-1%	-1%	0%	15%	0%	0%	0%	0%	21%	64%	12%	0%	0%	3%	0%	0%	0%	73%	6%	0%	15%	0%	0%
Hyundai	-2%	-2%	0%	32%	0%	0%	5%	20%	17%	51%	7%	0%	0%	0%	0%	0%	0%	75%	21%	0%	32%	0%	0%
Kia	-2%	-2%	0%	19%	0%	0%	2%	7%	21%	62%	9%	0%	0%	0%	0%	0%	0%	75%	0%	0%	19%	0%	0%
Lotus	-1%	0%	1%	40%	30%	11%	0%	0%	0%	32%	58%	59%	30%	7%	11%	2%	46%	75%	54%	58%	89%	0%	23%
Mazda	-3%	-3%	0%	31%	17%	0%	3%	13%	17%	50%	17%	46%	2%	0%	0%	0%	0%	75%	77%	23%	48%	0%	1%
Mitsubishi	-5%	-5%	0%	70%	22%	0%	3%	14%	16%	57%	9%	52%	4%	0%	0%	0%	0%	75%	77%	46%	92%	0%	1%
Nissan	-3%	-3%	0%	30%	1%	0%	1%	4%	22%	67%	5%	3%	0%	1%	0%	0%	0%	74%	78%	1%	31%	0%	0%
Porsche	-5%	-2%	2%	18%	30%	15%	0%	0%	3%	49%	36%	58%	30%	21%	12%	4%	44%	75%	47%	59%	88%	0%	9%
Spyker	-13%	-12%	1%	55%	30%	4%	0%	0%	12%	72%	9%	59%	30%	4%	7%	0%	41%	75%	56%	60%	93%	0%	26%
Subaru	-5%	-5%	0%	88%	10%	0%	0%	0%	17%	56%	27%	46%	5%	0%	0%	0%	0%	75%	80%	55%	98%	0%	0%
Suzuki	0%	0%	0%	98%	2%	0%	1%	5%	21%	62%	12%	11%	0%	0%	0%	0%	0%	75%	79%	57%	100%	0%	0%
Tata	-15%	-14%	1%	34%	24%	15%	0%	0%	14%	78%	0%	60%	30%	19%	8%	0%	38%	75%	49%	58%	92%	0%	11%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-2%	-2%	0%	23%	0%	0%	1%	4%	20%	53%	7%	0%	0%	15%	0%	0%	0%	63%	2%	0%	24%	0%	0%
Volkswagen	-6%	-5%	1%	68%	30%	1%	0%	0%	16%	72%	11%	60%	30%	1%	0%	0%	33%	75%	64%	60%	100%	0%	29%
Fleet	-4%	-4%	0%	37%	7%	1%	2%	7%	19%	60%	8%	19%	5%	4%	0%	0%	4%	72%	48%	13%	45%	0%	3%

Table 3.5-33 Alternative 3- (Cars +20) Truck Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-13%	-12%	1%	65%	30%	5%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	61%	60%	100%	0%	26%
Chrysler/Fiat	-7%	-7%	0%	22%	9%	3%	19%	75%	1%	3%	3%	60%	6%	0%	0%	0%	0%	75%	74%	30%	34%	0%	2%
Daimler	-15%	-14%	1%	51%	28%	10%	11%	89%	0%	0%	0%	60%	29%	0%	0%	0%	65%	75%	61%	60%	89%	11%	30%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-7%	-7%	0%	30%	15%	6%	18%	71%	1%	5%	2%	59%	14%	2%	0%	0%	1%	73%	68%	22%	51%	0%	9%
Geely	-15%	-14%	1%	64%	30%	6%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	52%	60%	100%	0%	30%
General Motors	-7%	-7%	0%	35%	12%	5%	20%	78%	0%	1%	0%	59%	7%	0%	0%	0%	0%	75%	71%	22%	51%	0%	3%
Honda	-4%	-4%	0%	68%	0%	0%	14%	57%	7%	21%	0%	23%	0%	0%	0%	0%	0%	75%	31%	0%	68%	0%	0%
Hyundai	-5%	-5%	0%	95%	0%	0%	20%	80%	0%	0%	0%	54%	0%	0%	0%	0%	0%	75%	54%	0%	95%	0%	0%
Kia	-5%	-5%	0%	94%	0%	0%	20%	79%	0%	0%	1%	0%	0%	0%	0%	0%	0%	75%	1%	0%	94%	0%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-9%	-9%	0%	59%	17%	0%	14%	54%	8%	23%	2%	60%	4%	0%	0%	0%	0%	75%	66%	27%	77%	0%	3%
Mitsubishi	-10%	-10%	0%	75%	25%	0%	17%	69%	3%	10%	0%	60%	21%	0%	0%	0%	13%	75%	63%	23%	100%	0%	4%
Nissan	-4%	-4%	0%	47%	15%	3%	16%	64%	5%	14%	1%	53%	6%	0%	0%	0%	0%	75%	70%	14%	66%	0%	2%
Porsche	-15%	-14%	1%	59%	30%	11%	20%	79%	0%	0%	1%	60%	30%	0%	0%	0%	65%	75%	61%	60%	100%	0%	30%
Spyker	-3%	-2%	1%	61%	30%	9%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	61%	75%	56%	60%	100%	0%	30%
Subaru	-11%	-11%	0%	92%	8%	0%	6%	25%	15%	46%	8%	60%	8%	0%	0%	0%	6%	75%	74%	24%	100%	0%	5%
Suzuki	-8%	-8%	0%	75%	25%	0%	20%	80%	0%	0%	0%	60%	25%	0%	0%	0%	20%	75%	60%	20%	100%	0%	5%
Tata	-10%	-9%	1%	58%	30%	12%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	63%	60%	100%	0%	30%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-3%	-3%	0%	63%	0%	0%	17%	66%	2%	7%	3%	0%	0%	5%	0%	0%	0%	71%	13%	0%	63%	0%	0%
Volkswagen	-14%	-13%	1%	63%	30%	7%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	54%	60%	100%	0%	30%
Fleet	-6%	-6%	0%	50%	10%	3%	18%	71%	2%	6%	1%	41%	8%	1%	0%	0%	6%	74%	52%	18%	63%	0%	5%

Table 3.5-34 Alternative 3- (Cars +20) Fleet Technology Penetration in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-16%	-11%	6%	7%	22%	15%	0%	0%	4%	73%	7%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
BMW	-10%	-10%	0%	69%	25%	6%	5%	21%	13%	51%	10%	59%	30%	0%	0%	0%	17%	75%	73%	60%	100%	0%	16%
Chrysler/Fiat	-6%	-6%	0%	30%	10%	1%	9%	36%	13%	39%	3%	47%	4%	0%	0%	0%	0%	75%	77%	23%	41%	0%	1%
Daimler	-12%	-12%	1%	56%	28%	6%	3%	31%	6%	59%	0%	58%	29%	5%	2%	0%	39%	75%	61%	60%	95%	4%	23%
Ferrari	-8%	-3%	5%	6%	22%	15%	0%	0%	4%	78%	2%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
Ford	-6%	-6%	0%	38%	12%	3%	10%	39%	11%	33%	6%	43%	7%	2%	0%	0%	0%	74%	71%	14%	53%	0%	4%
Geely	-12%	-11%	1%	61%	30%	8%	8%	32%	11%	46%	2%	59%	30%	0%	1%	0%	48%	75%	55%	60%	99%	0%	30%
General Motors	-6%	-6%	0%	36%	6%	3%	10%	41%	11%	34%	3%	36%	4%	0%	0%	0%	0%	75%	75%	12%	45%	0%	2%
Honda	-2%	-2%	0%	32%	0%	0%	4%	18%	17%	51%	8%	7%	0%	2%	0%	0%	0%	73%	14%	0%	32%	0%	0%
Hyundai	-3%	-3%	0%	45%	0%	0%	8%	32%	14%	41%	6%	11%	0%	0%	0%	0%	0%	75%	28%	0%	45%	0%	0%
Kia	-2%	-2%	0%	36%	0%	0%	6%	23%	16%	48%	7%	0%	0%	0%	0%	0%	0%	75%	0%	0%	36%	0%	0%
Lotus	-1%	0%	1%	40%	30%	11%	0%	0%	0%	32%	58%	59%	30%	7%	11%	2%	46%	75%	54%	58%	89%	0%	23%
Mazda	-4%	-4%	0%	36%	17%	0%	5%	20%	15%	45%	14%	49%	2%	0%	0%	0%	0%	75%	75%	24%	53%	0%	1%
Mitsubishi	-7%	-7%	0%	72%	23%	0%	8%	33%	12%	41%	6%	55%	10%	0%	0%	0%	5%	75%	72%	38%	95%	0%	2%
Nissan	-3%	-3%	0%	36%	5%	1%	6%	22%	17%	51%	4%	18%	2%	1%	0%	0%	0%	75%	76%	5%	42%	0%	1%
Porsche	-7%	-5%	2%	28%	30%	14%	5%	19%	3%	38%	28%	59%	30%	16%	9%	3%	49%	75%	50%	60%	91%	0%	14%
Spyker	-12%	-11%	1%	56%	30%	5%	3%	11%	10%	61%	8%	59%	30%	4%	6%	0%	44%	75%	56%	60%	94%	0%	26%
Subaru	-6%	-6%	0%	89%	10%	0%	2%	6%	17%	53%	22%	49%	6%	0%	0%	0%	2%	75%	78%	48%	99%	0%	1%
Suzuki	-1%	-1%	0%	94%	6%	0%	5%	18%	17%	51%	10%	19%	5%	0%	0%	0%	4%	75%	75%	51%	100%	0%	1%
Tata	-13%	-12%	1%	46%	27%	13%	10%	40%	7%	39%	0%	60%	30%	10%	4%	0%	52%	75%	56%	59%	96%	0%	20%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-2%	-2%	0%	39%	0%	0%	7%	28%	13%	35%	5%	0%	0%	12%	0%	0%	0%	66%	6%	0%	39%	0%	0%
Volkswagen	-8%	-7%	1%	67%	30%	2%	4%	16%	13%	57%	9%	60%	30%	1%	0%	0%	40%	75%	62%	60%	100%	0%	29%
Fleet	-5%	-5%	0%	41%	8%	2%	7%	30%	13%	41%	6%	27%	6%	3%	0%	0%	4%	73%	49%	15%	51%	0%	4%

Table 3.5-35 Alternative 4- (Cars -20) Car Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-16%	-11%	6%	7%	22%	15%	0%	0%	4%	73%	7%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
BMW	-10%	-8%	2%	27%	30%	14%	0%	0%	9%	72%	9%	59%	30%	16%	11%	2%	43%	75%	49%	59%	89%	0%	14%
Chrysler/Fiat	-7%	-7%	0%	68%	28%	1%	1%	4%	19%	74%	2%	59%	29%	0%	0%	0%	1%	75%	78%	58%	98%	0%	3%
Daimler	-13%	-9%	4%	12%	29%	13%	0%	4%	5%	79%	0%	58%	30%	23%	12%	10%	39%	75%	41%	60%	87%	1%	7%
Ferrari	-8%	-3%	5%	6%	22%	15%	0%	0%	4%	78%	2%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
Ford	-8%	-8%	1%	63%	28%	1%	6%	23%	13%	52%	5%	59%	29%	3%	0%	0%	24%	74%	61%	59%	94%	0%	27%
Geely	-12%	-9%	3%	16%	30%	14%	3%	11%	6%	65%	2%	55%	30%	22%	13%	5%	43%	75%	39%	58%	87%	0%	8%
General Motors	-7%	-7%	0%	71%	23%	1%	1%	5%	19%	69%	5%	57%	21%	0%	0%	0%	1%	75%	79%	55%	95%	0%	1%
Honda	-2%	-2%	0%	61%	18%	0%	0%	0%	19%	66%	12%	47%	6%	3%	0%	0%	0%	73%	77%	42%	79%	0%	0%
Hyundai	-4%	-4%	0%	73%	27%	0%	5%	20%	15%	53%	7%	55%	27%	0%	0%	0%	5%	75%	75%	53%	100%	0%	5%
Kia	-3%	-3%	0%	79%	16%	0%	2%	7%	19%	63%	9%	43%	5%	0%	0%	0%	2%	75%	78%	53%	95%	0%	0%
Lotus	-4%	0%	4%	0%	27%	14%	0%	0%	0%	45%	40%	56%	30%	26%	15%	15%	30%	75%	36%	56%	83%	2%	4%
Mazda	-5%	-4%	1%	62%	30%	1%	3%	13%	13%	58%	11%	60%	30%	6%	2%	0%	52%	75%	56%	60%	98%	0%	24%
Mitsubishi	-7%	-6%	1%	61%	30%	1%	3%	14%	14%	60%	6%	59%	30%	5%	3%	0%	57%	75%	55%	59%	97%	0%	25%
Nissan	-3%	-3%	0%	70%	29%	0%	1%	4%	19%	72%	4%	56%	29%	1%	0%	0%	3%	74%	74%	59%	99%	0%	10%
Porsche	-7%	-2%	5%	1%	24%	15%	0%	0%	3%	55%	26%	56%	30%	29%	16%	15%	30%	75%	32%	60%	84%	0%	1%
Spyker	-15%	-10%	5%	4%	28%	15%	0%	0%	8%	74%	6%	59%	30%	25%	12%	15%	34%	75%	36%	59%	88%	0%	5%
Subaru	-7%	-5%	1%	49%	30%	0%	0%	0%	14%	64%	18%	60%	30%	17%	4%	0%	25%	75%	62%	60%	96%	0%	13%
Suzuki	-1%	0%	1%	37%	30%	0%	1%	5%	16%	65%	8%	60%	30%	28%	5%	0%	56%	75%	64%	55%	95%	0%	2%
Tata	-16%	-11%	6%	5%	23%	15%	0%	0%	5%	79%	0%	58%	27%	26%	16%	15%	34%	75%	27%	59%	84%	0%	4%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-3%	-3%	0%	44%	4%	0%	1%	4%	18%	55%	7%	24%	1%	15%	0%	0%	0%	63%	67%	14%	48%	0%	0%
Volkswagen	-7%	-5%	3%	17%	30%	15%	0%	0%	8%	72%	9%	59%	30%	22%	11%	6%	43%	75%	48%	59%	89%	0%	8%
Fleet	-5%	-5%	1%	55%	22%	2%	2%	7%	16%	63%	7%	50%	19%	7%	2%	1%	12%	72%	67%	48%	84%	0%	7%

Table 3.5-36 Alternative 4- (Cars -20) Truck Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-13%	-13%	1%	61%	30%	9%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	57%	60%	100%	0%	30%
Chrysler/Fiat	-8%	-8%	1%	42%	27%	3%	19%	75%	1%	3%	2%	60%	29%	0%	0%	0%	39%	75%	56%	53%	71%	0%	27%
Daimler	-15%	-14%	1%	51%	28%	10%	11%	89%	0%	0%	0%	60%	29%	0%	0%	0%	65%	75%	61%	60%	89%	11%	30%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-9%	-8%	1%	61%	29%	6%	18%	71%	1%	6%	2%	59%	29%	3%	0%	0%	51%	74%	53%	59%	98%	0%	28%
Geely	-15%	-14%	1%	64%	30%	6%	20%	80%	0%	0%	0%	60%	30%	8%	0%	0%	65%	75%	52%	60%	100%	0%	22%
General Motors	-9%	-9%	1%	36%	24%	5%	20%	78%	0%	1%	0%	59%	29%	0%	0%	0%	17%	75%	62%	47%	65%	0%	20%
Honda	-8%	-8%	0%	75%	25%	0%	14%	57%	7%	21%	0%	60%	25%	0%	0%	0%	13%	75%	66%	34%	100%	0%	10%
Hyundai	-14%	-13%	1%	70%	30%	0%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	63%	75%	51%	60%	100%	0%	29%
Kia	-10%	-9%	1%	75%	25%	0%	20%	79%	0%	0%	1%	60%	25%	0%	0%	0%	20%	75%	60%	35%	100%	0%	20%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-15%	-13%	1%	55%	30%	3%	14%	54%	6%	23%	1%	58%	30%	10%	2%	0%	54%	75%	53%	60%	98%	0%	20%
Mitsubishi	-15%	-14%	1%	60%	30%	4%	17%	69%	1%	11%	0%	60%	30%	4%	1%	0%	62%	75%	51%	60%	99%	0%	26%
Nissan	-7%	-6%	1%	64%	29%	3%	16%	64%	5%	15%	1%	60%	29%	4%	0%	0%	51%	75%	61%	57%	100%	0%	24%
Porsche	-15%	-14%	1%	53%	30%	15%	20%	79%	0%	0%	1%	60%	30%	30%	0%	0%	65%	75%	61%	60%	98%	2%	0%
Spyker	-3%	-2%	1%	61%	30%	9%	20%	80%	0%	0%	0%	60%	30%	9%	0%	0%	61%	75%	56%	60%	100%	0%	21%
Subaru	-15%	-13%	1%	46%	30%	0%	6%	25%	12%	47%	5%	56%	30%	20%	4%	0%	38%	75%	57%	60%	96%	0%	10%
Suzuki	-12%	-11%	1%	65%	30%	5%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	65%	75%	50%	60%	100%	0%	30%
Tata	-10%	-9%	1%	58%	30%	12%	20%	80%	0%	0%	0%	60%	30%	22%	0%	0%	65%	75%	63%	60%	100%	0%	8%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-5%	-5%	0%	71%	20%	3%	17%	67%	2%	7%	2%	57%	9%	5%	0%	0%	0%	71%	62%	21%	94%	0%	9%
Volkswagen	-14%	-13%	1%	63%	30%	7%	20%	80%	0%	0%	0%	60%	30%	10%	0%	0%	65%	75%	54%	60%	100%	0%	20%
Fleet	-9%	-8%	1%	57%	25%	4%	18%	71%	2%	7%	1%	59%	24%	3%	0%	0%	28%	74%	60%	45%	87%	0%	19%

Table 3.5-37 Alternative 4- (Cars -20) Fleet Technology Penetration in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-16%	-11%	6%	7%	22%	15%	0%	0%	4%	73%	7%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
BMW	-11%	-9%	2%	36%	30%	12%	5%	21%	6%	53%	7%	59%	30%	12%	8%	1%	49%	75%	51%	59%	92%	0%	18%
Chrysler/Fiat	-7%	-7%	0%	56%	28%	2%	9%	36%	11%	41%	2%	59%	29%	0%	0%	0%	18%	75%	68%	56%	86%	0%	14%
Daimler	-13%	-11%	3%	22%	29%	13%	3%	25%	4%	59%	0%	59%	29%	17%	9%	7%	46%	75%	46%	60%	88%	3%	13%
Ferrari	-8%	-3%	5%	6%	22%	15%	0%	0%	4%	78%	2%	59%	30%	26%	16%	15%	35%	75%	24%	60%	84%	0%	4%
Ford	-9%	-8%	1%	62%	29%	3%	10%	39%	9%	37%	4%	59%	29%	3%	0%	0%	33%	74%	58%	59%	95%	0%	27%
Geely	-13%	-11%	3%	31%	30%	11%	8%	32%	4%	45%	1%	57%	30%	18%	9%	4%	50%	75%	43%	59%	91%	0%	12%
General Motors	-8%	-8%	0%	54%	23%	3%	10%	41%	10%	36%	3%	58%	25%	0%	0%	0%	9%	75%	71%	51%	80%	0%	11%
Honda	-4%	-4%	0%	65%	20%	0%	4%	18%	16%	52%	8%	51%	12%	2%	0%	0%	4%	73%	74%	40%	86%	0%	3%
Hyundai	-6%	-6%	0%	72%	28%	0%	8%	32%	12%	42%	6%	56%	28%	0%	0%	0%	17%	75%	70%	54%	100%	0%	10%
Kia	-4%	-4%	0%	78%	18%	0%	6%	23%	15%	49%	7%	47%	10%	0%	0%	0%	6%	75%	74%	49%	96%	0%	5%
Lotus	-4%	0%	4%	0%	27%	14%	0%	0%	0%	45%	40%	56%	30%	26%	15%	15%	30%	75%	36%	56%	83%	2%	4%
Mazda	-7%	-6%	1%	61%	30%	1%	5%	20%	12%	52%	10%	59%	30%	6%	2%	0%	53%	75%	56%	60%	98%	0%	24%
Mitsubishi	-10%	-9%	1%	61%	30%	2%	8%	33%	10%	43%	4%	59%	30%	5%	2%	0%	59%	75%	53%	60%	98%	0%	25%
Nissan	-4%	-4%	0%	68%	29%	1%	6%	22%	15%	54%	3%	57%	29%	2%	0%	0%	18%	75%	70%	58%	99%	0%	14%
Porsche	-9%	-5%	4%	13%	25%	15%	5%	19%	2%	42%	20%	57%	30%	29%	12%	11%	38%	75%	39%	60%	87%	1%	1%
Spyker	-13%	-9%	4%	12%	29%	14%	3%	11%	7%	63%	5%	59%	30%	23%	10%	13%	38%	75%	39%	59%	90%	0%	7%
Subaru	-9%	-7%	1%	48%	30%	0%	2%	6%	14%	60%	15%	59%	30%	18%	4%	0%	28%	75%	61%	60%	96%	0%	12%
Suzuki	-3%	-2%	1%	42%	30%	1%	5%	18%	13%	53%	6%	60%	30%	23%	4%	0%	57%	75%	61%	56%	96%	0%	7%
Tata	-13%	-10%	3%	32%	27%	13%	10%	40%	3%	40%	0%	59%	29%	24%	8%	8%	49%	75%	45%	59%	92%	0%	6%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-4%	-4%	0%	55%	10%	1%	7%	29%	12%	36%	5%	37%	4%	11%	0%	0%	0%	66%	65%	17%	66%	0%	4%
Volkswagen	-9%	-6%	2%	26%	30%	13%	4%	16%	6%	57%	7%	59%	30%	20%	9%	5%	48%	75%	49%	59%	91%	0%	10%
Fleet	-7%	-6%	1%	56%	23%	3%	7%	30%	11%	43%	5%	53%	21%	6%	1%	1%	18%	73%	65%	47%	85%	0%	11%

Table 3.5-38 Alternative 1- (Trucks +20) Car Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-20%	-12%	8%	0%	0%	29%	0%	0%	0%	76%	1%	77%	29%	27%	23%	22%	5%	100%	5%	77%	77%	0%	23%
BMW	-11%	-10%	2%	8%	62%	20%	0%	0%	0%	85%	6%	91%	75%	1%	9%	0%	21%	100%	41%	91%	91%	0%	49%
Chrysler/Fiat	-7%	-7%	0%	24%	73%	3%	0%	4%	0%	94%	2%	100%	74%	0%	0%	0%	0%	100%	98%	100%	99%	0%	2%
Daimler	-15%	-13%	2%	8%	61%	14%	0%	0%	0%	86%	0%	86%	74%	3%	14%	0%	31%	100%	39%	86%	85%	1%	44%
Ferrari	-10%	-3%	8%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	5%	77%	77%	0%	0%
Ford	-9%	-8%	1%	23%	68%	4%	0%	29%	0%	64%	5%	98%	72%	1%	0%	0%	12%	99%	69%	98%	95%	0%	29%
Geely	-14%	-12%	2%	7%	55%	26%	0%	13%	0%	73%	1%	87%	75%	0%	13%	0%	38%	100%	38%	87%	87%	0%	49%
General Motors	-7%	-7%	0%	29%	65%	3%	0%	6%	0%	88%	6%	100%	68%	0%	0%	0%	0%	100%	100%	100%	97%	0%	0%
Honda	-2%	-2%	0%	28%	60%	0%	0%	0%	0%	85%	12%	97%	36%	3%	0%	0%	0%	97%	97%	97%	89%	0%	0%
Hyundai	-4%	-4%	0%	25%	75%	0%	0%	24%	0%	69%	7%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%	0%
Kia	-3%	-3%	0%	43%	57%	0%	0%	7%	0%	84%	9%	100%	21%	0%	0%	0%	0%	100%	100%	100%	100%	0%	0%
Lotus	-3%	0%	3%	7%	56%	0%	0%	0%	0%	55%	25%	80%	56%	11%	20%	5%	25%	100%	25%	80%	80%	0%	39%
Mazda	-6%	-5%	1%	23%	75%	0%	0%	15%	0%	72%	12%	98%	75%	0%	2%	0%	7%	100%	67%	98%	98%	0%	31%
Mitsubishi	-8%	-7%	1%	24%	75%	0%	0%	16%	0%	78%	4%	99%	75%	0%	1%	0%	8%	100%	58%	99%	99%	0%	41%
Nissan	-3%	-3%	0%	25%	74%	0%	0%	5%	0%	90%	4%	99%	74%	1%	0%	0%	0%	99%	89%	99%	99%	0%	10%
Porsche	-6%	-2%	4%	2%	60%	9%	0%	0%	0%	62%	15%	77%	69%	2%	23%	5%	22%	100%	22%	77%	77%	0%	48%
Spyker	-16%	-13%	3%	8%	62%	8%	0%	0%	0%	76%	4%	80%	71%	2%	20%	0%	30%	100%	30%	80%	80%	0%	48%
Subaru	-8%	-8%	1%	20%	75%	0%	0%	0%	0%	76%	18%	95%	75%	0%	5%	0%	0%	100%	75%	95%	95%	0%	19%
Suzuki	-1%	0%	1%	2%	75%	0%	0%	6%	0%	78%	9%	93%	75%	16%	7%	0%	3%	100%	73%	93%	93%	0%	3%
Tata	-19%	-16%	3%	0%	32%	38%	0%	0%	0%	83%	0%	83%	70%	7%	17%	5%	28%	100%	28%	83%	83%	0%	43%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-3%	-3%	0%	26%	27%	1%	0%	4%	0%	74%	7%	84%	19%	16%	0%	0%	0%	84%	84%	84%	55%	0%	0%
Volkswagen	-8%	-6%	2%	11%	73%	2%	0%	0%	0%	80%	7%	87%	75%	0%	13%	0%	39%	100%	40%	87%	87%	0%	47%
Fleet	-6%	-5%	0%	24%	60%	3%	0%	8%	0%	79%	7%	94%	57%	4%	2%	0%	6%	96%	81%	94%	87%	0%	13%

Table 3.5-39 Alternative 1- (Trucks +20) Truck Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-17%	-16%	1%	15%	65%	19%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Chrysler/Fiat	-9%	-8%	1%	9%	65%	8%	0%	94%	0%	4%	2%	100%	73%	0%	0%	0%	7%	100%	63%	100%	83%	0%	37%
Daimler	-20%	-18%	2%	12%	58%	23%	0%	100%	0%	0%	0%	100%	67%	0%	0%	0%	50%	100%	50%	100%	92%	8%	50%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-10%	-9%	1%	15%	63%	20%	0%	88%	0%	8%	1%	98%	73%	6%	0%	0%	45%	98%	49%	98%	98%	0%	45%
Geely	-20%	-19%	2%	22%	72%	6%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
General Motors	-9%	-8%	1%	14%	53%	15%	0%	98%	0%	2%	0%	100%	68%	0%	0%	0%	1%	100%	70%	100%	81%	0%	30%
Honda	-10%	-10%	0%	25%	75%	0%	0%	72%	0%	28%	0%	100%	75%	0%	0%	0%	0%	100%	97%	100%	100%	0%	3%
Hyundai	-13%	-11%	2%	25%	75%	0%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	0%	100%	50%	100%	100%	0%	50%
Kia	-14%	-14%	0%	25%	75%	0%	0%	99%	0%	0%	1%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-19%	-17%	1%	18%	75%	0%	0%	70%	0%	26%	1%	98%	75%	5%	2%	0%	35%	100%	56%	98%	98%	0%	37%
Mitsubishi	-18%	-16%	2%	22%	75%	0%	0%	86%	0%	12%	0%	99%	75%	2%	1%	0%	43%	100%	49%	99%	99%	0%	48%
Nissan	-7%	-6%	1%	20%	70%	9%	0%	80%	0%	19%	1%	100%	75%	0%	0%	0%	35%	100%	59%	100%	100%	0%	41%
Porsche	-20%	-18%	1%	11%	61%	28%	0%	99%	0%	0%	1%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Spyker	-4%	-2%	1%	15%	65%	19%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Subaru	-20%	-18%	1%	8%	75%	0%	0%	32%	0%	57%	6%	95%	75%	12%	5%	0%	16%	100%	67%	95%	95%	0%	16%
Suzuki	-15%	-14%	1%	25%	75%	0%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Tata	-13%	-11%	1%	9%	59%	33%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-6%	-6%	0%	20%	67%	8%	0%	82%	0%	9%	3%	94%	71%	6%	0%	0%	0%	94%	92%	94%	94%	0%	3%
Volkswagen	-18%	-17%	2%	19%	69%	11%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Fleet	-10%	-9%	1%	17%	64%	11%	0%	88%	0%	9%	1%	98%	72%	2%	0%	0%	14%	99%	71%	98%	92%	0%	27%

Table 3.5-40 Alternative 1- (Trucks +20) Fleet Technology Penetration in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-20%	-12%	8%	0%	0%	29%	0%	0%	0%	76%	1%	77%	29%	27%	23%	22%	5%	100%	5%	77%	77%	0%	23%
BMW	-13%	-11%	1%	10%	63%	20%	0%	26%	0%	62%	5%	93%	75%	1%	7%	0%	29%	100%	44%	93%	93%	0%	49%
Chrysler/Fiat	-8%	-7%	0%	17%	69%	5%	0%	43%	0%	55%	2%	100%	74%	0%	0%	0%	3%	100%	83%	100%	92%	0%	17%
Daimler	-16%	-14%	2%	9%	60%	16%	0%	23%	0%	66%	0%	89%	73%	2%	11%	0%	35%	100%	42%	89%	87%	2%	45%
Ferrari	-10%	-3%	8%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	5%	77%	77%	0%	0%
Ford	-9%	-8%	1%	20%	67%	9%	0%	48%	0%	47%	4%	98%	72%	3%	0%	0%	22%	98%	63%	98%	96%	0%	34%
Geely	-16%	-14%	2%	11%	60%	20%	0%	39%	0%	51%	1%	91%	75%	0%	9%	0%	42%	100%	42%	91%	91%	0%	49%
General Motors	-8%	-8%	0%	22%	59%	9%	0%	50%	0%	47%	3%	100%	68%	0%	0%	0%	0%	100%	85%	100%	90%	0%	14%
Honda	-5%	-5%	0%	27%	65%	0%	0%	21%	0%	68%	8%	98%	48%	2%	0%	0%	0%	98%	97%	98%	92%	0%	1%
Hyundai	-6%	-5%	0%	25%	75%	0%	0%	39%	0%	55%	6%	100%	75%	0%	0%	0%	0%	100%	90%	100%	100%	0%	10%
Kia	-5%	-5%	0%	39%	61%	0%	0%	27%	0%	66%	7%	100%	32%	0%	0%	0%	0%	100%	100%	100%	100%	0%	0%
Lotus	-3%	0%	3%	7%	56%	0%	0%	0%	0%	55%	25%	80%	56%	11%	20%	5%	25%	100%	25%	80%	80%	0%	39%
Mazda	-8%	-7%	1%	22%	75%	0%	0%	24%	0%	64%	10%	98%	75%	1%	2%	0%	12%	100%	65%	98%	98%	0%	32%
Mitsubishi	-11%	-10%	1%	23%	75%	0%	0%	39%	0%	56%	3%	99%	75%	1%	1%	0%	20%	100%	55%	99%	99%	0%	43%
Nissan	-4%	-4%	1%	23%	73%	3%	0%	27%	0%	69%	3%	99%	75%	1%	0%	0%	10%	99%	80%	99%	99%	0%	19%
Porsche	-9%	-6%	3%	4%	60%	13%	0%	21%	0%	49%	12%	82%	70%	1%	18%	4%	28%	100%	28%	82%	82%	0%	49%
Spyker	-14%	-12%	2%	9%	63%	10%	0%	13%	0%	66%	4%	83%	71%	1%	17%	0%	33%	100%	33%	83%	83%	0%	49%
Subaru	-11%	-10%	1%	17%	75%	0%	0%	7%	0%	72%	15%	95%	75%	3%	5%	0%	4%	100%	73%	95%	95%	0%	19%
Suzuki	-3%	-2%	1%	6%	75%	0%	0%	22%	0%	65%	7%	94%	75%	13%	6%	0%	11%	100%	69%	94%	94%	0%	11%
Tata	-16%	-14%	2%	4%	45%	36%	0%	46%	0%	44%	0%	91%	72%	4%	9%	3%	38%	100%	38%	91%	91%	0%	46%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-4%	-4%	0%	24%	42%	4%	0%	33%	0%	50%	5%	88%	38%	12%	0%	0%	0%	88%	87%	88%	70%	0%	1%
Volkswagen	-10%	-8%	2%	13%	72%	4%	0%	20%	0%	64%	5%	89%	75%	0%	11%	0%	41%	100%	42%	89%	89%	0%	47%
Fleet	-7%	-7%	1%	21%	61%	6%	0%	35%	0%	56%	5%	96%	62%	3%	2%	0%	9%	97%	78%	96%	89%	0%	17%

Table 3.5-41 Alternative 2- (Trucks -20) Car Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-20%	-12%	8%	0%	0%	29%	0%	0%	0%	76%	1%	77%	29%	27%	23%	22%	5%	100%	5%	77%	77%	0%	23%
BMW	-12%	-9%	2%	5%	51%	20%	0%	0%	0%	79%	5%	84%	72%	7%	16%	0%	34%	100%	34%	84%	84%	0%	43%
Chrysler/Fiat	-9%	-7%	1%	18%	73%	3%	0%	4%	0%	91%	1%	96%	75%	3%	4%	0%	3%	100%	49%	96%	96%	0%	45%
Daimler	-15%	-13%	3%	6%	56%	14%	0%	0%	0%	80%	0%	80%	70%	4%	20%	1%	29%	100%	29%	80%	79%	1%	46%
Ferrari	-10%	-3%	8%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	5%	77%	77%	0%	0%
Ford	-11%	-9%	1%	14%	70%	4%	0%	29%	0%	62%	4%	95%	74%	6%	5%	0%	23%	99%	52%	95%	94%	0%	37%
Geely	-15%	-11%	4%	3%	44%	24%	0%	13%	0%	68%	1%	82%	68%	5%	18%	6%	26%	100%	26%	82%	82%	0%	45%
General Motors	-9%	-8%	1%	19%	72%	3%	0%	6%	0%	87%	3%	96%	75%	1%	4%	0%	3%	100%	54%	96%	95%	0%	41%
Honda	-4%	-3%	0%	24%	73%	0%	0%	0%	0%	85%	11%	97%	73%	3%	0%	0%	0%	97%	83%	97%	97%	0%	14%
Hyundai	-5%	-4%	1%	25%	75%	0%	0%	24%	0%	69%	7%	100%	75%	0%	0%	0%	12%	100%	77%	100%	100%	0%	23%
Kia	-3%	-3%	0%	25%	75%	0%	0%	7%	0%	84%	9%	100%	75%	0%	0%	0%	0%	100%	91%	100%	100%	0%	9%
Lotus	-3%	0%	3%	7%	56%	0%	0%	0%	0%	55%	25%	80%	56%	11%	20%	5%	25%	100%	25%	80%	80%	0%	39%
Mazda	-6%	-5%	2%	19%	75%	0%	0%	15%	0%	75%	8%	98%	75%	4%	2%	0%	9%	100%	49%	98%	98%	0%	45%
Mitsubishi	-9%	-7%	2%	15%	74%	0%	0%	16%	0%	72%	4%	92%	74%	3%	8%	0%	36%	100%	43%	92%	92%	0%	46%
Nissan	-5%	-4%	1%	23%	74%	0%	0%	5%	0%	90%	3%	98%	75%	0%	2%	0%	2%	100%	57%	98%	98%	0%	41%
Porsche	-7%	-2%	5%	0%	52%	9%	0%	0%	0%	69%	8%	77%	61%	2%	23%	14%	13%	100%	13%	77%	77%	0%	48%
Spyker	-16%	-13%	3%	3%	65%	8%	0%	0%	0%	74%	4%	78%	73%	2%	22%	0%	28%	100%	28%	78%	78%	0%	48%
Subaru	-9%	-7%	2%	7%	75%	0%	0%	0%	0%	81%	12%	94%	75%	11%	6%	0%	2%	100%	47%	94%	94%	0%	35%
Suzuki	-2%	0%	2%	2%	75%	0%	0%	6%	0%	82%	5%	93%	75%	16%	7%	0%	43%	100%	43%	93%	93%	0%	34%
Tata	-19%	-12%	8%	0%	13%	22%	0%	0%	0%	77%	0%	77%	35%	20%	23%	22%	5%	100%	5%	77%	77%	0%	30%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-4%	-3%	0%	20%	63%	1%	0%	4%	0%	74%	7%	85%	63%	15%	0%	0%	1%	85%	72%	85%	85%	0%	13%
Volkswagen	-8%	-6%	2%	9%	70%	2%	0%	0%	0%	77%	5%	82%	72%	1%	18%	0%	32%	100%	32%	82%	82%	0%	49%
Fleet	-7%	-6%	1%	18%	69%	3%	0%	8%	0%	78%	6%	92%	71%	5%	5%	0%	10%	96%	59%	92%	92%	0%	31%

Table 3.5-42 Alternative 2- (Trucks -20) Truck Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-17%	-16%	1%	15%	65%	19%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Chrysler/Fiat	-12%	-10%	2%	20%	70%	8%	0%	95%	0%	3%	1%	99%	75%	9%	1%	0%	48%	100%	49%	99%	99%	0%	41%
Daimler	-20%	-18%	2%	12%	58%	23%	0%	100%	0%	0%	0%	100%	67%	0%	0%	0%	50%	100%	50%	100%	92%	8%	50%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-12%	-10%	2%	13%	64%	20%	0%	88%	0%	8%	1%	98%	74%	28%	1%	0%	47%	99%	48%	98%	98%	0%	23%
Geely	-20%	-19%	2%	22%	72%	6%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
General Motors	-13%	-11%	2%	17%	67%	15%	0%	98%	0%	2%	0%	100%	75%	15%	0%	0%	50%	100%	50%	100%	100%	0%	35%
Honda	-14%	-13%	1%	25%	75%	0%	0%	72%	0%	28%	0%	100%	75%	2%	0%	0%	36%	100%	57%	100%	100%	0%	41%
Hyundai	-18%	-16%	2%	25%	75%	0%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Kia	-14%	-13%	1%	25%	75%	0%	0%	99%	0%	1%	0%	100%	75%	0%	0%	0%	49%	100%	50%	100%	100%	0%	50%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-19%	-18%	2%	18%	75%	0%	0%	70%	0%	27%	1%	98%	75%	5%	2%	0%	36%	100%	48%	98%	98%	0%	45%
Mitsubishi	-20%	-18%	2%	22%	70%	0%	0%	86%	0%	11%	0%	98%	70%	7%	2%	0%	43%	100%	48%	98%	98%	0%	43%
Nissan	-9%	-7%	2%	15%	70%	9%	0%	80%	0%	18%	1%	98%	74%	17%	2%	0%	41%	100%	48%	98%	98%	0%	33%
Porsche	-20%	-18%	1%	11%	61%	28%	0%	99%	0%	0%	1%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Spyker	-4%	-2%	1%	15%	65%	19%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Subaru	-19%	-17%	2%	8%	75%	0%	0%	32%	0%	60%	4%	95%	75%	12%	5%	0%	16%	100%	45%	95%	95%	0%	38%
Suzuki	-16%	-15%	1%	25%	75%	0%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Tata	-13%	-11%	2%	9%	59%	33%	0%	100%	0%	0%	0%	100%	75%	33%	0%	0%	50%	100%	50%	100%	100%	0%	17%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-9%	-8%	1%	20%	68%	8%	0%	86%	0%	10%	1%	97%	72%	6%	0%	0%	43%	97%	50%	97%	97%	0%	43%
Volkswagen	-18%	-17%	2%	19%	69%	11%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Fleet	-13%	-11%	2%	18%	69%	11%	0%	89%	0%	9%	1%	99%	74%	11%	1%	0%	45%	99%	50%	99%	99%	0%	38%

Table 3.5-43 Alternative 2- (Trucks -20) Fleet Technology Penetration in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-20%	-12%	8%	0%	0%	29%	0%	0%	0%	76%	1%	77%	29%	27%	23%	22%	5%	100%	5%	77%	77%	0%	23%
BMW	-13%	-11%	2%	8%	55%	20%	0%	26%	0%	58%	4%	88%	73%	5%	12%	0%	38%	100%	38%	88%	88%	0%	45%
Chrysler/Fiat	-10%	-9%	2%	19%	72%	5%	0%	43%	0%	53%	1%	98%	75%	5%	2%	0%	22%	100%	49%	98%	97%	0%	44%
Daimler	-16%	-14%	3%	7%	56%	16%	0%	23%	0%	61%	0%	84%	69%	3%	16%	0%	34%	100%	34%	84%	82%	2%	47%
Ferrari	-10%	-3%	8%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	5%	77%	77%	0%	0%
Ford	-11%	-9%	2%	14%	68%	9%	0%	48%	0%	45%	3%	96%	74%	13%	4%	0%	30%	99%	51%	96%	95%	0%	33%
Geely	-16%	-13%	3%	9%	53%	18%	0%	39%	0%	48%	1%	87%	70%	3%	13%	4%	33%	100%	33%	87%	87%	0%	47%
General Motors	-11%	-9%	1%	18%	70%	9%	0%	50%	0%	46%	2%	98%	75%	8%	2%	0%	25%	100%	52%	98%	97%	0%	38%
Honda	-7%	-6%	1%	24%	73%	0%	0%	21%	0%	69%	8%	98%	73%	3%	0%	0%	11%	98%	75%	98%	98%	0%	22%
Hyundai	-8%	-7%	1%	25%	75%	0%	0%	39%	0%	55%	6%	100%	75%	0%	0%	0%	20%	100%	71%	100%	100%	0%	28%
Kia	-6%	-5%	0%	25%	75%	0%	0%	27%	0%	66%	7%	100%	75%	0%	0%	0%	10%	100%	83%	100%	100%	0%	17%
Lotus	-3%	0%	3%	7%	56%	0%	0%	0%	0%	55%	25%	80%	56%	11%	20%	5%	25%	100%	25%	80%	80%	0%	39%
Mazda	-9%	-7%	2%	19%	75%	0%	0%	24%	0%	67%	7%	98%	75%	4%	2%	0%	13%	100%	49%	98%	98%	0%	45%
Mitsubishi	-13%	-11%	2%	17%	73%	0%	0%	39%	0%	52%	2%	94%	73%	4%	6%	0%	38%	100%	44%	94%	94%	0%	45%
Nissan	-6%	-5%	1%	21%	73%	3%	0%	27%	0%	69%	2%	98%	75%	5%	2%	0%	14%	100%	54%	98%	98%	0%	38%
Porsche	-10%	-6%	4%	2%	54%	13%	0%	21%	0%	54%	6%	82%	64%	1%	18%	11%	21%	100%	21%	82%	82%	0%	49%
Spyker	-14%	-11%	3%	4%	65%	10%	0%	13%	0%	64%	4%	81%	74%	1%	19%	0%	31%	100%	31%	81%	81%	0%	49%
Subaru	-11%	-9%	2%	7%	75%	0%	0%	7%	0%	76%	10%	94%	75%	12%	6%	0%	5%	100%	47%	94%	94%	0%	36%
Suzuki	-4%	-3%	2%	6%	75%	0%	0%	22%	0%	68%	4%	94%	75%	13%	6%	0%	44%	100%	44%	94%	94%	0%	37%
Tata	-16%	-11%	5%	4%	34%	27%	0%	46%	0%	41%	0%	88%	54%	26%	12%	12%	26%	100%	26%	88%	88%	0%	24%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-6%	-5%	1%	20%	65%	4%	0%	34%	0%	51%	5%	89%	67%	12%	0%	0%	17%	89%	64%	89%	89%	0%	24%
Volkswagen	-10%	-8%	2%	11%	70%	4%	0%	20%	0%	62%	4%	86%	72%	1%	14%	0%	36%	100%	36%	86%	86%	0%	49%
Fleet	-9%	-8%	1%	18%	69%	6%	0%	35%	0%	55%	4%	94%	72%	7%	3%	0%	22%	97%	56%	94%	94%	0%	33%

Table 3.5-44 Alternative 3- (Cars +20) Car Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-20%	-15%	5%	0%	0%	43%	0%	0%	0%	73%	4%	77%	43%	27%	23%	7%	20%	100%	20%	77%	77%	0%	23%
BMW	-11%	-9%	1%	11%	63%	20%	0%	0%	0%	87%	8%	95%	75%	0%	5%	0%	0%	100%	50%	95%	95%	0%	45%
Chrysler/Fiat	-7%	-7%	0%	24%	73%	3%	0%	4%	0%	94%	2%	100%	74%	0%	0%	0%	0%	100%	98%	100%	99%	0%	2%
Daimler	-15%	-13%	1%	11%	65%	14%	0%	0%	0%	91%	0%	91%	74%	0%	9%	0%	27%	100%	46%	91%	91%	1%	45%
Ferrari	-10%	-3%	7%	0%	0%	28%	0%	0%	0%	77%	0%	77%	28%	27%	23%	22%	5%	100%	5%	77%	77%	0%	23%
Ford	-8%	-8%	0%	23%	68%	4%	0%	29%	0%	64%	5%	99%	72%	1%	0%	0%	0%	99%	86%	99%	95%	0%	13%
Geely	-13%	-12%	2%	8%	58%	26%	0%	13%	0%	77%	2%	92%	75%	0%	8%	0%	12%	100%	44%	92%	92%	0%	48%
General Motors	-7%	-7%	0%	29%	65%	3%	0%	6%	0%	88%	6%	100%	68%	0%	0%	0%	0%	100%	99%	100%	97%	0%	0%
Honda	-2%	-2%	0%	18%	30%	0%	0%	0%	0%	85%	12%	97%	11%	3%	0%	0%	0%	97%	97%	97%	48%	0%	0%
Hyundai	-3%	-3%	0%	38%	34%	0%	0%	24%	0%	68%	7%	100%	24%	0%	0%	0%	0%	100%	100%	100%	73%	0%	0%
Kia	-3%	-3%	0%	5%	31%	0%	0%	7%	0%	84%	9%	100%	5%	0%	0%	0%	0%	100%	100%	100%	36%	0%	0%
Lotus	-2%	0%	2%	7%	75%	0%	0%	0%	0%	49%	36%	85%	75%	3%	15%	0%	36%	100%	36%	85%	85%	0%	46%
Mazda	-4%	-4%	0%	25%	75%	0%	0%	15%	0%	70%	15%	100%	75%	0%	0%	0%	0%	100%	98%	100%	100%	0%	2%
Mitsubishi	-7%	-7%	1%	25%	75%	0%	0%	16%	0%	78%	6%	100%	75%	0%	0%	0%	0%	100%	75%	100%	100%	0%	25%
Nissan	-3%	-3%	0%	36%	63%	0%	0%	5%	0%	90%	5%	99%	27%	1%	0%	0%	0%	99%	99%	99%	99%	0%	0%
Porsche	-5%	-2%	3%	8%	60%	9%	0%	0%	0%	60%	19%	79%	69%	2%	21%	0%	29%	100%	29%	79%	79%	0%	48%
Spyker	-15%	-14%	2%	9%	69%	8%	0%	0%	0%	80%	6%	87%	75%	0%	13%	0%	34%	100%	41%	87%	87%	0%	45%
Subaru	-8%	-7%	0%	22%	75%	0%	0%	0%	0%	77%	20%	97%	75%	0%	3%	0%	0%	100%	85%	97%	97%	0%	12%
Suzuki	0%	0%	0%	21%	75%	0%	0%	6%	0%	79%	11%	96%	75%	0%	4%	0%	3%	100%	93%	96%	96%	0%	3%
Tata	-19%	-16%	2%	0%	37%	38%	0%	0%	0%	83%	0%	83%	75%	7%	17%	0%	33%	100%	33%	83%	83%	0%	43%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-3%	-3%	0%	6%	27%	1%	0%	4%	0%	74%	7%	84%	4%	16%	0%	0%	0%	84%	84%	84%	34%	0%	0%
Volkswagen	-7%	-6%	1%	16%	73%	2%	0%	0%	0%	85%	8%	92%	75%	0%	8%	0%	0%	100%	46%	92%	92%	0%	46%
Fleet	-6%	-5%	0%	20%	52%	3%	0%	8%	0%	79%	7%	95%	44%	4%	2%	0%	1%	96%	86%	95%	76%	0%	9%

Table 3.5-45 Alternative 3- (Cars +20) Truck Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-17%	-15%	1%	15%	65%	19%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Chrysler/Fiat	-8%	-7%	1%	9%	65%	8%	0%	94%	0%	4%	2%	100%	73%	0%	0%	0%	7%	100%	72%	100%	83%	0%	28%
Daimler	-20%	-18%	2%	12%	58%	23%	0%	100%	0%	0%	0%	100%	67%	0%	0%	0%	50%	100%	50%	100%	92%	8%	50%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-9%	-8%	1%	14%	63%	20%	0%	88%	0%	8%	1%	97%	73%	3%	0%	0%	16%	97%	62%	97%	97%	0%	35%
Geely	-20%	-19%	2%	22%	72%	6%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
General Motors	-9%	-8%	1%	14%	53%	15%	0%	98%	0%	2%	0%	100%	68%	0%	0%	0%	15%	100%	66%	100%	81%	0%	34%
Honda	-9%	-9%	0%	25%	75%	0%	0%	72%	0%	28%	0%	100%	75%	0%	0%	0%	0%	100%	98%	100%	100%	0%	2%
Hyundai	-10%	-10%	0%	25%	75%	0%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%	0%
Kia	-9%	-9%	0%	25%	75%	0%	0%	99%	0%	0%	1%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-13%	-12%	1%	25%	75%	0%	0%	70%	0%	28%	2%	100%	75%	0%	0%	0%	0%	100%	67%	100%	100%	0%	33%
Mitsubishi	-18%	-17%	1%	25%	75%	0%	0%	86%	0%	14%	0%	100%	75%	0%	0%	0%	43%	100%	57%	100%	100%	0%	43%
Nissan	-6%	-5%	1%	20%	70%	9%	0%	80%	0%	19%	1%	100%	75%	0%	0%	0%	0%	100%	74%	100%	100%	0%	26%
Porsche	-20%	-18%	1%	11%	61%	28%	0%	99%	0%	0%	1%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Spyker	-4%	-2%	1%	15%	65%	19%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Subaru	-19%	-19%	0%	25%	75%	0%	0%	32%	0%	61%	8%	100%	75%	0%	0%	0%	16%	100%	84%	100%	100%	0%	16%
Suzuki	-14%	-13%	1%	25%	75%	0%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Tata	-13%	-11%	1%	9%	59%	33%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-5%	-5%	0%	29%	57%	8%	0%	82%	0%	9%	3%	94%	66%	6%	0%	0%	0%	94%	94%	94%	94%	0%	0%
Volkswagen	-18%	-17%	2%	19%	69%	11%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Fleet	-9%	-8%	1%	19%	62%	11%	0%	88%	0%	9%	1%	98%	71%	2%	0%	0%	11%	98%	76%	98%	92%	0%	23%

Table 3.5-46 Alternative 3- (Cars +20) Fleet Technology Penetration in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-20%	-15%	5%	0%	0%	43%	0%	0%	0%	73%	4%	77%	43%	27%	23%	7%	20%	100%	20%	77%	77%	0%	23%
BMW	-12%	-11%	1%	12%	64%	20%	0%	26%	0%	64%	6%	96%	75%	0%	4%	0%	13%	100%	50%	96%	96%	0%	47%
Chrysler/Fiat	-7%	-7%	0%	17%	69%	5%	0%	43%	0%	55%	2%	100%	74%	0%	0%	0%	3%	100%	87%	100%	92%	0%	13%
Daimler	-16%	-15%	1%	11%	64%	16%	0%	23%	0%	70%	0%	93%	73%	0%	7%	0%	32%	100%	47%	93%	91%	2%	46%
Ferrari	-10%	-3%	7%	0%	0%	28%	0%	0%	0%	77%	0%	77%	28%	27%	23%	22%	5%	100%	5%	77%	77%	0%	23%
Ford	-8%	-8%	1%	20%	67%	9%	0%	48%	0%	47%	4%	98%	72%	2%	0%	0%	5%	98%	78%	98%	96%	0%	20%
Geely	-15%	-14%	2%	12%	62%	20%	0%	39%	0%	54%	1%	94%	75%	0%	6%	0%	24%	100%	46%	94%	94%	0%	49%
General Motors	-8%	-8%	0%	22%	59%	9%	0%	50%	0%	47%	3%	100%	68%	0%	0%	0%	7%	100%	83%	100%	90%	0%	16%
Honda	-4%	-4%	0%	20%	43%	0%	0%	21%	0%	68%	8%	98%	30%	2%	0%	0%	0%	98%	97%	98%	63%	0%	0%
Hyundai	-5%	-5%	0%	36%	42%	0%	0%	39%	0%	55%	6%	100%	35%	0%	0%	0%	0%	100%	100%	100%	78%	0%	0%
Kia	-4%	-4%	0%	9%	41%	0%	0%	27%	0%	66%	7%	100%	20%	0%	0%	0%	0%	100%	100%	100%	50%	0%	0%
Lotus	-2%	0%	2%	7%	75%	0%	0%	0%	0%	49%	36%	85%	75%	3%	15%	0%	36%	100%	36%	85%	85%	0%	46%
Mazda	-6%	-6%	0%	25%	75%	0%	0%	24%	0%	63%	13%	100%	75%	0%	0%	0%	0%	100%	92%	100%	100%	0%	8%
Mitsubishi	-11%	-10%	1%	25%	75%	0%	0%	39%	0%	57%	4%	100%	75%	0%	0%	0%	14%	100%	69%	100%	100%	0%	31%
Nissan	-4%	-4%	0%	31%	65%	3%	0%	27%	0%	69%	4%	99%	41%	1%	0%	0%	0%	99%	92%	99%	99%	0%	8%
Porsche	-8%	-6%	3%	9%	61%	13%	0%	21%	0%	47%	15%	83%	70%	1%	17%	0%	33%	100%	33%	83%	83%	0%	49%
Spyker	-14%	-12%	2%	10%	69%	10%	0%	13%	0%	70%	5%	88%	75%	0%	12%	0%	36%	100%	42%	88%	88%	0%	46%
Subaru	-10%	-10%	0%	23%	75%	0%	0%	7%	0%	73%	17%	98%	75%	0%	2%	0%	4%	100%	85%	98%	98%	0%	13%
Suzuki	-2%	-2%	0%	22%	75%	0%	0%	22%	0%	65%	9%	97%	75%	0%	3%	0%	11%	100%	86%	97%	97%	0%	11%
Tata	-16%	-14%	2%	4%	47%	36%	0%	46%	0%	44%	0%	91%	75%	4%	9%	0%	41%	100%	41%	91%	91%	0%	46%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-4%	-4%	0%	14%	38%	4%	0%	33%	0%	50%	5%	88%	26%	12%	0%	0%	0%	88%	88%	88%	56%	0%	0%
Volkswagen	-9%	-8%	1%	17%	73%	4%	0%	20%	0%	68%	6%	94%	75%	0%	6%	0%	10%	100%	47%	94%	94%	0%	47%
Fleet	-7%	-6%	0%	20%	56%	6%	0%	35%	0%	56%	5%	96%	53%	3%	1%	0%	5%	97%	83%	96%	81%	0%	13%

Table 3.5-47 Alternative 4- (Cars -20) Car Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-20%	-11%	9%	0%	0%	5%	0%	0%	0%	76%	1%	77%	5%	50%	23%	22%	5%	100%	5%	77%	77%	0%	0%
BMW	-12%	-9%	3%	3%	48%	20%	0%	0%	0%	74%	4%	78%	68%	7%	22%	0%	28%	100%	28%	78%	78%	0%	43%
Chrysler/Fiat	-9%	-7%	2%	18%	72%	3%	0%	4%	0%	91%	1%	96%	75%	3%	4%	0%	11%	100%	46%	96%	96%	0%	47%
Daimler	-16%	-11%	4%	0%	52%	14%	0%	0%	0%	78%	0%	78%	66%	4%	22%	7%	21%	100%	21%	78%	77%	1%	46%
Ferrari	-10%	-3%	8%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	5%	77%	77%	0%	0%
Ford	-11%	-10%	2%	12%	70%	4%	0%	29%	0%	59%	3%	92%	74%	6%	8%	0%	30%	99%	43%	92%	91%	0%	43%
Geely	-15%	-10%	5%	3%	30%	23%	0%	13%	0%	66%	1%	80%	53%	14%	20%	10%	20%	100%	20%	80%	80%	0%	36%
General Motors	-9%	-8%	1%	21%	72%	3%	0%	6%	0%	88%	4%	98%	75%	1%	2%	0%	3%	100%	57%	98%	97%	0%	41%
Honda	-4%	-3%	1%	22%	73%	0%	0%	0%	0%	86%	9%	96%	73%	4%	2%	0%	0%	98%	65%	96%	96%	0%	29%
Hyundai	-7%	-6%	2%	18%	75%	0%	0%	24%	0%	69%	3%	97%	75%	5%	3%	0%	16%	100%	47%	97%	97%	0%	45%
Kia	-4%	-3%	1%	20%	75%	0%	0%	7%	0%	83%	6%	97%	75%	2%	3%	0%	4%	100%	59%	97%	97%	0%	36%
Lotus	-5%	0%	5%	2%	52%	0%	0%	0%	0%	62%	15%	77%	52%	11%	23%	12%	15%	100%	15%	77%	77%	0%	39%
Mazda	-7%	-5%	2%	14%	66%	0%	0%	15%	0%	70%	6%	91%	66%	11%	9%	1%	39%	100%	41%	91%	91%	0%	39%
Mitsubishi	-10%	-7%	2%	6%	71%	0%	0%	16%	0%	68%	3%	88%	71%	10%	12%	0%	34%	100%	38%	88%	88%	0%	40%
Nissan	-5%	-4%	2%	17%	74%	0%	0%	5%	0%	88%	2%	95%	74%	4%	5%	0%	14%	100%	45%	95%	95%	0%	46%
Porsche	-8%	-2%	6%	0%	46%	5%	0%	0%	0%	73%	4%	77%	51%	5%	23%	22%	5%	100%	5%	77%	77%	0%	45%
Spyker	-16%	-11%	5%	0%	56%	8%	0%	0%	0%	74%	2%	77%	64%	2%	23%	11%	16%	100%	16%	77%	77%	0%	48%
Subaru	-9%	-7%	2%	5%	74%	0%	0%	0%	0%	79%	11%	90%	74%	11%	10%	0%	37%	100%	40%	90%	90%	0%	39%
Suzuki	-3%	0%	3%	2%	44%	0%	0%	6%	0%	75%	4%	86%	44%	40%	14%	0%	36%	100%	36%	86%	86%	0%	10%
Tata	-19%	-12%	8%	0%	13%	22%	0%	0%	0%	77%	0%	77%	35%	20%	23%	22%	5%	100%	5%	77%	77%	0%	30%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-4%	-4%	1%	21%	63%	1%	0%	4%	0%	75%	6%	86%	64%	14%	0%	0%	2%	86%	65%	86%	86%	0%	21%
Volkswagen	-9%	-5%	4%	6%	65%	2%	0%	0%	0%	73%	4%	77%	66%	1%	23%	4%	24%	100%	24%	77%	77%	0%	49%
Fleet	-8%	-6%	2%	16%	67%	3%	0%	8%	0%	77%	5%	91%	70%	6%	6%	1%	13%	97%	49%	91%	90%	0%	37%

Table 3.5-48 Alternative 4- (Cars -20) Truck Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-17%	-16%	1%	15%	65%	19%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Chrysler/Fiat	-12%	-11%	2%	20%	69%	8%	0%	95%	0%	3%	1%	99%	73%	10%	1%	0%	48%	100%	49%	99%	99%	0%	40%
Daimler	-20%	-18%	2%	12%	58%	23%	0%	100%	0%	0%	0%	100%	67%	0%	0%	0%	50%	100%	50%	100%	92%	8%	50%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-12%	-10%	2%	12%	62%	20%	0%	88%	0%	8%	1%	97%	72%	30%	2%	0%	46%	99%	47%	97%	97%	0%	21%
Geely	-20%	-19%	2%	22%	72%	6%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
General Motors	-13%	-11%	2%	17%	67%	15%	0%	98%	0%	2%	0%	100%	75%	15%	0%	0%	50%	100%	50%	100%	100%	0%	35%
Honda	-15%	-14%	2%	18%	75%	0%	0%	72%	0%	26%	0%	98%	75%	8%	2%	0%	36%	100%	48%	98%	98%	0%	42%
Hyundai	-20%	-19%	2%	25%	75%	0%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Kia	-17%	-16%	1%	25%	75%	0%	0%	99%	0%	1%	0%	100%	75%	0%	0%	0%	49%	100%	50%	100%	100%	0%	50%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-20%	-18%	2%	18%	63%	0%	0%	70%	0%	25%	1%	95%	63%	15%	5%	0%	37%	100%	45%	95%	95%	0%	35%
Mitsubishi	-20%	-18%	2%	22%	70%	0%	0%	86%	0%	11%	0%	98%	70%	7%	2%	0%	48%	100%	48%	98%	98%	0%	43%
Nissan	-9%	-8%	2%	15%	62%	9%	0%	80%	0%	16%	1%	97%	67%	23%	3%	0%	41%	100%	47%	97%	97%	0%	27%
Porsche	-20%	-18%	2%	0%	50%	50%	0%	99%	0%	0%	1%	100%	75%	39%	0%	0%	50%	100%	50%	100%	100%	0%	11%
Spyker	-4%	-2%	1%	15%	65%	19%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Subaru	-20%	-17%	3%	8%	48%	0%	0%	32%	0%	55%	3%	90%	48%	34%	10%	0%	16%	100%	40%	90%	90%	0%	16%
Suzuki	-16%	-15%	1%	25%	75%	0%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Tata	-13%	-11%	2%	0%	59%	41%	0%	100%	0%	0%	0%	100%	75%	50%	0%	0%	50%	100%	50%	100%	100%	0%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-10%	-8%	2%	18%	68%	8%	0%	86%	0%	9%	1%	96%	72%	16%	1%	0%	43%	97%	46%	96%	96%	0%	37%
Volkswagen	-18%	-17%	2%	19%	69%	11%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Fleet	-13%	-11%	2%	17%	67%	11%	0%	89%	0%	8%	1%	98%	73%	15%	1%	0%	45%	99%	48%	98%	98%	0%	35%

Table 3.5-49 Alternative 4- (Cars -20) Fleet Technology Penetration in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-20%	-11%	9%	0%	0%	5%	0%	0%	0%	76%	1%	77%	5%	50%	23%	22%	5%	100%	5%	77%	77%	0%	0%
BMW	-13%	-11%	3%	6%	52%	20%	0%	26%	0%	54%	3%	84%	70%	5%	16%	0%	34%	100%	34%	84%	84%	0%	45%
Chrysler/Fiat	-10%	-9%	2%	19%	71%	5%	0%	43%	0%	53%	1%	98%	74%	6%	2%	0%	27%	100%	48%	98%	97%	0%	44%
Daimler	-17%	-13%	4%	3%	54%	16%	0%	23%	0%	60%	0%	83%	66%	3%	17%	6%	27%	100%	27%	83%	81%	2%	47%
Ferrari	-10%	-3%	8%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	5%	77%	77%	0%	0%
Ford	-12%	-10%	2%	12%	68%	9%	0%	48%	0%	44%	2%	93%	73%	13%	6%	0%	35%	99%	44%	93%	93%	0%	37%
Geely	-17%	-13%	4%	9%	42%	18%	0%	39%	0%	47%	0%	86%	59%	10%	14%	7%	29%	100%	29%	86%	86%	0%	40%
General Motors	-11%	-9%	1%	19%	70%	9%	0%	50%	0%	47%	2%	99%	75%	8%	1%	0%	25%	100%	53%	99%	98%	0%	38%
Honda	-7%	-6%	1%	21%	73%	0%	0%	21%	0%	69%	7%	96%	73%	5%	2%	0%	11%	98%	60%	96%	96%	0%	33%
Hyundai	-10%	-8%	2%	19%	75%	0%	0%	39%	0%	56%	3%	97%	75%	4%	3%	0%	22%	100%	47%	97%	97%	0%	46%
Kia	-7%	-6%	1%	21%	75%	0%	0%	27%	0%	66%	5%	97%	75%	1%	3%	0%	13%	100%	57%	97%	97%	0%	39%
Lotus	-5%	0%	5%	2%	52%	0%	0%	0%	0%	62%	15%	77%	52%	11%	23%	12%	15%	100%	15%	77%	77%	0%	39%
Mazda	-9%	-7%	2%	15%	65%	0%	0%	24%	0%	63%	5%	92%	65%	11%	8%	0%	39%	100%	41%	92%	92%	0%	39%
Mitsubishi	-13%	-11%	2%	11%	70%	0%	0%	39%	0%	49%	2%	91%	70%	9%	9%	0%	39%	100%	41%	91%	91%	0%	41%
Nissan	-7%	-5%	2%	17%	71%	3%	0%	27%	0%	67%	2%	95%	72%	9%	4%	0%	22%	100%	46%	95%	95%	0%	40%
Porsche	-10%	-5%	5%	0%	47%	15%	0%	21%	0%	57%	3%	82%	56%	12%	18%	17%	15%	100%	15%	82%	82%	0%	38%
Spyker	-15%	-10%	5%	2%	57%	10%	0%	13%	0%	65%	2%	80%	66%	1%	20%	10%	20%	100%	20%	80%	80%	0%	49%
Subaru	-12%	-9%	2%	5%	68%	0%	0%	7%	0%	74%	9%	90%	68%	16%	10%	0%	32%	100%	40%	90%	90%	0%	33%
Suzuki	-5%	-3%	3%	6%	50%	0%	0%	22%	0%	62%	3%	88%	50%	33%	12%	0%	38%	100%	38%	88%	88%	0%	17%
Tata	-17%	-11%	5%	0%	34%	31%	0%	46%	0%	41%	0%	88%	54%	34%	12%	12%	26%	100%	26%	88%	88%	0%	16%
Tesla	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	-6%	-5%	1%	20%	65%	4%	0%	34%	0%	51%	5%	90%	67%	15%	0%	0%	17%	90%	58%	90%	90%	0%	27%
Volkswagen	-11%	-8%	3%	9%	66%	3%	0%	20%	0%	59%	3%	82%	68%	1%	18%	3%	29%	100%	29%	82%	82%	0%	49%
Fleet	-9%	-8%	2%	16%	67%	6%	0%	35%	0%	55%	3%	93%	71%	9%	5%	0%	24%	98%	49%	93%	93%	0%	36%

3.5.6 Additional Detail on Mass Reduction Technology

For MY 2021 and MY 2025, additional details are presented on the distribution of mass reduction in the fleet by vehicle class. For presentation in this analysis, we aggregated the 19 vehicle types into 9 narrower vehicle classes.[YY]

Table 3.5-50 Aggregation of Vehicle types for Mass Reduction Presentation

	VehType	2025 sales	**Vehicle Class**
SubAuto_4_4_4_DOHC	1	2,343,764	Small car
Auto_4_4_4_DOHC	2	3,717,990	Standard car
Auto_6_6_4_DOHC	3	2,684,824	Standard car
Auto_6_6_2_SOHC	4	486,136	Standard car
Auto_8_8_4_DOHC	5	566,356	Large car
Auto_8_8_2_OHV	6	168,301	Large car
MPVnt_4_4_4_DOHC	7	1,098,943	Small MPV
MPVt_6_6_4_DOHC	8	3,910,859	Large MPV
MPVt_6_6_2_SOHC	9	90,504	Large MPV
MPVt_6_6_2_OHV	10	442,375	Large MPV
MPVt_8_8_4_DOHC	11	263,513	Truck
MPVt_8_8_2_OHV	12	123,898	Truck
Truck_4_4_4_DOHC	13	61,359	Small MPV
Truck_6_6_4_DOHC	14	258,882	Large MPV
Truck_6_6_2_OHV	15	162,502	Large MPV
Truck_8_8_4_DOHC	16	217,954	Truck
Truck_8_8_2_SOHC	17	103,184	Truck
Truck_8_8_3_SOHC	18	161,734	Truck
Truck_8_8_2_OHV	19	387,383	Truck

[YY] Just to limit the size of this table.

After aggregations here are the weight reductions by vehicle class.

	Reference		Control		Sales
	2021	2025	2021	2025	2025
Subcompact car I4	-0.2%	-0.2%	-0.3%	-0.5%	2,343,764
Compact car I4	-1.3%	-1.3%	-1.6%	-1.7%	3,717,990
Midsize car V6	-5.3%	-5.2%	-7.2%	-8.3%	3,170,959
Large car V8	-7.2%	-7.2%	-10.6%	-13.2%	734,656
Small MPV I4	-5.1%	-5.1%	-8.2%	-13.3%	1,160,302
Midsize MPV V6	-5.6%	-5.7%	-7.6%	-11.2%	4,443,738
Large MPV V8	-7.1%	-7.0%	-9.7%	-12.3%	387,411
Full pickup V6	-1.8%	-1.7%	-2.0%	-1.9%	421,385
Full pickup V8	-7.0%	-7.0%	-7.6%	-8.8%	870,254

3.5.7 Air Conditioning Cost

As previously referenced, once the OMEGA costs were determined, the estimated air conditioning costs, as discussed in Chapter 5 of the Joint TSD were added onto the total cost. These costs are shown below.

Table 3.5-51 Total Costs for A/C Control Used in This Final rule (2010$)

Car/ Truck	Case	2021	2025
Car	Reference	$68	$64
	Control	$79	$69
	Total	$147	$133
Truck	Reference	$52	$49
	Control	$95	$84
	Total	$147	$133
Fleet	Total	$147	$133

3.5.8 Stranded Capital

Because the production of automotive components is capital-intensive, it is possible for substantial capital investments in manufacturing equipment and facilities to become "stranded" (where their value is lost, or diminished). This would occur when the capital is rendered useless (or less useful) by some factor that forces a major change in vehicle design, plant operations, or manufacturer's product mix, such as a shift in consumer demand for certain vehicle types. It can also be caused by new standards that phase-in at a rate too rapid to accommodate planned replacement or redisposition of existing capital to other activities. The lost value of capital equipment is then amortized in some way over production of the new technology components. A discussion of this issue is presented in Chapter 3 of the TSD. To help ensure a conservative cost analysis for the rule (i.e., an analysis that might err on the side of over-costing), EPA asked FEV to calculate potential stranded capital on six specific technologies, using a set of conservative assumptions described in the TSD. EPA then included these potential additional technology costs as a post-process to the OMEGA model (Table 3.5-53). These "stranded capital" costs were not directly incorporated into the technology inputs because they are a function of how rapidly technologies are phased in. Costs for potential stranded capital (as shown in TSD 3) depend both on the stranded technology and the replacing technology.

Table 3.5-52 Potential Stranded Capital Costs (2009$)

Replaced technology	New technology	Stranded capital cost per vehicle when replaced technology's production is ended after:		
		3 years	5 years	8 years
6-speed AT	6-speed DCT	$55	$39	$16
6-speed AT	8-speed AT	$48	$34	$14
6-speed DCT	8-speed DCT	$28	$20	$8
Conventional V6	DSTGDI I4	$56	$40	$16
Conventional V8	DSTGDI V6	$60	$43	$17
Conventional V6	Power-split HEV	$111	$79	$32

DSTGDI=Downsized, turbocharged engine with stoichiometric gasoline direct injection.

For MY 2016, the eight year stranded capital costs were used. For MYs 2016-2021 and 2021-2021, the five year stranded capital costs were used. This properly reflects EPA's analytic assumption that redesign schedules are evenly spread through time.

For transmissions, EPA determined the change in quantity of 6 and 8 speed automatic and dual clutch transmissions. For each of these transmissions, manufacturers that increased their production quantity had no stranded capital, otherwise, we applied a per piece cost corresponding to the table above. This methodology overstates the potential stranded capital costs, as it includes changes in production from the vehicle forecast. For engines, the stranded capital work done by FEV does not precisely correspond to the technologies considered in OMEGA; significantly, the pieces of "stranded" technology were often not those that were similarly "stranded" by the OMEGA projections. As an example, OMEGA might forecast a 24 bar BMEP turbo-charged downsized engine in MY 2021, and then 27 bar BMEP engine technology in MY 2025. The stranded 24 bar engine, while based on a FEV cost analysis, does not directly correspond to any technology listed above. As a result, EPA created a projection that for each manufacturer listed the number of engines with 8, 6, 4 or 3, as well as the number of EVs and Atkinson cycle HEVs. A decrease in any of these quantities resulted in a $50.50 (2010$) per engine increase in cost, which is a rough average of the five year stranded capital cost for the three engine technologies.

Total potential stranded capital determined by this analysis is shown below, and includes all manufacturers including SVMs. These costs are not differentiated between car and truck. As the values are small, we applied these same potential stranded capital costs to all alternatives. The highest costs are in MY 2021, reflecting the rapid technology change during the time leading up to that MY.

Table 3.5-53 Estimated Potential Stranded Capital[ZZ] (2010$)

	MY2016			MY 2021			MY 2025		
Manufacturer	Engine	Trans-mission	Total	Engine	Trans-mission	Total	Engine	Trans-mission	Total
Aston Martin	$51	$16	$67	$27	$8	$35	$14	$3	$17
BMW	$9	$3	$13	$15	$16	$31	$7	$4	$11
Chrysler/Fiat	$60	$0	$60	$10	$14	$24	$11	$5	$16
Daimler	$11	$6	$17	$13	$9	$22	$6	$4	$10
Ferrari	$0	$1	$1	$28	$12	$40	$19	$3	$22
Ford	$15	$0	$15	$9	$12	$21	$4	$5	$9
Geely	$13	$0	$13	$14	$16	$30	$7	$5	$12
General Motors	$18	$0	$18	$8	$10	$18	$9	$5	$14
Honda	$12	$0	$12	$3	$10	$13	$17	$4	$21
Hyundai	$7	$0	$7	$3	$6	$9	$11	$4	$15
Kia	$7	$0	$7	$26	$17	$43	$21	$4	$25
Lotus	$30	$0	$30	$13	$0	$13	$8	$2	$10
Mazda	$12	$0	$12	$23	$15	$38	$10	$4	$13
Mitsubishi	$9	$0	$9	$23	$15	$39	$9	$4	$13
Nissan	$11	$0	$11	$4	$9	$13	$10	$4	$14
Porsche	$16	$1	$17	$17	$10	$27	$12	$3	$15
Spyker	$41	$0	$41	$6	$8	$14	$11	$4	$15
Subaru	$7	$0	$7	$8	$7	$15	$2	$3	$5
Suzuki	$32	$0	$32	$6	$8	$14	$7	$4	$11
Tata	$12	$4	$16	$9	$12	$21	$16	$4	$20
Tesla	$1	$0	$1	$0	$0	$0	$0	$0	$0
Toyota	$2	$0	$2	$13	$6	$19	$16	$9	$25
Volkswagen	$9	$2	$12	$15	$10	$25	$1	$4	$5
Fleet	**$13**	**$0**	**$14**	**$10**	**$10**	**$20**	**$10**	**$5**	**$16**

[ZZ] Note that the total potential stranded capital for Aston Martin engines is greater than $50, the cost of the potential stranded capital. This is because the market forecast includes a decrease in sales for Aston Martin, and a projected change in number of cylinders for every one of their engines. Also note, as described in section III.B.5 of the preamble, small volume manufacturers with U.S. sales of less than 5,000 vehicles would be able to petition EPA for an alternative standard for MY 2017 and later. Manufacturers currently meeting the 5,000 vehicle cut point include Lotus, Aston Martin, and McLaren. Thus, these potential stranded capital costs may be overstated for these small volume manufacturers.

3.6 Per Vehicle Costs MYs 2021 and 2025

As described above, to get the relevant per-vehicle technology costs which are attributable to the program alone, we must account for any cost that is incurred due to compliance with existing vehicle programs. In order to bring the MY 2008 based market forecast up to reference case technology levels, EPA first used OMEGA to calculate costs reflected in the existing MY 2016 program, which is the reference case for this analysis. The OMEGA estimates indicate that, on average, manufacturers will need to spend $783 to meet the 2016MY standards in the 2021MY, and $719 to meet the 2016MY standards in the 2025MY per vehicle. Reference case costs, inclusive of AC costs, are provided in Table 3.6-1 .

Table 3.6-1 Reference Case Costs (2010$)

Company	2021			2025		
	Cars	**Trucks**	**Fleet**	**Cars**	**Trucks**	**Fleet**
Aston Martin	$2,632	$0	$2,632	$2,417	$0	$2,417
BMW	$1,989	$2,126	$2,025	$1,820	$1,955	$1,855
Chrysler/Fiat	$811	$978	$887	$718	$909	$801
Daimler	$2,212	$2,238	$2,219	$2,044	$2,065	$2,049
Ferrari	$2,455	$0	$2,455	$2,248	$0	$2,248
Ford	$911	$1,334	$1,054	$859	$1,255	$981
Geely-Volvo	$2,038	$1,959	$2,014	$1,865	$1,804	$1,847
GM	$769	$924	$846	$712	$853	$780
Honda	$110	$416	$205	$94	$397	$183
Hyundai	$401	$670	$456	$376	$647	$430
Kia	$303	$712	$395	$281	$688	$367
Lotus	$1,867	$0	$1,867	$1,715	$0	$1,715
Mazda	$726	$890	$755	$673	$835	$700
Mitsubishi	$1,182	$1,566	$1,316	$1,076	$1,443	$1,198
Nissan	$410	$890	$559	$373	$818	$505
Porsche	$1,884	$1,910	$1,890	$1,728	$1,739	$1,730
Spyker-Saab	$1,913	$2,112	$1,941	$1,751	$1,946	$1,776
Subaru	$1,044	$1,191	$1,080	$1,023	$1,147	$1,051
Suzuki	$1,016	$1,330	$1,072	$951	$1,244	$1,001
Tata-JLR	$2,518	$2,548	$2,533	$2,313	$2,345	$2,328
Tesla[AAA]	$68	$0	$68	$63	$0	$63
Toyota	$160	$417	$260	$149	$375	$231
VW	$1,743	$1,735	$1,742	$1,589	$1,574	$1,586
Fleet	$710	$917	$783	$655	$849	$719

[AAA] While costs related to air-conditioning are shown for Tesla, as a manufacturer of solely electric vehicles, Tesla can comply with reference, control, and alternative standards without incurring additional costs from this regulation.

EPA then used OMEGA to calculate the costs of meeting the standards in the model years 2021 and 2025, which are shown in Table 3.6-2 . EPA has accounted for the cost to meet the MY 2016 standards in the reference case. In other words, Table 3.6-2 contains per-vehicle costs for the final rule (the emission "control case") that are incremental to the reference case costs shown in Table 3.6-1 .

Table 3.6-2 Control Case Costs for the Standards MY 2021 (2010$)

Company	2021 Costs			2021 Sales		
	Cars	**Trucks**	**Fleet**	**Cars**	**Truck**	**Fleet**
Aston Martin	$6,724	$0	$6,724	1,058	0	1,058
BMW	$967	$529	$852	359,098	128,724	487,822
Chrysler/Fiat	$681	$796	$733	421,013	348,613	769,626
Daimler	$1,985	$659	$1,655	300,378	99,449	399,827
Ferrari	$6,712	$0	$6,712	7,059	0	7,059
Ford	$680	$875	$746	1,401,617	714,181	2,115,798
Geely-Volvo	$2,132	$734	$1,698	92,726	41,768	134,494
GM	$519	$720	$619	1,564,277	1,530,020	3,094,297
Honda	$532	$829	$624	1,198,880	535,916	1,734,796
Hyundai	$773	$875	$794	613,355	156,466	769,821
Kia	$625	$908	$689	331,319	95,432	426,751
Lotus	$3,739	$0	$3,739	278	0	278
Mazda	$959	$1,246	$1,010	274,740	59,227	333,967
Mitsubishi	$611	$1,127	$791	65,851	35,309	101,160
Nissan	$644	$904	$725	912,629	408,029	1,320,658
Porsche	$4,878	$604	$3,871	36,475	11,242	47,716
Spyker-Saab	$3,019	$607	$2,674	21,294	3,560	24,854
Subaru	$982	$1,594	$1,128	230,780	72,773	303,553
Suzuki	$1,032	$1,210	$1,064	95,725	20,767	116,492
Tata-JLR	$3,916	$1,061	$2,495	58,677	58,153	116,830
Tesla	$79	$0	$79	28,623	0	28,623
Toyota	$488	$600	$532	1,903,706	1,215,539	3,119,245
VW	$1,492	$508	$1,293	585,607	148,734	734,341
Fleet	$767	$763	$766	10,505,165	5,683,902	16,189,066

Table 3.6-3 Control Case Costs for the Standards MY 2025 (2010$)

Company	2025			2025 Sales		
	Cars	**Trucks**	**Fleet**	**Cars**	**Truck**	**Fleet**
Aston Martin	$7,480	$0	$7,480	1,182	0	1,182
BMW	$2,147	$1,250	$1,910	405,256	145,409	550,665
Chrysler/Fiat	$1,617	$2,388	$1,950	436,479	331,762	768,241
Daimler	$3,011	$1,284	$2,616	340,719	101,067	441,786
Ferrari	$7,864	$0	$7,864	7,658	0	7,658
Ford	$1,811	$2,505	$2,025	1,540,109	684,476	2,224,586
Geely-Volvo	$3,177	$1,504	$2,681	101,107	42,588	143,696
GM	$1,518	$2,237	$1,861	1,673,936	1,524,008	3,197,943
Honda	$1,525	$1,923	$1,642	1,340,321	557,697	1,898,018
Hyundai	$1,673	$2,268	$1,792	677,250	168,136	845,386
Kia	$1,572	$1,977	$1,658	362,783	97,653	460,436
Lotus	$3,566	$0	$3,566	316	0	316
Mazda	$1,979	$2,449	$2,057	306,804	61,368	368,172
Mitsubishi	$1,939	$2,169	$2,015	73,305	36,387	109,692
Nissan	$1,618	$2,391	$1,847	1,014,775	426,454	1,441,229
Porsche	$4,807	$1,274	$4,044	40,696	11,219	51,915
Spyker-Saab	$3,580	$964	$3,238	23,130	3,475	26,605
Subaru	$1,926	$2,495	$2,054	256,970	74,722	331,692
Suzuki	$2,112	$1,848	$2,066	103,154	21,374	124,528
Tata-JLR	$5,077	$1,447	$3,390	65,418	56,805	122,223
Tesla	$69	$0	$69	31,974	0	31,974
Toyota	$1,239	$1,700	$1,407	2,108,053	1,210,016	3,318,069
VW	$2,412	$1,237	$2,181	630,163	154,284	784,447
Fleet	$1,726	$2,059	$1,836	11,541,560	5,708,899	17,250,459

EPA estimates that the additional technology required for manufacturers to meet the GHG standards for this rule will cost on average $766/vehicle and $1,836/vehicle in the 2021 and 2025 MYs, respectively. These costs include our estimates of stranded capital and costs associated with the A/C program as explained in sections 3.6 and 3.7 above.

The OMEGA results project that under the primary final rule approximately 1% of the vehicles sold in MYs 2017-2025 will be EVs or PHEVs.

Table 3.6-4 Sales by Technology

MY	ICE Only Sales	MHEV +HEV Sales	EV+PHEV Sales	Total Sales
2017	14,779,343	975,369	51,609	15,806,322
2018	14,364,044	1,137,524	74,842	15,576,410
2019	14,165,763	1,314,056	98,839	15,578,658
2020	14,249,833	1,520,778	125,327	15,895,939
2021	14,304,401	1,732,100	152,565	16,189,066
2022	13,707,594	2,526,963	205,216	16,439,772
2023	12,976,088	3,420,545	258,856	16,655,489
2024	12,266,523	4,352,578	314,986	16,934,087
2025	11,551,765	5,325,056	373,638	17,250,459
Total	122,365,357	22,304,969	1,655,878	146,326,204
Fraction	**84%**	15%	**1%**	**100%**

3.7 Alternative Program Stringencies

Table 3.7-1 Control Case Costs for the Alternative 1 (Trucks +20) Standards (2010$)

Company	2021			2025		
	Cars	Trucks	Fleet	Cars	Trucks	Fleet
Aston Martin	$6,724	$0	$6,724	$7,480	$0	$7,480
BMW	$444	$529	$467	$1,679	$1,250	$1,566
Chrysler/Fiat	$296	$474	$377	$1,236	$1,832	$1,494
Daimler	$1,428	$616	$1,226	$2,441	$1,284	$2,176
Ferrari	$6,712	$0	$6,712	$7,864	$0	$7,864
Ford	$404	$505	$438	$1,537	$1,906	$1,650
Geely-Volvo	$1,373	$722	$1,171	$2,410	$1,504	$2,141
GM	$176	$367	$271	$1,196	$1,513	$1,347
Honda	$398	$567	$450	$1,344	$1,452	$1,376
Hyundai	$556	$875	$620	$1,520	$2,007	$1,617
Kia	$514	$674	$550	$1,442	$1,477	$1,449
Lotus	$3,739	$0	$3,739	$3,566	$0	$3,566
Mazda	$834	$967	$858	$1,803	$2,449	$1,911
Mitsubishi	$445	$510	$468	$1,495	$1,838	$1,609
Nissan	$417	$670	$495	$1,439	$1,748	$1,530
Porsche	$4,258	$604	$3,397	$4,341	$1,274	$3,678
Spyker-Saab	$2,671	$607	$2,375	$3,272	$964	$2,971
Subaru	$878	$822	$865	$1,722	$2,252	$1,842
Suzuki	$760	$1,210	$840	$1,967	$1,848	$1,946
Tata-JLR	$2,161	$562	$1,365	$3,801	$1,075	$2,534
Tesla	$79	$0	$79	$69	$0	$69
Toyota	$328	$406	$359	$1,020	$1,411	$1,163
VW	$1,056	$508	$945	$2,129	$1,237	$1,953
Fleet	$497	$492	$496	$1,460	$1,582	$1,500

Table 3.7-2 Control Case Costs for the Alternative 2 (Trucks -20) Standards (2010$)

Company	2021			2025		
	Cars	Trucks	Fleet	Cars	Trucks	Fleet
Aston Martin	$6,724	$0	$6,724	$7,480	$0	$7,480
BMW	$1,569	$576	$1,307	$2,676	$1,250	$2,300
Chrysler/Fiat	$904	$1,460	$1,156	$2,233	$2,792	$2,474
Daimler	$2,704	$662	$2,196	$3,503	$1,284	$2,995
Ferrari	$6,712	$0	$6,712	$7,864	$0	$7,864
Ford	$962	$1,418	$1,116	$2,283	$2,631	$2,390
Geely-Volvo	$3,065	$846	$2,376	$3,986	$1,504	$3,250
GM	$916	$1,262	$1,087	$2,234	$2,828	$2,517
Honda	$754	$1,035	$841	$1,718	$2,363	$1,907
Hyundai	$937	$1,067	$963	$1,906	$2,504	$2,025
Kia	$861	$910	$872	$1,744	$2,328	$1,868
Lotus	$3,739	$0	$3,739	$3,566	$0	$3,566
Mazda	$1,139	$1,467	$1,198	$2,155	$2,624	$2,233
Mitsubishi	$1,153	$1,263	$1,192	$2,468	$2,169	$2,369
Nissan	$929	$1,126	$990	$2,027	$2,503	$2,168
Porsche	$5,579	$861	$4,468	$5,305	$1,274	$4,434
Spyker-Saab	$3,410	$607	$3,009	$3,719	$964	$3,360
Subaru	$1,311	$1,594	$1,379	$2,262	$2,495	$2,314
Suzuki	$1,277	$1,210	$1,265	$2,470	$1,953	$2,381
Tata-JLR	$6,220	$1,061	$3,652	$7,074	$1,809	$4,627
Tesla	$79	$0	$79	$69	$0	$69
Toyota	$556	$1,044	$746	$1,546	$2,210	$1,788
VW	$1,975	$508	$1,678	$2,857	$1,237	$2,538
Fleet	$1,062	$1,159	$1,096	$2,146	$2,434	$2,241

Table 3.7-3 Control Case Costs for the Alternative 3 (Cars +20) Standards (2010$)

Company	2021			2025		
	Cars	**Trucks**	**Fleet**	**Cars**	**Trucks**	**Fleet**
Aston Martin	$6,724	$0	$6,724	$5,723	$0	$5,723
BMW	-$258	$474	-$65	$1,068	$1,195	$1,102
Chrysler/Fiat	$296	$474	$377	$1,236	$1,659	$1,419
Daimler	$692	$616	$673	$1,723	$1,284	$1,622
Ferrari	$6,712	$0	$6,712	$7,416	$0	$7,416
Ford	$238	$287	$254	$1,212	$1,505	$1,302
Geely-Volvo	$579	$722	$623	$1,708	$1,504	$1,647
GM	$187	$442	$313	$1,201	$1,619	$1,400
Honda	$305	$377	$327	$990	$1,382	$1,105
Hyundai	$304	$535	$351	$1,118	$1,218	$1,138
Kia	$364	$313	$353	$989	$1,230	$1,040
Lotus	$2,125	$0	$2,125	$2,346	$0	$2,346
Mazda	$395	$491	$412	$1,223	$1,587	$1,284
Mitsubishi	$275	$241	$263	$1,133	$1,658	$1,307
Nissan	$259	$335	$282	$1,176	$1,407	$1,244
Porsche	$3,315	$548	$2,663	$3,472	$1,274	$2,997
Spyker-Saab	$1,437	$532	$1,308	$2,223	$964	$2,059
Subaru	$462	$511	$474	$1,369	$1,526	$1,405
Suzuki	$342	$419	$356	$1,297	$1,776	$1,379
Tata-JLR	$2,161	$562	$1,365	$3,297	$1,075	$2,264
Tesla	$79	$0	$79	$69	$0	$69
Toyota	$324	$294	$312	$857	$1,303	$1,020
VW	$147	$484	$215	$1,292	$1,237	$1,281
Fleet	$298	$388	$330	$1,151	$1,448	$1,249

Table 3.7-4 Control Case Costs for the Alternative 4 (Cars -20) Standards (2010$)

Company	2021			2025		
	Cars	**Trucks**	**Fleet**	**Cars**	**Trucks**	**Fleet**
Aston Martin	$6,724	$0	$6,724	$7,885	$0	$7,885
BMW	$2,597	$616	$2,075	$3,684	$1,250	$3,041
Chrysler/Fiat	$912	$1,562	$1,206	$2,332	$2,851	$2,556
Daimler	$4,014	$664	$3,181	$4,580	$1,284	$3,826
Ferrari	$6,712	$0	$6,712	$7,864	$0	$7,864
Ford	$1,343	$1,521	$1,403	$2,832	$2,728	$2,800
Geely-Volvo	$4,153	$925	$3,151	$5,049	$1,504	$3,998
GM	$879	$1,155	$1,015	$2,043	$2,828	$2,417
Honda	$1,019	$1,227	$1,083	$2,086	$2,790	$2,293
Hyundai	$1,311	$1,879	$1,426	$2,654	$2,718	$2,666
Kia	$1,217	$1,359	$1,249	$2,425	$2,552	$2,452
Lotus	$5,282	$0	$5,282	$4,908	$0	$4,908
Mazda	$1,881	$2,100	$1,920	$3,086	$2,958	$3,064
Mitsubishi	$1,625	$1,444	$1,562	$3,078	$2,186	$2,782
Nissan	$1,182	$1,539	$1,292	$2,524	$2,722	$2,583
Porsche	$5,849	$1,347	$4,788	$6,148	$2,205	$5,296
Spyker-Saab	$4,917	$773	$4,324	$5,040	$964	$4,507
Subaru	$1,915	$2,061	$1,950	$2,793	$3,238	$2,893
Suzuki	$2,204	$1,276	$2,039	$3,301	$1,953	$3,070
Tata-JLR	$6,360	$1,061	$3,723	$7,074	$2,214	$4,815
Tesla	$79	$0	$79	$69	$0	$69
Toyota	$708	$1,091	$857	$1,631	$2,565	$1,971
VW	$3,234	$766	$2,734	$4,018	$1,237	$3,471
Fleet	$1,422	$1,261	$1,365	$2,556	$2,612	$2,574

3.8 Comparative cost of advanced technologies under credit scenarios

As part of the analysis of the flexibility programs, EPA calculated an illustrative example of the relative cost-effectiveness of certain advanced technologies.

Table 3.8-1 shows the cost per gram per mile of going from the MY 2016 type technologies to MY 2021 technologies. Note that in all cases, the advanced technologies are significantly more expensive than the average costs per vehicle from the OMEGA, even when considering the impacts of the multiplier and advanced technology incentives.

Table 3.8-1 Gram/mile cost of advanced technologies

	Reference Case CO2	MY 2021 CO2	Delta g/mile	Delta Cost^	$ per g/mile
OMEGA projection of	224	178	$46	$767	$ 17

average 2021 Car in control Case					
EV100 (45 sqft, VT 3, no multiplier)	263	-	263	$16,877	$64
EV100 (45 sqft, VT 3, 1.5 multiplier)	263	-	395	$16,877	$43
OMEGA projection of average 2021 Truck in control Case	296	239	57	$763	$13
HEV (65 sqft, VT 16, no credit)	334	251	93	$6,054	$65
HEV (65 sqft, VT 16, 20 g credit)	334	231	113	$6,054	$54

^Note that we use average reference case cost of $710for cars and $917for trucks, not the vehicle specific cost. If these vehicles reference case costs were higher than average, then their costs under the final rule would be less, and conversely if their costs were lower than averages, then their compliance costs would be greater.

The reference case CO_2 values are determined in the case of the OMEGA projections, from the actual OMEGA runs, and in the case of the 45 and 65 square foot vehicles from the applicable GHG curve. In this table, the EV is assumed to have a compliance value of zero grams per mile without the multiplier incentive. For the incentive, we simply multiplied the delta gram per mile by 1.5. This overstates the impact of the credit, because the multiplier would also increase the number of vehicles in a manufacturer's fleet by 1.5. The cost per gram/mile is actually greater than shown in this illustrative table because the size of the fleet impacts the benefit of the multiplier.

For HEVs, the technology in this example has an effectiveness of 49.8% relative to a baseline (no technology) vehicle with a CO_2 of 500 g/mile. This effectiveness is used to derive the cost-effectiveness value.

HEVs and EVs, regardless of their cost-effectiveness, are more effective than the conventional technologies, and retain that advantage despite their disadvantages on a cost-effectiveness basis. Further in MY 2025, when the average cost per gram/mile is higher, these technologies are relatively more cost effective.

3.9 How Many of Today's Vehicles Can Meet or Surpass the MY 2017-2025 CO2 Footprint-based Targets with Current Powertrain Designs?

As part of its evaluation of the feasibility of these standards, EPA evaluated all MY 2012 and MY 2013 vehicles sold in the U.S. today against the final CO_2 footprint-based standard curves to determine which of these vehicles would meet or be lower than the final MY 2017 – MY 2025 footprint-based CO_2 targets assuming air conditioning credit generation consistent with today's final rule. Under the final MY 2017 – MY 2025 greenhouse gas emissions standards, each vehicle will have a unique CO_2 target based on the vehicle's footprint (with each manufacturer having its own unique fleetwide standard). In this analysis, EPA assumed that manufacturers would utilize all available air conditioner credits because air conditioner improvements are considered to be among the cheapest and easiest technologies to reduce greenhouse gas emissions, manufacturers are already investing in air conditioner improvements, and air conditioner changes do not impact engine, transmission, or aerodynamic designs (so utilizing air conditioning credits would not affect consideration of cost and leadtime for use of these other technologies).EPA applied increasing air conditioner credits over time with a phase-in of alternative refrigerant for the generation of HFC leakage reduction credits consistent with the assumed phase-in schedule discussed in Preamble Section III.C.1. No adjustments were made to vehicle CO_2 performance other then this assumption of air conditioning credit generation. Under this analysis, a wide range of these existing vehicles would meet the MY 2017 CO_2 targets, and a few meet even the MY 2025 CO_2 targets.

Using publicly available data[BBB], EPA compiled a list of all available vehicles and their 2-cycle CO_2 g/mile performance (that is, the performance over the city and highway compliance tests). Data is currently available for all MY2012 vehicles and some MY2013 vehicles. EPA gathered vehicle footprint data from EPA reports,[CCC] manufacturer submitted CAFE reports, and manufacturer websites.

Table 3.9-5 shows that a significant number of vehicles sold today would meet or be lower than the final footprint-based CO_2 targets with current powertrain designs, assuming air conditioning credit generation consistent with this final rule. The table highlights the vehicles with CO_2 emissions that meet or are lower than the applicable footprint targets from MY 2017 to 2025 in green, and shows the percentage below the target for each year. The list of vehicles includes midsize cars, minivans, sport utility vehicles, compact cars, and small pickup trucks – all of which meet the MY 2017 target values with no technology improvements other then air conditioning system upgrades. These vehicles utilize a wide variety of powertrain technologies, including internal combustion, hybrid-electric, plug-in hybrid-electric, and full electric, and operate on a variety of different fuels including gasoline, diesel, electricity, and compressed natural gas. Nearly every major manufacturer produces some vehicles that would meet or be lower than the MY2017 footprint CO_2 target with only simple improvements in air conditioning systems.

[BBB] www.fueleconomy.gov

[CCC] EPA's "Light Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends Report, 1975 through 2010" (Docket No. EPA-HQ-OAR-2010-0799-1126)

Vehicles that are above, but within 5%, of the targets are highlighted in yellow. This list also includes vehicles from multiple classes, including large cars and standard pickup trucks. Four versions of the F-150 pickup truck are within 5% of the targets through at least 2021. This includes two engine options (the 3.7L V6 and the 3.5L V6), and three wheelbase options[DDD].

Prior to each model year, EPA receives projected sales data from each manufacturer. Based on this data, approximately 17% of MY2012 sales will be vehicles that meet or are below their vehicle specific MY 2017 targets, requiring only improvements in air conditioning systems. This is more than double the percentage of sales from MY2011 that EPA projected to meet the MY2017 targets. An additional 12% of projected MY2012 sales will be within 5% of the MY2017 footprint CO_2 target with only simple improvements to air conditioning systems. The percentage of MY2011 and MY2012 vehicle sales that meet or are within 5% the final MY2017-MY2025 standards are shown in Table 3.9-1 and Table 3.9-2. Overall, nearly 30% of MY2012 vehicle sales will meet or be within 5% of the final MY2017 targets and over 40% of MY2012 sales will meet or be within 10% of the final MY2017 targets with only simple improvements to air conditioning systems, five full model years before the standard takes effect.

Table 3.9-1 Percentage of Projected Sales Compliant with Final Targets

Model Year	2017	2018	2019	2020	2025
2011	7.0%	6.2%	5.9%	5.2%	1.8%
2012	16.8%	13.6%	8.4%	6.6%	3.1%

Table 3.9-2 Percentage of Projected Sales Within 5% of Final Targets

Model Year	2017	2018	2019	2020	2025
2011	7.6%	2.5%	1.5%	1.7%	0.8%
2012	12.2%	10.9%	7.1%	2.6%	0.3%

With improvements to air conditioning systems, the most efficient gasoline internal combustion engines would meet the MY 2022 final footprint targets (e.g. the Ford Focus 2.0L). After MY 2022, the only current vehicles that continue to meet the footprint-based CO_2 targets (assuming improvements in air conditioning) are CNG, hybrid-electric, plug-in hybrid-electric, and fully electric vehicles. However, the MY 2022 standards will not be in effect for another ten years. EPA expects that gasoline vehicles will continue to improve in that timeframe and will be able to meet the standard (using the technologies discussed in

[DDD] The F-150 engine and wheelbase combinations listed in Table 3.9-5 correspond to models that are currently available. Not all possible engine and wheelbase combinations are produced.

Chapter 3 of the Joint TSD and as discussed in Preamble Section III.D) including air conditioner improvements. Supporting that expectation is the fact that since this rule was proposed, the number of gasoline vehicles available in the marketplace that meet or are below the final MY 2017 targets, assuming improvements to air conditioning systems, has more than doubled to approximately 65 vehicles. Table 3.9-3 shows the number of currently available MY 2012 and MY 2013 vehicles (as well as the MY 2011 and MY 2012 vehicles that were available when the proposal for this rule was published) that meet or exceed the MY 2017 targets, assuming air conditioning improvements. Table 3.9-4 shows the number of vehicles that are within 5% of the MY 2017 targets, also by technology.

Table 3.9-3 Number of Vehicle Models that Meet MY 2017 Targets by Technology

Model Year	Gasoline	Diesel	CNG	HEV	PHEV	EV	FCV	Total
2011/2012	27	1	1	27	1	3	0	60
2012/2013	65	3	1	29	1	8	1	108

Table 3.9-4 Number of Vehicle Models Within 5% of 2017 Targets by Technology

Model Year	Gasoline	Diesel	CNG	HEV	PHEV	EV	FCV	Total
2011/2012	38	6	0	3	0	0	0	47
2012/2013	58	6	0	2	0	0	0	66

Today's Toyota Prius, Prius c, Prius v, Camry Hybrid, Lexus CT200h, Ford Fusion Hybrid, Chevrolet Volt, Nissan Leaf, Honda Civic Hybrid, Honda Insight, Mitsubishi i, and Hyundai Sonata Hybrid all meet or surpass the footprint-based CO_2 targets through MY 2025. In fact, the current Prius, Volt, and Leaf meet the MY 2025 CO_2 targets without air conditioning credits.

This assessment of MY 2012 and MY 2013 vehicles also makes clear that substantial additional technology penetration across the fleet, and lead time in which to do so, is needed for manufacturers to meet the final standards. Notably, based on the OMEGA modeling, we project that the MY 2017-2025 standards can primarily be achieved by advanced gasoline vehicles – for example, in MY 2025, we project more than 80 percent of the new vehicles could be advanced gasoline powertrains. The assessment of MY 2012 and MY 2013 vehicles available in the market today indicates advanced gasoline vehicles (as well as diesels) can achieve the targets for the early model years of the final standards (i.e., model years 2017-2022) with only improvements in air conditioning systems. However, significant improvements in technologies are needed and penetrations of those technologies must increase substantially in order for individual manufacturers (and the fleet overall) to achieve the standards for the early years of the program, and certainly for the later years (i.e., model years 2021-2025). These technology improvements include: gasoline direct injection fuel systems; downsized and turbocharged gasoline engines (including in some cases with the application of cooled exhaust gas recirculation); continued improvements in engine friction reduction and low friction lubricants; transmissions with an increased number of forward gears (e.g., 8 speeds); improvements in transmission shifting logic; improvements in transmission gear box efficiency; vehicle mass reduction; lower rolling resistance tires, and improved vehicle aerodynamics. In many (though not all) cases these technologies are beginning to penetrate the U.S. light-duty vehicle market.

In general, these technologies must go through the automotive product development cycle in order to be introduced into the U.S. fleet, and in some cases additional research is needed before the technologies CO_2 benefits can be fully realized and large-scale manufacturing can be achieved. This topic is discussed in more detail in Chapter 3.5 of the final Joint Technical Support Document. In that Chapter, we explain that many CO_2 reducing technologies should be able to penetrate the new vehicle market at high levels between now and MY 2016, there are also many of the key technologies we project as being needed to achieve the 2017-2025 standards which will only be able to penetrate the market at relatively low levels (e.g., a maximum level of 30%) or less by MY 2016, and which even by MY 2021 will still be constrained. These include important powertrain technologies such as 8-speed transmissions and second or third generation downsized engines with turbocharging.

The majority of these technologies must be integrated into vehicles during the product redesign schedule, which is typically on a 5-year cycle. EPA discussed in the MY2012-2016 rule the significant costs and potential risks associated with requiring major technologies to be added in-between the typical 5-year vehicle redesign schedule, (see 75 FR at 25467-68). In addition, engines and transmissions generally have longer lifetimes than 5 years, typically on the order of 10 years or more. Thus major powertrain technologies generally take longer to penetrate the new vehicle fleet than can be done in a 5-year redesign cycle. As detailed in Chapter 3.5 of the Joint TSD, EPA projects that 8-speed transmissions could increase their maximum penetration in the fleet from 30% in MY2016 to 80% in 2021 and to 100% in MY2025. Similarly, we project that second generation downsized and turbocharged engines (represented in our assessment as engines with a brake-mean effective pressure of 24 bars) could penetrate the new vehicle fleet at a maximum level of 15% in MY2016, 30% in MY2021, and 75% in MY2025. When coupled with the typical 5 year vehicle redesign schedule, EPA projects that it is not possible for all of the advanced gasoline vehicle technologies we have assessed to penetrate the fleet in a single 5 year vehicle redesign schedule.

Given the status of the technologies we project to be used to achieve the MY 2017-2025 standards and the product development and introduction process which is fairly standard in the automotive industry today, our assessment of the MY 2012 and MY 2013 vehicles in comparison to the final targets supports our overall feasibility assessment, and reinforces our assessment of the lead time needed for the industry to achieve the final standards.

Table 3.9-5 Vehicles that Meet or Exceed Final Targets With Current Powertrain Designs

Model Year	Manufacturer	Vehicle	Unadjusted Fuel Economy (mpg)	Tailpipe CO_2 (g/mile)	Footprint (ft^2)	Powertrain Type	Transmission	Engine Displacement (L)	Vehicle Class	Car/ Truck	Compliance								
											2017	2018	2019	2020	2021	2022	2023	2024	2025
2012	Azure Dynamics	Transit Connect Electric Van	89.0	0	47.9	EV	A1	n/a	Van	T	100%	100%	100%	100%	100%	100%	100%	100%	100%
2012	Azure Dynamics	Transit Connect Electric Wagon	89.0	0	47.9	EV	A1	n/a	Van	T	100%	100%	100%	100%	100%	100%	100%	100%	100%
2012	CODA	CODA	103.9	0	41.4	EV	A1	n/a	Subcompact Cars	C	100%	100%	100%	100%	100%	100%	100%	100%	100%
2012	Ford	Focus FWD BEV	150.0	0	44.2	EV	A1	n/a	Compact Cars	C	100%	100%	100%	100%	100%	100%	100%	100%	100%
2012	Mercedes-Benz	F-Cell	75.5	0	49.4	Fuel Cell	A1	n/a	Small Station Wagons	C	100%	100%	100%	100%	100%	100%	100%	100%	100%
2011	Mercedes-Benz	Smart fortwo (cabriolet)	123.9	0	26.8	EV	A1	n/a	Two Seaters	C	100%	100%	100%	100%	100%	100%	100%	100%	100%
2011	Mercedes-Benz	Smart fortwo (coupe)	123.9	0	26.8	EV	A1	n/a	Two Seaters	C	100%	100%	100%	100%	100%	100%	100%	100%	100%
2012	Mitsubishi	i-MiEV	160.3	0	38.4	EV	A1	n/a	Subcompact Cars	C	100%	100%	100%	100%	100%	100%	100%	100%	100%
2012	Nissan	Leaf	141.7	0	44.7	EV	A1	n/a	Midsize Cars	C	100%	100%	100%	100%	100%	100%	100%	100%	100%
2012	Chevrolet	Volt	122.0	56	45.3	PHEV	CVT	1.4	Compact Cars	C	80%	79%	79%	79%	79%	78%	77%	75%	74%
2012	Toyota	Prius	70.7	126	44.2	HEV	CVT	1.8	Midsize Cars	C	46%	44%	42%	40%	37%	34%	31%	28%	24%
2012	Toyota	Prius c	70.7	126	42.3	HEV	CVT	1.5	Compact Cars	C	44%	42%	39%	37%	34%	31%	28%	24%	21%
2012	Honda	Civic Hybrid	63.1	141	43.5	HEV	CVT	1.5	Compact Cars	C	38%	35%	33%	30%	27%	23%	20%	16%	12%
2012	Toyota	Prius v	58.7	151	46.1	HEV	CVT	1.8	Midsize Station Wagons	C	36%	34%	31%	28%	25%	22%	18%	14%	10%
2012	Toyota	Camry Hybrid LE	57.4	155	47.2	HEV	CVT	2.5	Midsize Cars	C	36%	34%	31%	28%	25%	21%	18%	14%	10%
2012	Toyota	Camry Hybrid XLE	54.8	162	46.9	HEV	CVT	2.5	Midsize Cars	C	33%	30%	27%	24%	20%	17%	13%	9%	4%
2012	Hyundai	Sonata Hybrid	52.2	170	47.8	HEV	A6	2.4	Midsize Cars	C	30%	27%	24%	21%	17%	14%	10%	5%	1%
2012	Lexus	CT 200h	57.5	155	42.7	HEV	CVT	1.8	Compact Cars	C	30%	27%	24%	21%	17%	13%	9%	5%	0%
2012	Ford	Fusion Hybrid FWD	54.2	164	45.6	HEV	CVT	2.5	Midsize Cars	C	30%	27%	24%	21%	17%	13%	9%	5%	0%
2012	Lincoln	MKZ Hybrid FWD	54.2	164	45.6	HEV	CVT	2.5	Midsize Cars	C	30%	27%	24%	21%	17%	13%	9%	5%	0%
2012	Honda	Insight	58.9	151	40.5	HEV	A7	1.3	Compact Cars	C	29%	26%	23%	20%	16%	12%	8%	3%	-1%
2012	Honda	Insight	58.8	151	40.5	HEV	CVT	1.3	Compact Cars	C	29%	26%	23%	19%	16%	12%	8%	3%	-1%
2012	Kia	Optima Hybrid	50.6	175	48.2	HEV	A6	2.4	Midsize Cars	C	28%	25%	22%	19%	15%	11%	7%	3%	-2%
2012	Honda	Civic CNG	41.3	163	43.4	CNG	A5	1.8	Subcompact Cars	C	27%	24%	20%	17%	13%	9%	5%	1%	-4%
2013	Lexus	RX 450h	40.4	220	48.0	HEV	A6	3.5	Sport Utility Vehicle	T	23%	22%	21%	19%	13%	8%	4%	-1%	
2012	Toyota	Highlander Hybrid 4WD	38.5	231	48.8	HEV	CVT	3.5	Sport Utility Vehicle	T	21%	19%	18%	16%	10%	5%	0%		
2013	Lexus	RX 450h AWD	38.6	230	48.0	HEV	A6	3.5	Sport Utility Vehicle	T	20%	18%	17%	15%	8%	4%	-1%		
2012	Ford	Focus FWD	41.1	216	44.2	Gasoline	A6	2.0	Compact Cars	T	19%	18%	17%	15%	8%	3%	-2%		
2012	Chevrolet	C15 Silverado 2WD Hybrid	28.5	311	68.0	HEV	CVT	6.0	Standard Pick-up Truck	T	14%	14%	14%	14%	8%	3%	-2%		
2012	GMC	C15 Sierra 2WD Hybrid	28.5	311	68.0	HEV	CVT	6.0	Standard Pick-up Truck	T	14%	14%	14%	14%	8%	3%	-2%		
2012	Chevrolet	K15 Silverado 4WD Hybrid	28.4	313	68.0	HEV	CVT	6.0	Standard Pick-up Truck	T	13%	13%	14%	13%	7%	2%	-2%		
2012	GMC	K15 Sierra 4WD Hybrid	28.4	313	68.0	HEV	CVT	6.0	Standard Pick-up Truck	T	13%	13%	14%	13%	7%	2%	-2%		
2012	Scion	iQ	52.3	170	31.6	Gasoline	CVT	1.3	Minicompact Cars	C	19%	16%	12%	8%	4%	-1%			
2012	Lexus	HS 250h	47.3	188	44.5	HEV	CVT	2.4	Compact Cars	C	17%	13%	9%	5%	1%	-4%			
2013	Mazda	CX-5 4WD	36.8	241	46.1	Gasoline	A6	2.0	Sport Utility Vehicle	T	13%	11%	9%	7%	0%				
2013	Mercedes-Benz	Smart fortwo (Convertible)	50.3	177	26.8	Gasoline	A5	1.0	Two Seaters	C	16%	12%	8%	4%	0%				
2013	Mercedes-Benz	Smart fortwo (Coupe)	50.3	177	26.8	Gasoline	A5	1.0	Two Seaters	C	16%	12%	8%	4%	0%				
2012	Honda	CR-Z	50.1	177	39.5	HEV	A7	1.5	Two Seaters	C	15%	12%	8%	4%	-1%				
2013	Hyundai	Elantra Blue	45.2	197	45.2	Gasoline	A6	1.8	Midsize Cars	C	14%	10%	6%	2%	-3%				
2013	Hyundai	Elantra	44.7	199	45.2	Gasoline	M6	1.8	Midsize Cars	C	13%	9%	5%	1%	-4%				
2013	Hyundai	Elantra Coupe	44.6	199	45.2	Gasoline	M6	1.8	Midsize Cars	C	13%	9%	5%	1%	-4%				
2013	Hyundai	Elantra	44.4	200	45.2	Gasoline	A6	1.8	Midsize Cars	C	12%	9%	4%	0%	-5%				
2013	Lexus	GS 450h	41.6	214	48.5	HEV	A6	3.5	Midsize Cars	C	12%	8%	4%	0%	-5%				
2012	Toyota	Sienna	29.4	302	56.1	Gasoline	A6	2.7	Minivan 2WD	T	7%	5%	3%	1%					
2012	Dodge	Ram C/V	25.9	343	65.9	Gasoline	A6	3.6	Minivan 2WD	T	5%	5%	4%	2%					
2013	Lincoln	MKT Livery FWD	30.5	292	53.5	Gasoline	A6	2.0	Sport Utility Vehicle	T	6%	4%	3%	0%					
2012	Chevrolet	Cruze ECO	44.4	200	44.8	Gasoline	M6	1.4	Midsize Cars	C	11%	8%	3%	-1%					
2013	Kia	Rio ECO	46.7	190	42.1	Gasoline	A6	1.6	Compact Cars	C	11%	7%	3%	-1%					
2012	Hyundai	Veloster	43.8	203	44.6	Gasoline	A6	1.6	Compact Cars	C	10%	6%	2%	-3%					
2013	Kia	Rio	45.8	194	42.1	Gasoline	M6	1.6	Compact Cars	C	9%	5%	1%	-4%					

Model Year	Manufacturer	Vehicle	Unadjusted Fuel Economy (mpg)	Tailpipe CO_2 (g/mile)	Footprint (ft^2)	Powertrain Type	Transmission	Engine Displacement (L)	Vehicle Class	Car/ Truck	Compliance								
											2017	2018	2019	2020	2021	2022	2023	2024	2025
2013	Hyundai	Elantra Coupe	42.8	208	45.2	Gasoline	A6	1.8	Midsize Cars	C	9%	5%	0%	-4%					
2012	Ford	Focus SFE FWD	43.6	204	44.2	Gasoline	A6	2.0	Compact Cars	C	9%	5%	0%	-4%					
2012	Ford	Focus SFE FWD FFV	43.6	204	44.2	Gasoline	A6	2.0	Compact Cars	C	9%	5%	0%	-4%					
2012	Honda	Civic HF	44.3	201	43.4	Gasoline	A5	1.8	Compact Cars	C	9%	5%	0%	-4%					
2012	Toyota	Tacoma 2WD - Access cab	29.9	297	54.0	Gasoline	M5	2.7	Small Pick-up Truck	T	5%	3%	1%	-1%					
2012	Honda	Odyssey 2WD	29.0	307	55.9	Gasoline	A6	3.5	Minivan 2WD	T	5%	3%	1%	-1%					
2012	Hyundai	Veloster	43.1	206	44.6	Gasoline	M6	1.6	Compact Cars	C	8%	4%	0%	-5%					
2013	Dodge	Dart	42.3	210	45.6	Gasoline	M6	1.4	Midsize Cars	C	8%	4%	0%	-5%					
2013	Kia	Rio	45.1	197	42.1	Gasoline	A6	1.6	Compact Cars	C	8%	4%	-1%						
2013	Hyundai	Accent	45.3	196	41.7	Gasoline	M6	1.6	Compact Cars	C	7%	3%	-1%						
2012	Volkswagen	Passat	46.4	220	47.2	Diesel	M6	2.0	Midsize Cars	C	7%	3%	-1%						
2013	Hyundai	Accent	45.1	197	41.7	Gasoline	A6	1.6	Compact Cars	C	7%	3%	-2%						
2012	Mazda	Mazda3 DI 4-Door	43.8	203	43.1	Gasoline	A6	2.0	Compact Cars	C	7%	3%	-2%						
2012	Nissan	Versa	45.1	197	41.5	Gasoline	CVT	1.6	Compact Cars	C	7%	2%	-2%						
2012	Infiniti	M35h	38.8	229	49.1	Gasoline	A7	3.5	Midsize Cars	C	6%	2%	-2%						
2012	BMW	528i	36.8	241	51.6	Gasoline	A8	2.0	Midsize Cars	C	6%	2%	-3%						
2012	Honda	Civic	43.0	207	43.4	Gasoline	A5	1.8	Compact Cars	C	6%	2%	-3%						
2012	Ford	Focus FWD	42.1	211	44.2	Gasoline	A6	2.0	Compact Cars	C	5%	1%	-4%						
2012	Ford	Focus FWD FFV	42.1	211	44.2	Gasoline	A6	2.0	Compact Cars	C	5%	1%	-4%						
2012	Kia	Soul ECO	42.8	208	43.3	Gasoline	A6	1.6	Small Station Wagons	C	5%	1%	-4%						
2012	Honda	CR-Z	44.9	198	39.5	Gasoline	M6	1.5	Two Seaters	C	5%	1%	-4%						
2012	Toyota	Yaris	44.9	198	39.9	Gasoline	M5	1.5	Compact Cars	C	5%	1%	-4%						
2012	Mazda	Mazda3 DI 5-Door	42.9	207	43.1	Gasoline	A6	2.0	Midsize Cars	C	5%	1%	-4%						
2012	Mercedes-Benz	S 350 BLUETEC 4MATIC	32.3	315	56.6	Diesel	A7	3.0	Large Cars	T	3%	1%	-1%	-3%					
2013	BMW	X3 xDrive28i	31.5	283	48.8	Gasoline	A8	2.0	Sport Utility Vehicle	T	2%	0%	-2%	-5%					
2012	Toyota	Tacoma 2WD - Access Cab	28.1	317	55.9	Gasoline	A4	2.7	Small Pick-up Truck	T	2%	0%	-2%						
2012	Toyota	Tacoma 2WD - Double Cab	28.1	317	55.9	Gasoline	A4	2.7	Small Pick-up Truck	T	2%	0%	-2%						
2012	Cadillac	Escalade 2WD Hybrid	28.5	311	54.8	HEV	CVT	6.0	Sport Utility Vehicle	T	2%	-1%	-2%						
2012	Chevrolet	C1500 Tahoe 2WD Hybrid	28.5	311	54.8	HEV	CVT	6.0	Sport Utility Vehicle	T	2%	-1%	-2%						
2012	GMC	C1500 Yukon 2WD Hybrid	28.5	311	54.8	HEV	CVT	6.0	Sport Utility Vehicle	T	2%	-1%	-2%						
2012	Ford	Fiesta SFE FWD	44.6	199	39.3	Gasoline	A6	1.6	Subcompact Cars	C	4%	0%	-5%						
2012	Fiat	500	44.5	200	34.7	Gasoline	M5	1.4	Minicompact Cars	C	4%	0%	-5%						
2013	Buick	Lacrosse	38.7	230	48.0	Gasoline	A6	2.40	Midsize Cars	C	4%	0%	-5%						
2012	Chevrolet	K1500 Tahoe 4WD Hybrid	28.4	313	54.8	HEV	CVT	6.00	Sport Utility Vehicle	T	1%	-1%	-3%						
2012	GMC	K1500 Yukon 4WD Hybrid	28.4	313	54.8	HEV	CVT	6.0	Sport Utility Vehicle	T	1%	-1%	-3%						
2013	Ford	Escape AWD	33.2	268	45.3	Gasoline	A6	1.6	Sport Utility Vehicle	T	1%	-1%	-3%						
2012	Chevrolet	Cruze ECO	40.9	217	44.8	Gasoline	A6	1.4	Midsize Cars	C	4%	-1%							
2012	Ford	Fiesta FWD	44.2	201	39.3	Gasoline	A6	1.6	Subcompact Cars	C	3%	-1%							
2012	Volkswagen	Passat	44.6	228	47.2	Diesel	A6	2.0	Midsize Cars	C	3%	-1%							
2012	Honda	Civic	41.8	212	43.4	Gasoline	M5	1.8	Compact Cars	C	3%	-1%							
2012	Chevrolet	Sonic	44.0	202	41.0	Gasoline	M6	1.4	Compact Cars	C	3%	-2%							
2012	Chevrolet	Sonic 5	44.0	202	41.0	Gasoline	M6	1.4	Subcompact Cars	C	3%	-2%							
2012	Ford	Fiesta FWD	43.9	202	39.3	Gasoline	M5	1.6	Subcompact Cars	C	3%	-2%							
2012	Chevrolet	Cruze	40.4	220	44.8	Gasoline	M6	1.4	Midsize Cars	C	2%	-2%							
2012	Kia	Forte ECO	40.7	218	44.4	Gasoline	A6	2.0	Midsize Cars	C	2%	-2%							
2012	Mini	Mini Cooper	43.6	204	36.7	Gasoline	M6	1.6	Minicompact Cars	C	2%	-2%							
2012	Mini	Mini Cooper Coupe	43.6	204	38.8	Gasoline	M6	1.6	Two Seaters	C	2%	-2%							
2013	Mazda	CX-5 2WD	39.2	227	46.1	Gasoline	M6	2.0	Sport Utility Vehicle	C	2%	-3%							
2013	Buick	Regal	38.7	230	46.8	Gasoline	A6	2.4	Midsize Cars	C	2%	-3%							
2013	Chevrolet	Malibu	38.7	230	46.6	Gasoline	A6	2.4	Midsize Cars	C	1%	-3%							

Model Year	Manufacturer	Vehicle	Unadjusted Fuel Economy (mpg)	Tailpipe CO_2 (g/mile)	Footprint (ft^2)	Powertrain Type	Transmission	Engine Displacement (L)	Vehicle Class	Car/ Truck	Compliance								
											2017	2018	2019	2020	2021	2022	2023	2024	2025
2012	BMW	528i xDrive	35.3	252	51.6	Gasoline	A8	2.0	Midsize Cars	C	1%	-3%							
2012	Chevrolet	Cruze	40.1	222	44.8	Gasoline	A6	1.4	Midsize Cars	C	1%	-3%							
2012	Mazda	Mazda3 DI 4-Door	41.3	215	43.1	Gasoline	M6	2.0	Compact Cars	C	1%	-4%							
2012	Toyota	Yaris	43.1	206	39.9	Gasoline	A4	1.5	Compact Cars	C	1%	-4%							
2012	Audi	A6	35.4	251	50.9	Gasoline	CVT	2.0	Midsize Cars	C	1%	-4%							
2012	Mazda	Mazda3 DI 5-Door	41.1	216	43.1	Gasoline	M6	2.0	Midsize Cars	C	0%	-4%							
2012	BMW	328i	39.4	225	45.0	Gasoline	A8	2.0	Compact Cars	C	0%	-4%							
2012	Ford	F150 Pickup 2WD (157 in)	24.0	371	73.0	Gasoline	A6	3.5	Standard Pick-up Truck	T	-3%	-3%	-3%	-4%	-4%				
2012	Ford	F150 Pickup 2WD (163 in)	24.0	371	75.8	Gasoline	A6	3.5	Standard Pick-up Truck	T	-3%	-3%	-3%	-4%	-4%				
2012	Ford	F150 Pickup 2WD FFV (145 in)	24.5	363	67.5	Gasoline	A6	3.7	Standard Pick-up Truck	T	-1%	-1%	-1%	-2%					
2012	Ford	F150 Pickup 2WD (145 in)	24.0	371	67.5	Gasoline	A6	3.5	Standard Pick-up Truck	T	-3%	-3%	-3%	-5%					
2012	Cadillac	Escalade 4WD Hybrid	28.0	317	54.8	Gasoline	CVT	6.0	Sport Utility Vehicle	T	0%	-3%	-4%						
2012	GMC	K1500 Yukin Denali Hybrid 4WD	28.0	317	54.8	Gasoline	CVT	6.0	Sport Utility Vehicle	T	0%	-3%	-4%						
2012	Chevrolet	Equinox AWD	30.8	289	48.8	Gasoline	A6	2.4	Sport Utility Vehicle	T	0%	-3%	-5%						
2012	Chevrolet	Equinox AWD	30.8	289	48.8	Gasoline	A6	2.4	Sport Utility Vehicle	T	0%	-3%	-5%						
2012	GMC	Terrain AWD	30.8	289	48.8	Gasoline	A6	2.4	Sport Utility Vehicle	T	0%	-3%	-5%						
2012	GMC	Terrain AWD	30.8	289	48.8	Gasoline	A6	2.4	Sport Utility Vehicle	T	0%	-3%	-5%						
2012	Honda	Odyssey 2WD	27.5	324	55.9	Gasoline	A5	3.5	Minivan	T	0%	-3%	-5%						
2012	Toyota	Tacoma 2WD - Access Cab	28.1	317	54.0	Gasoline	A4	2.7	Small Pick-up Truck	T	-1%	-4%							
2012	Toyota	Tacoma 2WD - Double Cab	28.1	317	54.0	Gasoline	A4	2.7	Small Pick-up Truck	T	-1%	-4%							
2012	Nissan	Quest	27.2	326	55.9	Gasoline	CVT	3.5	Minivan	T	-1%	-4%							
2012	Ford	Transit Connect Wagon FWD	31.1	286	47.9	Gasoline	A4	2.0	Van	T	-1%	-3%							
2012	Subaru	Outback Wagon AWD	31.9	279	45.7	Gasoline	CVT	2.5	Sport Utility Vehicle	T	-2%	-5%							
2012	Toyota	Venza AWD	30.2	294	48.8	Gasoline	A6	2.70	Sport Utility Vehicle	T	-2%	-5%							
2012	Toyota	Sienna	26.9	331	56.1	Gasoline	A6	3.5	Minivan	T	-2%	-5%							
2012	Suzuki	Equator 2WD	27.3	325	55.0	Gasoline	M5	2.5	Small Pick-up Truck	T	-2%	-5%							
2012	Honda	CR-V 4WD	33.0	269	44.1	Gasoline	A5	2.4	Sport Utility Vehicle	T	-2%	-4%							
2012	Volkswagen	Jetta	46.1	221	43.9	Diesel	A6	2.0	Compact Cars	C	0%	-5%							
2013	Mazda	CX-5 2WD	38.5	231	46.1	Gasoline	A6	2.0	Sport Utility Vehicle	C	0%	-5%							
2012	Toyota	Camry	37.7	236	47.1	Gasoline	A6	2.5	Midsize Cars	C	0%	-5%							
2012	Volkswagen	Jetta	46.1	221	43.9	Diesel	M6	2.0	Compact Cars	C	0%	-5%							
2012	Porsche	Panamera S Hybrid	34.4	259	52.1	Gasoline	A8	3.0	Large Cars	C	0%	-5%							

3.10 Analysis of Ferrari & Chrysler/Fiat

Note that in the primary analyses, Ferrari is shown as a separate entity, but in this side-analysis, it is combined with other Fiat-owned companies for purposes of GHG compliance. Ferrari could be combined with other Fiat-owned companies for purposes of GHG compliance at the manufacturer's discretion (assuming Ferrari meets the criteria for demonstrating operational independence but Fiat-owned companies decide to aggregate anyway, or assuming that Ferrari does not meet the operational independence criteria). We conducted an OMEGA run to evaluate a scenario where Ferrari's compliance would be included with other Fiat-owned companies, including Chrysler. Unlike Ferrari under the scenario in which Ferrari was modeled as a stand-alone company, Chrysler/Fiat would comply, even with the Ferrari vehicles included. In preamble Section III.B., EPA describes the provisions we are finalizing on the concept of allowing companies that are able to demonstrate "operational independence" to be eligible for small volume manufacturer (SVM) alternative standards. If Ferrari were to qualify for these operational independence provisions, they would likely petition for an alternative standard under the SVM provisions, rather than comply as part of Chrysler/Fiat.

Under the assumptions made in the main analysis, where Ferrari is shown as a separate entity, and complies with the promulgated CO_2 curves, under the MY 2025 OMEGA projections, Ferrari falls short of its 2025 target (150 grams/mile CO_2) by seventeen grams.[EEE] Under this scenario, Ferrari would produce a fleet consisting of almost entirely HEVs (50%), EVs (23%) and PHEVs (22%) with a MY 2025 compliance cost of approximately $7,900 relative to the MY 2016 standards.

If Ferrari is included in the Chrysler/Fiat GHG compliance fleet, Chrylser/Fiat's baseline (no technology added) CO_2 in 2025 is 2 grams higher (345.6 vs 347.6). For Chrysler/Fiat, the cost of complying with the reference case standards would increase by approximately $58, and the cost of complying with the standards would increase by $104 for a net average increase in MY 2025 compliance costs of $46 per vehicle for Chrysler/Fiat. Net program costs would not change significantly.

3.11 Cost Sensitivities

3.11.1 Overview

We have conducted several sensitivity analyses on a variety of input parameters. We have run the OMEGA model to generate 2025MY results for each of these sensitivities. We have looked at different levels of mass reduction costs, battery pack costs, indirect cost multipliers, and learning rates. These sensitivities are summarized in

[EEE] Assuming that Ferrari complied with the primary proposed standards.

Table 3.11-1, followed by a discussion of the methods, with the results in Table 3.11-10 . Additional sensitivities with regard to benefits are shown in RIA Chapter 4.

Table 3.11-1 Summary of Cost Sensitivities

Sensitivity parameter	Low side sensitivity	High side sensitivity
Mass reduction direct manufacturing costs	40% lower	40% higher
Battery pack direct manufacturing costs	10% lower for P2 HEVs 20% lower for PHEV/EV	10% higher for P2 HEVs 20% higher for PHEV/EV
Indirect cost multipliers	Low side of 95% confidence interval of modified Delphi survey results	High side of 95% confidence interval of modified Delphi survey results
Learning rates[a]	P-value of 30% on steep portion of the curve; cost reductions of 4%/3%/2% per year for each 5 year increment on the flat portion of the learning curve	P-value of 10% on steep portion of the curve; cost reductions of 2%/1%/0% per year for each 5 year increment on the flat portion of the learning curve

[a] Higher learning rates results in lower costs, hence the low side sensitivity uses the higher learning rates while the high side sensitivity uses the lower learning rates.

3.11.2 Mass Sensitivity

For the mass reduction cost sensitivity, we adjusted the mass reduction DMC cost equation by +/-40%. That cost equation is shown in Table 3.11-2 along with the cost equation used for each side of the mass reduction cost sensitivity.

Table 3.11-2 Mass Reduction Cost Sensitivities

Sensitivity parameter	Mass reduction DMC equation used
Low side	DMC=\$2.60x, where x=% mass reduction
Primary case	DMC=\$4.33x, where x=% mass reduction
High side	DMC=\$6.06x, where x=% mass reduction

As mass reduction is a relatively cost effective technology, even with higher costs, OMEGA still chooses a relatively similar, but somewhat diminished degree of mass reduction. By contrast, even with lower costs, mass reduction is still limited by the constraints given by the safety analysis.. These impacts would be greater on manufacturers that use more mass reduction technology, and less on those that use less.

3.11.3 Battery Sensitivity

For the battery pack cost sensitivities, we decreased/increased the battery pack DMCs by the amounts shown in Table 3.11-3. As presented in Chapter 3 of the joint TSD, we have developed linear regressions for our battery pack costs. These linear regressions provide battery pack DCM as a function of net weight reduction of the vehicle. Table 3.11-3 and

Table 3.11-5 show the linear regressions used for our low side and high side sensitivity analyses, respectively, while Table 3.11-4 presents the linear regressions used for our primary analysis (as presented in Chapter 3 of the joint TSD).

Table 3.11-3 Linear Regressions of Battery Pack Direct Manufacturing Costs vs Net Weight Reduction used for Low Side Sensitivity (2010$)

Vehicle Class	P2 HEV	PHEV20	PHEV40	EV75	EV100	EV150
Small car	-$163x+$653	-$688x+$2,026	-$1,214x+$2,917	-$1,488x+$4,105	-$1,734x+$4,892	-$1,636x+$6,464
Standard car	-$216x+$721	-$1,235x+$2,370	-$1,756x+$3,511	-$2,203x+$4,818	-$2,367x+$5,645	-$2,042x+$7,803
Large car	-$332x+$843	-$1,505x+$2,987	-$3,760x+$4,808	-$3,485x+$6,180	-$3,718x+$6,904	-$2,272x+$8,896
Small MPV	-$202x+$701	-$858x+$2,268	-$1,565x+$3,397	-$1,649x+$4,797	-$2,119x+$5,834	-$15x+$8,087
Large MPV	-$272x+$788					
Truck	-$330x+$909					

Notes:
"x" in the equations represents the net weight reduction as a percentage, so a subcompact P2 HEV battery pack with a 20% applied weight reduction and, therefore, a 15% net weight reduction would cost (-$163)x(15%)+$653=$629.
The agencies did not regress PHEV or EV costs for the large MPV and truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Table 3.11-4 Linear Regressions of Battery Pack Direct Manufacturing Costs vs Net Weight Reduction used for the Primary Analysis (2010$)

Vehicle Class	P2 HEV	PHEV20	PHEV40	EV75	EV100	EV150
Small car	-$181x+$726	-$861x+$2,533	-$1,517x+$3,646	-$1,859x+$5,131	-$2,168x+$6,115	-$2,045x+$8,080
Standard car	-$240x+$801	-$1,543x+$2,962	-$2,195x+$4,389	-$2,754x+$6,023	-$2,958x+$7,056	-$2,552x+$9,753
Large car	-$369x+$937	-$1,881x+$3,734	-$4,700x+$6,010	-$4,356x+$7,725	-$4,647x+$8,630	-$2,840x+$11,120
Small MPV	-$224x+$779	-$1,073x+$2,835	-$1,957x+$4,247	-$2,061x+$5,997	-$2,649x+$7,293	-$19x+$10,109
Large MPV	-$303x+$876					
Truck	-$367x+$1,010					

Notes:
"x" in the equations represents the net weight reduction as a percentage, so a subcompact P2 HEV battery pack with a 20% applied weight reduction and, therefore, a 15% net weight reduction would cost (-$181)x(15%)+$726=$699.
The agencies did not regress PHEV or EV costs for the large MPV and truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Table 3.11-5 Linear Regressions of Battery Pack Direct Manufacturing Costs vs Net Weight Reduction used for the High Side Sensitivity (2010$)

Vehicle Class	P2 HEV	PHEV20	PHEV40	EV75	EV100	EV150
Small car	-$200x+$798	-$1,033x+$3,039	-$1,821x+$4,376	-$2,231x+$6,157	-$2,601x+$7,338	-$2,455x+$9,696
Standard car	-$264x+$881	-$1,852x+$3,555	-$2,633x+$5,266	-$3,305x+$7,227	-$3,550x+$8,467	-$3,063x+$11,704
Large car	-$406x+$1,031	-$2,257x+$4,480	-$5,639x+$7,212	-$5,227x+$9,269	-$5,577x+$10,357	-$3,407x+$13,344
Small MPV	-$247x+$857	-$1,287x+$3,402	-$2,348x+$5,096	-$2,473x+$7,196	-$3,179x+$8,752	-$23x+$12,131
Large MPV	-$333x+$963					
Truck	-$404x+$1,111					

Notes:
"x" in the equations represents the net weight reduction as a percentage, so a subcompact P2 HEV battery pack with a 20% applied weight reduction and, therefore, a 15% net weight reduction would cost (-$200)x(15%)+$798=$768.

The agencies did not regress PHEV or EV costs for the large MPV and truck vehicle classes since we do not believe these vehicle classes would use the technologies.

In the high case, the penetration of EVs decreased slightly, and MHEVs declined slightly as companies and MY 2025 TDS 24, start stop and HEV penetrations increased slightly. In the low cost case, the MY 2025 penetration of EVs increased, while the HEV penetration decreased. In general, these shifts were slight, as this rulemaking doesn't rely heavily on strong hybrids, EVs, or other battery technology vehicles. In general, changing the battery costs shifted the choice between HEVs and EVs. As both EVs and HEVs are less cost effective (in this set of inputs) than conventional technologies, the penetrations of non-battery dependent technologies was generally little changed.

3.11.4 ICM Sensitivity

For the ICM sensitivity, we looked at the 95% confidence intervals of the survey responses gathered as part of the modified Delphi process used to generate our low, medium and high2 complexity ICMs. We discuss this modified Delphi process in Chapter 3 of the joint TSD and provide details in a memorandum to the docket (EPA-HQ-OAR-2010-0799).[FFF] In that memorandum, the survey responses from each respondent are presented for each element of the ICM along with average responses, standard deviations and other statistical measures. Using these, we calculate the ICM elements at the low side of the 95% confidence interval and at the high side. Table 3.11-6 and Table 3.11-8 show the ICMs used for the low side and high side sensitivity analyses, respectively, while Table 3.11-7 shows the ICMs used for our primary analysis. For the High1 ICM, since it was generated using a consensus approach rather than blind surveys, we have scaled the ICM elements using the same ratios as resulted from the 95% confidence intervals for the High2 ICM.

Table 3.11-6 ICMs used for the Low Side Sensitivity

	Near term		Long term		Summed	
Complexity	Warranty	Non-warranty	Warranty	Non-warranty	Near term	Long term
Low	0.004	0.113	0.001	0.090	1.118	1.091
Medium	0.037	0.225	0.025	0.148	1.262	1.174
High1	0.043	0.361	0.027	0.217	1.404	1.243
High2	0.048	0.479	0.041	0.272	1.528	1.313

Table 3.11-7 ICMs used for the Primary Analysis

	Near term		Long term		Summed	
Complexity	Warranty	Non-warranty	Warranty	Non-warranty	Near term	Long term
Low	0.012	0.230	0.005	0.187	1.242	1.193
Medium	0.045	0.343	0.031	0.259	1.387	1.290
High1	0.065	0.499	0.032	0.314	1.564	1.345
High2	0.074	0.696	0.049	0.448	1.770	1.497

[FFF] "Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies," Helfand, G., and Sherwood, T., Memorandum dated August 2009.

Table 3.11-8 ICMs used for the High Side Sensitivity

	Near term		Long term		Summed	
Complexity	Warranty	Non-warranty	Warranty	Non-warranty	Near term	Long term
Low	0.019	0.347	0.010	0.284	1.366	1.294
Medium	0.052	0.461	0.037	0.369	1.513	1.406
High1	0.087	0.637	0.037	0.411	1.723	1.447
High2	0.099	0.914	0.057	0.623	2.012	1.680

3.11.5 Learning Rate Sensitivity

For the learning rate sensitivity, we increased the learning effects for the low side case and decreased the learning effects for the high side case. This sounds counterintuitive, but we have done this because the increased learning rates result in lower technology costs so, therefore, are more appropriate for the low side sensitivity. The reverse is true when decreasing the learning rates. For our primary analysis, as described in Chapter 3 of the joint TSD, we have used a 20% p-value for technologies on the steep portion of the learning curve and then have used learning rates of 3% per year for five years, 2% per year for 5 years, then 1% per year for 5 years for technologies on the flat portion of the learning curve. Table 3.11-9 shows how we have adjusted these learning rates for both the low and high side sensitivities.

Table 3.11-9 Learning Rates used for our Learning Rate Sensitivity

Sensitivity	Steep learning rate	Flat learning rate
Low side	30%	4%, 3%, 2%
Primary case	20%	3%, 2%, 1%
High side	10%	2%, 1%, 0%

3.11.6 Summary of Sensitivity Impacts

The average per-vehicle impacts of the sensitivity runs are shown in Table 3.11-10. Note that the majority of these impacts are less than $150 relative to the primary analysis costs. The ICM impacts are larger. For those sensitivities that change technology costs, generally, an increase in the cost of a single technology will provide a smaller incremental change in total cost than a equivalent decrease in cost of a single technology. This is due to the TARF function in the model which attempts to minimize incremental cost. By contrast, learning and ICM changes, because they affect every technology, tend to produce more symmetrical increases and decreases.

Table 3.11-10 Summary of Per-vehicle Cost Impacts of Sensitivity Analyses in MY 2025 relative to Primary Analysis (2010$)

Sensitivity Title	Reference Case Change	Control Case Change	Impact
Primary Case	--	--	--
Mass Cost High	$21	$65	$44

Mass Cost Low	-$24	-$87	-$63
Battery Cost High	$2	$72	$69
Battery Cost Low	-$2	-$74	-$72
ICM High	$110	$316	$206
ICM Low	-$114	-$317	-$203
Learning Rate High	$48	$177	$129
Learning Rate Low	-$44	-$159	-$115

3.11.7 NAS report

As in the proposal, we note that EPA has decided not to base a sensitivity case on the 2010 National Academy of Science Report "*Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, Assessment for Fuel Economy Technologies for Light-Duty Vehicles*" (The National Academies Press, June 2010).

As discussed in detail in Chapter 3 of the Joint Technical Support Document for this final rule, EPA and NHTSA have utilized the best available information in order to estimate the cost and effectiveness for a large number of technologies which can be used to reduce GHG emissions and improve fuel efficiency.

In 2007, NHTSA commissioned the National Academy of Science to perform an assessment of, among other things, the cost and effectiveness of technologies for improving the fuel economy of light-duty vehicles. The 2010 NAS Committee published their results of their assessment in June of 2010. EPA has reviewed this report in detail and for the reasons discussed below, we have not relied upon this report as a primary assessment for our cost and effectiveness estimates for this final rule, and we have also not used the report to perform a sensitivity assessment based on the 2010 NAS report for the same reasons.

Our principal reasons are twofold. First, the 2010 NAS Committee focused their report on the near-term, specifically the 2010-2015 time frame, and not on the time frame of this final rule, which is 2017 to 2025. Second, on a range of topics EPA and NHTSA have relied upon newer information for cost and effectiveness estimates.

With respect to the time frame of interest, in the Summary of the NAS 2010 report (pages S-1 and S-2), the NAS Committee discusses that their costs estimates are for the 2010-2015 time frame. In contrast, our costs are deemed valid for a given model year and then learned down from there using our learning curve effect (for years prior to the given model year, learning effects are backed out resulting in higher costs for earlier years). The 2010 NAS Report also discusses that there are longer-term technologies which are in the 5 to 15 year time horizon which are not the focus of the NAS 2010 report. There are a number of specific examples where this difference in time frame is relevant to any potential comparison between the 2010 NAS report and the EPA and NHTSA assessment for this final rule. For example, there are a number of technologies that EPA and NHTSA discuss in Chapter 3 of the Joint TSD which are not a single, discrete piece of hardware, but rather a continuum of improvements where the level of improvement can change given the potential time horizon. The 2010 NAS Committee considered at least six of these technologies: low friction lubricants, engine friction reduction, improved accessories, lower rolling resistance tires, aerodynamic drag improvement, and improved internals for automatic transmissions. The 2010 NAS report provides cost and effectiveness estimates for one increment of improvement for each of these technologies applicable to the 2010-2015 time frame. This is similar to the approach utilized by NHTSA and EPA for the MYs 2012-2016 rulemaking. However, for the MYs 2017-2025 final rules, where EPA and NHTSA are using a baseline set (or sets considering we use both a 2008MY and 2010MY baseline) of vehicles, the agencies estimate that for each these technologies two increments of improvement can be implemented across the fleet between promulgation of the final rule and MY 2025. Using the NAS Report estimates for these technologies thus, without basis, would not consider the further projected incremental improvements in these technologies.

A second example of the importance of the time frame is evaluation of the effectiveness of gasoline direct injection with turbocharging and downsizing. The 2010 NAS Committee considered one level of downsizing in the 2010-2015 time frame, and EPA and NHTSA took a similar approach for the MYs 2012-2016 rule. But, for the MYs 2017-2025 final rule, based on data in the literature, our discussions with the auto companies and automotive suppliers, and a 2011 Ricardo study commissioned by EPA, in the longer term additional levels of downsizing are achievable, including in some cases with the use of cooled exhaust gas recirculation, that provide additional CO_2/fuel consumption reductions. Those additional levels of downsizing were not considered by the 2010 NAS Committee in their assessment of near-term costs and effectiveness.

In addition to the difference in time frames being considered by the 2010 NAS report and this final rule, a second significant difference between the two assessments were the additional studies and information available to EPA and NHTSA which were not reviewed by 2010 NAS Committee. In many cases this was due to the additional two years EPA and NHTSA had available (while the NAS Committee's report was published in 2010, the bulk of their assessments occurred between 2007 and 2009), and in other areas this new information was the result of the many confidential meetings EPA and NHTSA had with auto companies and auto suppliers over the past two years.

The additional publically available studies which EPA and NHTSA utilized included new studies on the costs for mass reduction, lithium-ion battery packs, 8 speed automatic transmissions, 8 speed dual-clutch transmissions, hybrid electric vehicle, plug-in hybrid electric vehicle, and all electric vehicles. EPA and NHTSA also utilized new reports dealing with the use of indirect cost multipliers for estimating indirect manufacturing costs. EPA and NHTSA also are using a number of new studies which were not available to the 2010 NAS Committee for the estimation of the effectiveness of a large number of the 2017-2025 technologies; these include peer reviewed papers in the literature as well as the 2011 Ricardo study (discussed in detail in Chapter 3 of the Joint TSD). A partial list of the studies and data sources regarding technology feasibility, costs, lead time, and effectiveness considered by EPA which were not reviewed by the 2010 NAS Committee or were published after they completed their work, or was obtained confidentially from automotive suppliers includes:

- 2011 Ricardo Report "Computer Simulation of Light-duty Vehicle Technologies for Greenhouse Gas Emission Reductions in the 2020-2025 Timeframe"[28], this report has been peer reviewed and the peer review report and the response to peer review comments are available in the EPA docket EPA-HQ-OAR-2010-0799.

- Argonne National Laboratories 2011 Report “Modeling the Performance and Cost of Lithium-Ion Batteries for Electric-Drive Vehicles”[29] and the accompanying Battery Performance and Cost Model, which estimates lithium-ion battery pack cost for the 2020 time frame. This report was peer reviewed and revised in 2011, and the model, report, and peer review report are available in the EPA docket EPA-HQ-OAR-2010-0799.

- 2011 FEV Report “Light-Duty Technology Cost Analysis Power-split and P2 HEV Case Studies.”[30] This report was peer reviewed, and a copy of the report, the peer review report, and the response to peer review comments report are available in the EPA docket EPA-HQ-OAR-2010-0799.

- 2011 FEV Report “Light-Duty Technology Cost Analysis: Advanced 8-speed Transmissions”[31]. A copy of this report is available in the EPA docket EPA-HQ-OAR-2010-0799.

- 2010 Lotus Engineer Study “An Assessment of Mass Reduction Opportunities for a 2017 – 2020 Model Year Vehicle Program”[32], this report has been peer reviewed, and a copy of the report and the peer review report are available in the EPA docket EPA-HQ-OAR-2010-0799.

- EPA vehicle fuel economy certification data from MY2011 and MY2012 vehicles, including for example the MY2011 Ford F-150 with the 3.5L Ecoboost engine, MY2011 Sonata Hybrid, MY2012 Infiniti M35h hybrid, and several other advanced technology production vehicles.

- “EBDI - Application of a Fully Flexible High BMEP Downsized Spark Ignited Engine.” Society of Autmotive Engineers (SAE) Technical Paper No. 2010-01-0587, Cruff, L., Kaiser, M., Krause, S., Harris, R., Krueger, U., Williams, M., 2010.[33]

- “Water Cooled Exhaust Manifold and Full Load EGR Technology Applied to a Downsized Direct Injection Spark Ignition Engine.” SAE Technical Paper Series No. 2010-01-0356. Taylor, J., Fraser, N., Wieske, P., 2010.[34]

- “Requirements of External EGR Systems for Dual Cam Phaser Turbo GDI Engines.” SAE Technical Paper Series No. 2010-01-0588. Roth, D.B., Keller, P, Becker, M., 2010.[35]

- “Doing More with Less - The Fuel Economy Benefits of Cooled EGR on a Direct Injected Spark Ignited Boosted Engine,” SAE Technical Paper Series, No. 2010-01-0589. Kaiser, M., Krueger, U., Harris, R., Cruff, L., 2010.[36] EPA-HQ-OAR-2010-0799

- "Using indirect cost multipliers to estimate the total cost of adding new technology in the automobile industry," International Journal of Production Economics Rogozhin, A.,et al., 2009.[37]

- "Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies," EPA Technical Memorandum, Helfand, G., Sherwood, T., August 2009.[38]

- Confidential business information regarding the development status, effectiveness and costs for a large number of technologies obtained by EPA in meetings during 2010 and 2011 with more than a dozen worldwide automotive suppliers involved in the development and production of a wide range of technologies, including but not limited to fuel injection systems, transmissions, turbochargers, lower mass automotive components, tires, and automotive lithium-ion batteries.

- Technologies not considered by the NAS Committee which have been launched into production recently by auto makers, such as the 2013 Dodge Ram pickup truck which includes active ride height and active grill shutters that can improve aerodynamics, and the 2013 Audi A3 which in Europe includes a 1.4 liter, four cylinder gasoline engine with cylinder deactivation – a technology in production previously for six and eight cylinder engines only.[39]

With the exception of the confidential business information and copyrighted information, copies of the reports and studies listed above are available in the EPA docket for this final rule, EPA-HQ-OAR-2010-0799. Information on how to obtain copies of the SAE papers is also available in the EPA docket, or they can be order from SAE on-line at http://papers.sae.org/.

For the reasons described above, EPA has elected not to perform a sensitivity assessment based on the 2010 NAS Report, nor have we used the 2010 NAS Report as our primary basis for assessing the costs and effectiveness of technologies for the proposal or this final rule.

EPA requested comment on our overall approach for basing our assessment on technology feasibility, lead time, costs and effectiveness on the full range of information described in the Joint Technical Support Document (which includes consideration of the 2010 NAS Study), as opposed to an alternative approach in which EPA would base our technology feasibility, lead time, costs and effectiveness primarily on the 2010 NAS Study and place lower weighting or no weighting on the additional information which has become available since the 2010 NAS Study (including those data sources, studies and reports listed above). EPA received public comment from the Delphi Corportation recommending that "the National Research Council technology cost estimates and implementation cadence data be included in the agencies' analyses and be considered a primary source of information." This comment is discussed in the Response to Comment document, section 12.3.

EPA also requested comment specifically on EPA's use of the 2011 Ricardo study (listed above), and any ways to improve our estimates of technology effectiveness, including the use of full vehicle simulation modeling as was used in the 2011 Ricardo study or alternative approaches. We also requested comment on the 2011 Ricardo Study and the Ricardo response to comments report with respect to the peer review conducted on the Ricardo report. We received comments from the ICCT, and several other organizations, these comments are discussed in section 12 of the Response to Comments document. These documents are all available in the EPA docket for this rulemaking (EPA-HQ-OAR-2010-0799). Significant additional detail regarding the 2011 Ricardo study and how it was used to inform EPA's estimates of technology effectiveness is contained in Chapter 3 of the Joint Technical Support Document.

References

[28] 2011 Ricardo Report "Computer Simulation of Light-duty Vehicle Technologies for Greenhouse Gas Emission Reductions in the 2020-2025 Timeframe" (Docket No. EPA-HQ-OAR-2010-0799-1144)

[29] Argonne National Laboratories 2011 Report "Modeling the Performance and Cost of Lithium-Ion Batteries for Electric-Drive Vehicles" (Docket No. EPA-HQ-OAR-2010-0799-0031)

[30] 2011 FEV Report "Light-Duty Technology Cost Analysis Power-split and P2 HEV Case Studies" (Docket No. EPA-HQ-OAR-2010-0799-1102)

[31] 2011 FEV Report "Light-Duty Technology Cost Analysis: Advanced 8-speed Transmissions" (Docket No. EPA-HQ-OAR-2010-0799-1103)

[32] 2010 Lotus Engineer Study "An Assessment of Mass Reduction Opportunities for a 2017 – 2020 Model Year Vehicle Program" (EPA-HQ-OAR-2010-0799-0036)

[33] "EBDI - Application of a Fully Flexible High BMEP Downsized Spark Ignited Engine." Society of Automotive Engineers (SAE) Technical Paper No. 2010-01-0587, Cruff, L., Kaiser, M., Krause, S., Harris, R., Krueger, U., Williams, M., 2010

[34] "Water Cooled Exhaust Manifold and Full Load EGR Technology Applied to a Downsized Direct Injection Spark Ignition Engine." SAE Technical Paper Series No. 2010-01-0356. Taylor, J., Fraser, N., Wieske, P., 2010 (Docket No. EPA-HQ-OAR-2010-0799-1200)

[35] "Requirements of External EGR Systems for Dual Cam Phaser Turbo GDI Engines." SAE Technical Paper Series No. 2010-01-0588. Roth, D.B., Keller, P, Becker, M., 2010. (Docket No. EPA-HQ-OAR-2010-0799-1201)

[36] "Doing More with Less - The Fuel Economy Benefits of Cooled EGR on a Direct Injected Spark Ignited Boosted Engine," SAE Technical Paper Series, No. 2010-01-0589. Kaiser, M., Krueger, U., Harris, R., Cruff, L., 2010

[37] "Using indirect cost multipliers to estimate the total cost of adding new technology in the automobile industry," International Journal of Production Economics Rogozhin, A.,et al., 2009 (Docket No. EPA-HQ-OAR-2010-0799-0067)

[38] "Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies," EPA Technical Memorandum, Helfand, G., Sherwood, T., August 2009 (Docket No. EPA-HQ-OAR-2010-0799-0064)

[39] See "2013 Ram 1500 unveiled with eight-speed auto, start/stop, air suspension" at autoblog.com or "2013-ram-1500-unveiled-with-.pdf" in Docket No. EPA-HQ-OAR-2010-0799. See also "2013 Audi A3 Euro-Spec" at caranddriver.com or "2013-audi-a3-euro-spec-firs.pdf" in Docket No. EPA-HQ-OAR-2010-0799.

4 Projected Impacts on Emissions, Fuel Consumption, and Safety

4.1 Introduction

This chapter documents EPA's analysis of the emission, fuel consumption and safety impacts of the emission standards for light duty vehicles. Light duty vehicles include passenger vehicles such as cars, sport utility vehicles, vans, and pickup trucks. Such vehicles are used for both commercial and personal uses and are significant contributors to the total United States (U.S.) GHG emission inventory.

This chapter documents the analysis using the MY 2008 based market forecast. The analysis using the MY 2010 based market forecast is documented in RIA Chapter 10. The methods are generally identical between the two analyses; in places where they are not, a note is placed in this chapter.

Mobile sources represent a significant share of U.S. GHG emissions and include light-duty vehicles, light-duty trucks, medium-duty passenger vehicles, heavy-duty trucks, airplanes, railroads, marine vessels and a variety of other sources. In 2010, mobile sources emitted 30% of all U.S. GHGs, and have been the source of the largest absolute increase in U.S. GHGs since 1990. Transportation sources, which do not include certain off highway sources such as farm and construction equipment, account for 27% of U.S. GHG emissions, and motor vehicles (CAA section 202(a)), which include light-duty vehicles, light-duty trucks, medium-duty passenger vehicles, heavy-duty trucks, buses, and motorcycles, account for 23% of total U.S. GHGs.

Light-duty vehicles emit carbon dioxide, methane, nitrous oxide and hydrofluorocarbons. Carbon dioxide (CO_2) is the end product of fossil fuel combustion. During combustion, the carbon stored in the fuels is oxidized and emitted as CO_2 and smaller amounts of other carbon compounds. Methane (CH_4) emissions are a function of the methane content of the motor fuel, the amount of hydrocarbons passing uncombusted through the engine, and any post-combustion control of hydrocarbon emissions (such as catalytic converters). Nitrous oxide or N_2O (and nitrogen oxide or NO_X) emissions from vehicles and their engines are closely related to air-fuel ratios, combustion temperatures, and the use of pollution control equipment. For example, some types of catalytic converters installed to reduce motor vehicle NO_X, carbon monoxide (CO) and hydrocarbon (HC) emissions can promote the formation of N_2O. Hydrofluorocarbons (HFC) are progressively replacing chlorofluorocarbons (CFC) and hydrochlorofluorocarbons (HCFC) in vehicle air conditioning systems as CFCs and HCFCs are being phased out under the Montreal Protocol and Title VI of the CAA. There are multiple emissions pathways for HFCs with emissions occurring during charging of cooling and refrigeration systems, during operations, and during decommissioning and disposal.

This rule will significantly decrease the magnitude of these emissions. Because of anticipated changes to driving behavior, fuel production, and electricity generation, a number of co-pollutants would also be affected by this rule. This analysis quantifies the program's impacts on the greenhouse gases (GHGs) carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and hydrofluorocarbons (HFC-134a); program impacts on "criteria" air pollutants, including carbon monoxide (CO), fine particulate matter ($PM_{2.5}$) and sulfur dioxide (SO_2) and the ozone precursors hydrocarbons (VOC) and oxides of nitrogen (NOx); and impacts on several air toxics including benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein.

CO_2 emissions from automobiles are largely the product of fuel combustion, and consequently, reducing CO_2 emissions will also produce a significant reduction in projected fuel consumption. EPA's projections of these impacts are also shown in this chapter.

In addition to the intended effects of reducing CO_2 emissions, the agencies also consider the potential of the standards to affect vehicle safety. This topic is discussed in Preamble Section II.G. EPA's analysis of the change in light duty vehicle related fatalities due to projected usage of mass reduction technology is shown in this chapter.

This chapter primarily describes the methods used by EPA in its analysis. Detailed discussion of the inputs, such as VMT, emission factors, and safety coefficients are found in Chapter 4 of the Joint TSD.

4.2 Analytic Tools Used

As in the MYs 2012-2016 rule, EPA used its Optimization Model for reducing Emissions of Greenhouse gases from Automobiles (OMEGA) post-processor to project the impacts of this rule. Broadly speaking, the OMEGA core model is used to predict the most likely paths by which manufacturers would meet tailpipe CO_2 emission standards. OMEGA applies technologies with varying degrees of cost and effectiveness to a defined vehicle fleet in order to meet a specified GHG emission target and calculates the costs and benefits of doing so. The projections of impacts in OMEGA are conducted in a Microsoft Excel Workbook (the benefits post-processor). (for more detail, see RIA chapter 3) The OMEGA benefits post-processor produces a national scale analysis of the impacts (emission reductions, monetized co-benefits, safety impacts) of the analyzed program.

The benefits post-processor incorporates the inputs discussed (many extensively) in the Joint Technical Support Document. Specifically, Joint TSD Chapter 1 discusses the development of the vehicle fleet, Joint TSD Chapter 2 discusses the attribute based curves which define the CO_2 targets, Joint TSD Chapter 3 discusses the technologies which may be available to meet those targets,[GGG] and Joint TSD Chapter 4 discusses other relevant inputs (such as vehicle sales, vehicle miles traveled (VMT), and survival schedules).

The remainder of this chapter provides a summary of the discussion of the TSD inputs, additional data on methodology and inputs, and the results of the analysis.

[GGG] Specifically, the power consumption of plug-in hybrid and battery electric vehicles are discussed in Joint TSD Chapter 3 and used in this analysis. Mass reduction, an input to the mass-safety analysis, is also discussed therein.

4.3 Inputs to the emissions analysis

4.3.1 Methods

EPA estimated greenhouse impacts from several sources including: (a) the impact of the standards on tailpipe CO_2 emissions, (b) projected improvements in the efficiency of vehicle air conditioning systems, [HHH] (c) reductions in direct emissions of the potent greenhouse gas refrigerant HFC-134a from air conditioning systems, (d) "upstream" emission reductions from gasoline extraction, production and distribution processes as a result of reduced gasoline demand associated with this rule, and (e) "upstream" emission increases from power plants as electric powertrain vehicles increase in prevalence as a result of this rule (Table 4.3-17).[III] EPA additionally accounted for the greenhouse gas impacts of additional vehicle miles travelled (VMT) due to the "rebound" effect discussed in Section III.H.

Our estimates of non-GHG emission impacts from the GHG program are broken down by the three drivers of these changes: a) "downstream" emission changes, reflecting the estimated effects of VMT rebound (discussed in Sections III.F and III.H) and decreased consumption of motor vehicle fuel; b) "upstream" emission reductions due to decreased extraction, production and distribution of motor vehicle gasoline; c) "upstream" emission increases from power plants as electric powertrain vehicles increase in prevalence as a result of this rule. For all criteria and air toxic pollutants, the overall impact of the program is small compared to total U.S. inventories across all sectors.

As discussed in preamble section III.C.2, although electric vehicles have zero tailpipe emissions, EPA assumes that manufacturers will plan for these vehicles in their regulatory compliance strategy for criteria pollutant and air toxics emissions, and will not over-comply with those standards for non-GHG air pollutants. Since the Tier 2 emissions standards are fleet-average standards, we assume that if a manufacturer introduces EVs into its fleet, that it would correspondingly compensate through changes to vehicles elsewhere in its fleet, rather than produce an overall lower fleet-average emissions level.[40] Consequently, EPA assumes neither tailpipe pollutant benefit (other than CO2) nor an evaporative emission benefit from the introduction of electric vehicles into the fleet.

Two basic elements feed into OMEGA's calculation of vehicle tailpipe emissions. These elements are vehicle miles traveled (VMT) and emission rates.

$$\text{Total Emissions} = \text{VMT}_{\text{miles}} * \text{Emission rate}_{\text{grams/mile}}$$

Equation 9 - Emissions

[HHH] While EPA anticipates that the efficiency of the majority of mobile air conditioning systems will be improved in response to the MY 2012-2016 rulemaking, the agency expects that the remainder will be improved as a result of this action.

[III] The increased emissions from power plants includes feedstock gathering. This includes GHG emissions from the extraction of fuel for power plants, including coal and natural gas.

This equation is adjusted in calculations for various emissions, but provides the basic form used throughout this analysis. As an example, in an analysis of a single calendar year, the emission equation is repeatedly applied to determine the contribution of each model year in the calendar year's particular fleet. Appropriate VMT and emission factors by age are applied to each model year within the calendar year, and the products are then summed. Similarly, to determine the emissions of a single model year, appropriate VMT and emission factors by age are applied to each calendar year between when the model year fleet is produced and projected to be scrapped

Tailpipe SO_2 emissions, which are largely controlled by the sulfur content of the fuel, is an exception to this basic equation. As discussed in TSD 4, decreasing the quantity of fuel consumed decreases tailpipe SO_2 emissions proportionally to the decrease in fuel combusted.

4.3.1.1 Global Warming Potentials

Throughout this document, in order to refer to the four inventoried greenhouse gases on an equivalent basis, Global Warming Potentials (GWPs) are used. In simple terms, GWPs provide a common basis with which to combine several gases with different heat trapping abilities into a single inventory (Table 4.3-1). When expressed in CO_2 equivalent (CO_2 EQ) terms, each gas is weighted by its heat trapping ability relative to that of carbon dioxide.

Table 4.3-1 Global Warming Potentials for the Inventory GHGs[JJJ], [41]

Gas	Global Warming potential (CO_2 Equivalent)
CO_2	1
CH_4	25
N_2O	298
HFC (R134a)	1430

4.3.1.2 Years considered

This analysis presents the projected impacts of this rule in calendar years 2020, 2030, 2040 and 2050. We also present the emission impacts over the estimated full lifetime of MYs

[JJJ] As with the MY 2012-2016 Light Duty rule and the MY 2014-2018 Medium and Heavy Duty rule, the GWPs used in this rule are consistent with 100-year time frame values in the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). At this time, the 100-year GWP values from the 1995 IPCC Second Assessment Report are used in the official U.S. GHG inventory submission to the United Nations Framework Convention on Climate Change (UNFCCC) per the reporting requirements under that international convention. The UNFCCC recently agreed on revisions to the national GHG inventory reporting requirements, and will begin using the 100-year GWP values from AR4 for inventory submissions in the future.

2017-2025 vehicles.[KKK] The program was quantified as the difference in mass emissions between a control case under final standards and a reference case as described in Section 4.3.4.

4.3.2 Activity

4.3.2.1 Vehicle Sales

Vehicle sales projections from MY 2012 through MY 2025 were developed jointly by NHTSA and EPA and are discussed in Chapter 1 of the Joint TSD. For MYs between 2025 and 2035, EPA used the Volpe Center run of the NEMs model (discussed in Joint TSD Chapter 1) in order to project the sales of cars and trucks by "pre-MY 2011" definitions . 23 percent of "pre-MY 2011" defined trucks were then converted to cars (Table 4.3-2), consistent with the percent that changed in MY 2025 within the reference fleet forecast. This action reflects the assumption that the vehicle mix within the car and truck classes stops changing after MY 2025. These same methods and sales projections were used at proposal.

Table 4.3-2 MY 2011 and later Car and Truck Definitions[LLL]

CAR DEFINITION	TRUCK DEFINITION
Passenger Car – Vehicles defined pre-MY 2011as Cars + 2 wheel drive SUVs below 6,000 GVW	Light Duty Truck – Remaining light duty fleet

As the NEMS analysis only goes through 2035, and this analysis goes through 2050, sales from 2035-2050, the sales of cars and trucks were each projected to grow at the average annual rates of sales growth from 2017-2035 (1.16%).

4.3.2.2 Survival schedules[MMM]

TSD 4 documents the survival schedule used in this rule.

The agencies' analyses of fuel savings and related benefits from adopting more stringent fuel economy and GHG standards for MYs 2017-2025 passenger cars and light trucks begin by estimating the resulting changes in fuel use over the entire lifetimes of affected cars and light trucks. The change in total fuel consumption by vehicles produced during each of these model years is calculated as the difference in their total lifetime fuel use over the entire lifetimes of these vehicles as compared to a reference case.

[KKK] The "full lifetime" is the time span between sales and scrappage for a given MY, and includes estimates of sales, scrappage, and VMT accumulation by year. For a given vehicle, it is the mileage between when it is driven for its first and last miles.
[LLL] While the formal definitions are lengthy, brief summaries of the classifications are shown here.
[MMM] A lengthier discussion of both survival and mileage schedules are provides in Joint TSD Chapter 4.

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

The proportions of passenger cars and light trucks expected to remain in service at each age are estimated from R.L. Polk vehicle registration data for calendar years 1970-2010, and are shown in Table 4.3-3.[42] Note that these survival rates were calculated against the pre-MY 2011 definitions of cars and light trucks, and are not projected to change over time in the analysis. The rates are applied to vehicles based on their regulatory class (passenger car or light truck) regardless of fuel type or level of technology.

The survival and annual mileage estimates reported in this section's tables reflect the convention that vehicles are defined to be of age 1 during the calendar year that coincides with their model year. Thus for example, model year 2017 vehicles will be considered to be of age 1 during calendar year 2017. This convention is used in order to account for the fact that vehicles produced during a model year typically are first offered for sale in June through September of the preceding calendar year (for example, sales of a model year typically begin in June through September of the previous calendar year, depending on manufacturer). Thus, virtually all of the vehicles produced during a model year will be in use for some or all of the calendar year coinciding with their model year, and they are considered to be of age 1 during that year.[OOO]

[NNN] Vehicles are defined to be of age 1 during the calendar year corresponding to the model year in which they are produced; thus for example, model year 2000 vehicles are considered to be of age 1 during calendar year 2000, age 2 during calendar year 2001, and to reach their maximum age of 30 years during calendar year 2029. NHTSA considers the maximum lifetime of vehicles to be the age after which less than 2 percent of the vehicles originally produced during a model year remain in service. Applying these conventions to vehicle registration data indicates that passenger cars have a maximum age of 30 years, while light trucks have a maximum lifetime of 37 years. *See* Lu, S., NHTSA, Regulatory Analysis and Evaluation Division, "Vehicle Survivability and Travel Mileage Schedules," DOT HS 809 952, 8-11 (January 2006). *Available at* http://www-nrd.nhtsa.dot.gov/Pubs/809952.pdf (last accessed Sept. 9, 2011). For the Final Rule, the survivability schedules developed by Lu were updated using national vehicle registration data collected by R.L. Polk for calendar years 2006 – 2010.

[OOO] A slight increase in the fraction of new passenger cars remaining in service beyond age 10 has accounted for a small share of growth in the U.S. automobile fleet. The fraction of new automobiles remaining in service to various ages was computed from R.L. Polk vehicle registration data for 1977 through 2005 by the DOT's Center for Statistical Analysis

Table 4.3-3 Survival Rates

VEHICLE AGE	ESTIMATED SURVIVAL FRACTION CARS	ESTIMATED SURVIVAL FRACTION LIGHT TRUCKS
1	1.0000	1.0000
2	0.9878	0.9776
3	0.9766	0.9630
4	0.9614	0.9428
5	0.9450	0.9311
6	0.9298	0.9152
7	0.9113	0.8933
8	0.8912	0.8700
9	0.8689	0.8411
10	0.8397	0.7963
11	0.7999	0.7423
12	0.7556	0.6916
13	0.7055	0.6410
14	0.6527	0.5833
15	0.5946	0.5350
16	0.5311	0.4861
17	0.4585	0.4422
18	0.3832	0.3976
19	0.3077	0.3520
20	0.2414	0.3092
21	0.1833	0.2666
22	0.1388	0.2278
23	0.1066	0.2019
24	0.0820	0.1750
25	0.0629	0.1584
26	0.0514	0.1452
27	0.0420	0.1390
28	0.0337	0.1250
29	0.0281	0.1112
30	0.0235	0.1028
31	0.0000	0.0933
32	0.0000	0.0835
33	0.0000	0.0731
34	0.0000	0.0619
35	0.0000	0.0502
36	0.0000	0.0384
37	0.0000	0.0273

4.3.2.3 VMT

The second step in estimating lifetime fuel use by the cars or light trucks produced during a future model year is to calculate the total number of miles that they will be driven during each year of their expected lifetimes. To estimate total miles driven, the number of cars and light trucks projected to remain in use during each future calendar year is multiplied by the average number of miles a surviving car or light truck is expected to be driven at the age it will have reached in that year. Estimates of average annual miles driven by cars and light trucks of various ages were developed by NHTSA from the Federal Highway Administration's 2009 National Household Travel Survey. This updates the schedules of annual miles driven that were used in the NPRM, which were based on the previous National Household Travel Survey, conducted in 2001. Additionally, the agencies have accounted for the higher usage of fleet vehicles, which include rental vehicles as well as those owned by corporations and government agencies. These represent about 20% of new vehicle sales, are not represented in the NHTS, and are driven much more intensively (on average) than household vehicles for the first several years of their lives before being absorbed into the household vehicle population.[PPP] The updated mileage schedules are reported in Table 4.3-4. These estimates represent the average number of miles driven by a surviving light duty vehicle at each age over its estimated full lifetime. To determine the number of miles a typical vehicle produced during a given model year is expected to be driven at a specific age, the average annual mileage for a vehicle of that model year and age is multiplied by the corresponding survival rate for vehicles of that age. Further details are available in TSD 4.

[PPP] Using the Annual Energy Outlook 2012, early release version of the National Energy Modeling System, developed and maintained by the U.S. Energy Information Administration, the proportion of fleet vehicles and their typical usage were calculated and then averaged into the household mileage accumulation schedules developed using the 2009 NHTS. [NHTSA's documentation needed.]

Table 4.3-4CY 2009 Mileage Schedules based on NHTS Data

VEHICLE AGE	ESTIMATED VEHICLE MILES TRAVELED CARS	ESTIMATED VEHICLE MILES TRAVELED LIGHT TRUCKS
1	14,700	15,974
2	14,252	15,404
3	14,025	14,841
4	13,593	14,435
5	13,324	14,038
6	13,064	13,650
7	12,809	12,590
8	11,378	12,192
9	11,087	11,810
10	10,806	11,443
11	10,535	11,091
12	10,273	10,755
13	10,021	10,434
14	9,779	10,129
15	9,547	9,839
16	9,324	9,564
17	9,111	9,305
18	8,908	9,061
19	8,714	8,833
20	8,530	8,620
21	8,356	8,423
22	8,192	8,241
23	8,037	8,075
24	7,892	7,923
25	7,757	7,788
26	7,632	7,668
27	7,516	7,563
28	7,410	7,473
29	7,314	7,399
30	7,227	7,341
31	7,151	7,298
32	7,083	7,270
33	7,026	7,258
34	6,979	7,246
35	6,941	7,233
36	6,912	7,221
37	6,894	7,209

4.3.2.4 Adjusting vehicle use for years after 2009

The estimates of annual miles driven by passenger cars and light trucks at each age were also adjusted to reflect projected future growth in average use for vehicles of all ages. Increases in the average number of miles that cars and trucks are driven each year have been an important source of historical growth in *total* car and light truck use, and are expected to be a continued source of future growth in total light-duty vehicle travel as well. As an illustration of the importance of growth in average vehicle use, the total number of miles driven by passenger cars increased 35 percent from 1985 through 2005, equivalent to a compound annual growth rate of 1.5 percent.[43] During that same time, however, the total number of passenger cars registered in the U.S. grew by only about 0.3 percent annually.[QQQ] Thus growth in the average number of miles that automobiles are driven each year accounted for the remaining 1.2 percent (= 1.5 percent - 0.3 percent) annual growth in total automobile use.[RRR]

In the U.S., overall change in VMT is attributable to factors such as employment rate, vehicle ownership rates, demographic trends, the cost of driving, and other macroeconomic factors. Rather than independently developing estimates of these factors, the agencies have used the DOT Volpe Center NEMS[SSS] run which considers many of these factors, as a benchmark of total VMT levels in each future year. The VMT projections produced by this NEMS run are highly similar to those shown in AEO 2012 Early Release. The AEO 2012 Early Release Reference Case projection of total car and light truck use and of the number of cars and light trucks in use suggest that their average annual use will continue to increase from 2010 through 2035, although at a slower rate of increase than shown in AEO 2011.[TTT] In calendar year 2030, total VMT projected in AEO 2012 Early Release is 10% lower than that projected in AEO 2011.

In order to develop reasonable estimates of future growth in the average number of miles driven by cars and light trucks of all ages in the reference case, the agencies calculated the average rate of growth in the mileage schedules necessary for total car and light truck travel to closely correspond to AEO 2012 Early Release Reference Case. The growth rate in average annual car and light truck use produced by this calculation is approximately 0.6

[QQQ] A slight increase in the fraction of new passenger cars remaining in service beyond age 10 has accounted for a small share of growth in the U.S. automobile fleet. The fraction of new automobiles remaining in service to various ages was computed from R.L. Polk vehicle registration data for 1977 through 2005 by the NHTSA's Center for Statistical Analysis.

[RRR] *See supra* note k below.

[SSS] This is the version of NEMS that is used in AEO 2012 Early Release, and modified by the Volpe center to hold new vehicle fuel economy constant after 2016. See TSD 1 for additional details. This version produces VMT estimates that are highly similar to those in the AEO 2012 Early Release

[TTT] The agencies note that VMT growth has slowed, and because the impact of VMT is an important element in our benefit estimates, we will continue to monitor this trend to see whether this is a reversal in trend or temporary slowdown. See the 2009 National Household Travel Survey (http://nhts.ornl.gov/2009/pub/stt.pdf) and National transportation Statistics (http://www.bts.gov/publications/national_transportation_statistics/html/table_04_09.html) percent per year.[UUU] When the 0.6% annual growth rate is combined with the MY 2010 base sales projection (TSD 1), as well as the VMT, and survival schedules derived for this rule the estimated total vehicle usage in the EPA's reference cases closely approximates that contained in AEO 2012 ER. Thus, a growth rate is applied to the mileage figures reported in Table 4.3-4 (after adjusting vehicle populations for expected vehicle survival rates) to estimate average annual mileage during each calendar year analyzed and during the expected lifetimes of model year 2017-25 cars and light trucks in the reference case.[VVV]

EPA developed the reference case VMT using the single growth factor discussed above; this growth factor reflects driver responsiveness to changes in fuel prices, fuel efficiency, and other factors consistent with the AEO 2012 ER Reference Case.[WWW] To develop EPA's policy case VMT, EPA applied the elasticity of annual vehicle use with respect to fuel cost per mile corresponding to the 10 percent fuel economy rebound effect used in this analysis (*i.e.*, an elasticity of annual vehicle use with respect to fuel cost per mile driven of -0.10;) to the percentage change in cost-per-mile travel between each future year's vehicle under a policy case and a reference case in the same year. In other words, if the per-mile fuel cost of a MY 2025 vehicle under the policy case was 30% less than its counterpart under the reference case, the change in VMT would be 3%.[XXX] Thus, in the EPA analysis, VMT associated with the rebound effect only reflects the impact of the EPA program relative to the reference case.[YYY] The following equation summarizes in mathematical form how EPA captured the change in VMT due to increased fuel efficiency in the policy case (i.e., the EPA's approach for incorporating the rebound effect):

[UUU] It was not possible to estimate separate growth rates in average annual use for cars and light trucks, because of the significant reclassification of light truck models as passenger cars discussed previously.

[VVV] As indicated previously, a vehicle's age during any future calendar year is uniquely determined by the difference between that calendar year and the model year when it was produced.

[WWW] This approach is consistent with the MYs 2012-2016 rule, but represents a slight difference from our approach in the NPRM where we first accounted for changes in fuel cost-per-mile compared to 2009 before applying a growth factor to meet levels in AEO 2011. The use of a single growth factor ensures consistency with the AEO projections about future micro and macroeconomic trends and underlying assumptions about consumer responsiveness to those trends.

[XXX] Under the equation: percent difference in VMT = (rebound effect * (FCreference case – FCpolicy case)/FCreference case) and the rebound effect = 10%. A 30% change in fuel costs, multiplied by a 10% rebound effect would result in 3% additional driving.

[YYY] This approach is consistent with the MYs 2012-2016 rule, but represents a slight difference from our approach in the NPRM where rebound VMT was estimated based on the difference between FCPM in our policy case and the FCPM in the calendar year of our baseline VMT (i.e., 2001 NHTS). As discussed in our draft RIA, the NPRM approach implicitly assumes drivers are comparing their current fuel costs to fuel costs from a distant past when making decisions about the amount of miles to drive. Additionally, the NPRM approach implicitly assumes that factors in the years between a future calendar year and one in the distant past have no influence on VMT levels in future calendar year (which contrasts with AEO assumptions that the previous year VMT is a factor in current year VMT). The FRM approach of estimating rebound VMT based on the difference between policy case FCPM and reference case FCPM in the same calendar year better captures the likely real-world driver response to changes in fuel costs. Finally, this approach allows EPA to vary the rebound effect in the policy case while holding the reference case VMT constant in the sensitivity analyses in section 4.5.1 to ensure that we are capturing the effect of our standards alone.

Percent difference in VMT = (elasticity of VMT with respect to FCPM * ($FCPM_{reference\ case}$ – $FCPM_{policy\ case}$)/$FCPM_{reference\ case}$)

Where FCPM = fuel cost per mile

EPA made adjustments to vehicle use to account for projected changes in future fuel prices, fuel efficiency, and other factors that influence growth in average vehicle use during each future calendar year. Because the effects of fuel prices and other factors influencing growth in average vehicle use differ for each year, these adjustments result in different VMT schedules for each future year. The net impact resulting from these adjustments is continued growth over time in the average number of miles that vehicles of each age are driven, although at slower rates than those observed from 1985 – 2005. [ZZZ]

VMT equation[AAAA]

The following equation summarizes in mathematical form the adjustments that are made to the values of average miles driven by vehicle age derived from the 2009 NHTS to derive the estimates of average miles driven by vehicles of each model year during future calendar years that are used in this analysis.

$$VMT_{calendar\ year\ \ x\ ,age\ y} = \left(V_y\right) * (1 + GR)^{YS} * (1 - \ R * (FCPM_{t,y} - \ FCPM_{\ x,y})/FCPM_{t,y}$$

Where:
V_y = Average miles driven in CY 2009 (from NHTSA analysis of 2009 NHTS data) by a vehicle of age $_y$ during 2009
GR = Secular Growth Rate
YS = Years since 2009)
R= elasticity of VMT with respect to FCPM (-0.10). (Note that this term has no impact on the reference case because $FCPM_{\ xy}$ = $FCPM_{ty}$
$FCPM_{x,y}$ = Fuel cost per mile of a analyzed vehicle of age *y* in calendar year *x*
$FCPM_{t,y}$ = this variable represents the fuel cost per mile of a reference case vehicle of age *y* in calendar year t (Note: in the reference case, this variable is identical to FCPMx,y.)

In turn, fuel cost per mile of an age y vehicle in calendar year x is determined by the following equation, which can be extended for any number of fuels:

[ZZZ] Observed aggregate VMT in recent years has actually declined (about 0.4% per year over the past decade), but it is unclear if the underlying cause is general shift in behavior or a response to a set of temporary economic conditions.

[AAAA] While both agencies applied the VMT calculation described above in the NPRM, for the final rule, in the EPA baseline calculation, the rebound effect is in effect embedded in the growth rate. Under the regulatory alternatives, the rebound effect is based solely on the percentage increase in fuel economy over the relevant baseline model year. NHTSA continued to follow the NPRM approach because of its requirement to produce an Environmental Impact Statement for the rule, and the need for consistent results among the alternative scenarios it considers.

$$FCPM_{Calendar\ year\ x} = EC_y * EP_x + GC_y * GP_x + DC_y * DP_x$$

Where:
EC_y= Electricity consumption of age *y* vehicle (in KWh) per mile
EP_x = Electricity Price (in $ per KWh) during calendar year *x*
GC_y = Gasoline Consumption of age *y* vehicle (in gallons) per mile
GP_x = Gasoline Price (in $ per gallon) during calendar year *x*
DC_y = Diesel Consumption of age *y* vehicle (in gallons) per mile
DP_x = Diesel Price (in $ per gallon) during calendar year *x*

Since the proposal, EPA has made some adjustments to the modeling of VMT to improve consistency with the CAFE model and with the analysis used to collect the VMT and survival rate data. The OMEGA model benefits processor now separately tracks the VMT schedules of classic cars, cars that would be trucks under the pre-MY 2011 CAFE regulations, and post-MY 2011 trucks. VMT and survival rates are mapped according to the pre-MY 2011 CAFE regulation definitions. This adjustment changes the mapping of VMT, but has little effect on total VMT.

Table 4.3-5 Survival Weighted Per-Vehicle Reference VMT used in the Agencies' Analyses[BBBB]

	MY 2021		MY 2025	
	Cars	Light Trucks	Cars	Light Trucks
FRM	204,161	218,399	209,037	223,688
NPRM	204,688	242,576	210,898	249,713

The net effect of all of the changes results in slightly lower VMT schedules than those used in the proposal analysis, with a greater impact on the light truck schedules.

4.3.3 Upstream Emission Factors

As documented in Joint TSD Chapter 4, emission factors for this analysis were derived from several sources. Tailpipe emission factors other than CO_2 were derived from MOVES 2010a, with the complete documentations for these calculations provided in the Joint TSD.[44] As in the proposal, upstream emission factors for petroleum product production, transport and distribution were derived from EPA's "Impact spreadsheet" based on Argon National Labs Greet 1.8.[45, 46] Electricity related emission factors for were derived from EPA's Integrated

[BBBB] Due to the differences in VMT mapping between proposal and this final rulemaking, the car VMT shown here are not directly comparable between NPRM and FRM.

Planning Model (IPM), as discussed later in this document. These emission factors were used as inputs to the OMEGA post-processor.[47]

Several modifications were made to the analysis of upstream emission factors since proposal. These revisions are discussed later in the following sections

4.3.3.1 Updates to the Gasoline Production and Transport Emission Rates

As discussed in section 4.6.2, EPA made a number of updates to the upstream emission rates as a part of the process leading up to the air quality analysis. These updates led to changes in the inventory analysis from the emission rates inputs used in the proposal, and have provided improved consistency with the national emission inventory (NEI). No changes were made to the upstream GHG emission rates. We received no comments on the gasoline production and distribution rates used in this rulemaking.

The gasoline production and transport sector is composed of four distinct components:

- Domestic crude oil production and transport
- Petroleum production and refining emissions
- Production of energy for refinery use
- Gasoline transport, storage and distribution.

The emission factors associated with on-road combustion emissions were updated based on the HD GHG rule MOVES runs.[48, CCCC] Category 3 Ocean going vessel emission rates were also updated for consistency with the EPA 2010 Category 3 vessel rule.

Refinery related emissions were updated to reconcile the emission totals with those in the national emission inventory. For some pollutants, such as NOx, this change was a significant reduction in the emission rate related to "upstream" gasoline. For others emissions, there was little change in the rate.

As discussed in section 4.6.2, we also made adjustments to the feedstock mix for refinery use to be consistent with the IPM runs conducted for this rule. See section 4.6.3 for more details on the IPM analysis.

As in the NPRM, we assumed CY 2030 upstream emission rates for this analysis.

[CCCC] According to the EPA modified version of GREET 1.8, combustion emissions account for approximately 150 grams of CO2 per mmbtu of fuel produced. As the total estimate of CO2 emission per mmbtu is 18,792 grams, the 10% reduction in HD emissions has an impact of less than 0.1% on the total emissions from producing a gallon of fuel. As such, these changes had no meaningful impact on the GHG emission rates for fuel production.

Table 4.3-6 Comparison of NPRM and FRM Gasoline Production Emission Rates.

	g/mmbtu	
	NPRM	FRM
CO	4.3	2.7
NOx	13.3	6.5
PM2.5	1.8	1.0
SOx	8.2	4.4
VOC	44.6	44.2
1,3-Butadiene	0.001	0.001
Acetaldehyde	0.005	0.005
Acrolein	0.001	0.001
Benzene	0.096	0.090
Formaldehyde	0.036	0.038
Naphthalene	0.003	0.011
CH4	106.6	106.6
N2O	0.3	0.3
CO2	18792.2	18777.2

4.3.3.2 Updates to the Electricity Generation Emission Rates

An updated analysis of emissions from electricity generation using the IPM model is presented in section 4.6.3 of this chapter.

For this rulemaking, we conducted an Integrated Planning Model (IPM) analysis of the electricity sector in order to gauge the impacts of additional electric charging upon the power grid. This analysis is discussed in section 4.6.3.3 below. Because the IPM analysis was conducted with a specific electricity demand (that of the NPRM) and in specific years, for the FRM inventory analysis, we developed emission factors that could be extrapolated to additional scenarios for use as inputs to the OMEGA model.

In general, IPM runs in a single year are considered indicative of the surrounding decade. In other words, the 2030 results can be considered inclusive of the five years before and after 2030. As such, the 2030 impacts are an appropriate representation of the electrical grid in the time period surrounding 2030, which is a time when significant vehicles subject to this rule will be on the road.

The 2030 IPM results were post-processed to develop gram per kwh emission factors for use in the OMEGA model. The total emissions reported above were divided by the incremental power demand in 2030. For those emissions that IPM does not generate, we relied upon the NEI for air toxic emissions[49] and eGrid for N_2O and CH_4.[50]

IPM includes the emissions from the power generation, however, there are additional emissions attributable to feedstock generation, or the gathering and transport of fuel to the power plant. Emission factors from the version of GREET 1.8c (as modified for the EPA upstream analysis discussed above) were used to generate feedstock emission factors. As discussed in preamble III.C.2, and later in this chapter, the incremental mix of generation for the additional load was approximately 80% natural gas, 15% coal, and 5% other. The natural gas and coal emission factors from GREET were weighted in this ratio as used to generate the emission factors from GREET for the criteria pollutants and air toxics. For GHGs, additional EPA analysis was conducted to properly determine the appropriate impact of feedstock gathering. This analysis is also presented in III.C.2.

We also used the retail electricity price projections from this IPM run in our analysis of electricity fuel costs to drivers.

Table 4.3-7 Emission factors used in analysis of electricity generation

CY	IPM (g/kwh)	Feedstock (g/kwh)	Total (g/kwh)
VOC	8.28E-03	4.69E-02	5.52E-02
CO	2.89E-01	5.01E-02	3.39E-01
NOx	1.13E-01	1.27E-01	2.41E-01
PM2.5	5.81E-03	6.51E-02	7.09E-02
SO2	1.90E-01	4.69E-02	2.37E-01
CO2	4.45E+02	3.55E+01	4.80E+02
N2O	6.76E-03	6.81E-04	7.44E-03
CH4	8.60E-03	3.31E+00	3.32E+00
1,3-butadiene	0.0E+00	0.00E+00	0.00E+00
Acetaldehyde	5.5E-05	9.47E-06	6.40E-05
Acrolein	2.8E-05	3.15E-05	5.95E-05
Benzene	1.3E-04	1.41E-03	1.54E-03
Formaldehyde	3.0E-05	7.51E-06	3.79E-05

4.3.4 Scenarios

4.3.4.1 Air conditioning

HFC-134a (refrigerant) emission factors were applied on a gram per mile basis, and are consistent with the Interim Joint TAR analysis of the on-road HFC impact per mile of 11.5 gram/mile for cars and 13.0 gram/mile for trucks. For this analysis, the per-mile impact of HFC reduction was determined by multiplying the fractional phase in of the credit by the Interim Joint TAR assessment of the g/mile impact. Relative to the NPRM estimates, the TAR estimates of HFC-134a leakage are smaller. See TSD 5 for a detailed discussion of the TAR estimates of HFC-134a emissions, and why the total reductions estimated here may be conservative in this regard. As VMT is increasing and the impact the vehicle HFC-134a control programs are calculated on a gram/mile basis, this analysis implicitly assumes that a vehicle driven more miles will have its HFC-134a reservoir refilled more times.

Table 4.3-8 – A/C Credits

	Reference						Control					
	Car			Truck			Car			Truck		
	Indirect	Direct	Total	Indirect	Direct	Total	Indirect	Direct	Total	Indirect	Direct	Total
MY 2017	4.8	5.4	10.2	4.8	6.6	11.5	5.0	7.8	12.8	5	7	12
MY 2018	4.8	5.4	10.2	4.8	6.6	11.5	5.0	9.3	14.3	6.5	11	17.5
MY2019	4.8	5.4	10.2	4.8	6.6	11.5	5.0	10.8	15.8	7.2	13.4	20.6
MY2020	4.8	5.4	10.2	4.8	6.6	11.5	5.0	12.3	17.3	7.2	15.3	22.5
MY2021	4.8	5.4	10.2	4.8	6.6	11.5	5.0	13.8	18.8	7.2	17.2	24.4
MY2022	4.8	5.4	10.2	4.8	6.6	11.5	5.0	13.8	18.8	7.2	17.2	24.4
MY2023	4.8	5.4	10.2	4.8	6.6	11.5	5.0	13.8	18.8	7.2	17.2	24.4
MY2024	4.8	5.4	10.2	4.8	6.6	11.5	5.0	13.8	18.8	7.2	17.2	24.4
MY2025	4.8	5.4	10.2	4.8	6.6	11.5	5.0	13.8	18.8	7.2	17.2	24.4

Indirect air conditioning emissions, or the additional load put on the engine by the operation of the air conditioning unit, were modeled similarly to the modeling in the MY 2012-2016 rulemaking, although with slightly different values. The credits for air conditioning efficiency improvements from the tables above (i.e. “indirect”) were applied directly to the two cycle emissions projected by OMEGA.

Air conditioning credits are modeled similarly to the MYs 2012-2016 rule and identically to the approach in the proposal, and their derivation is more fully described in TSD 5. In the impacts modeling, both credits are modeled as environmentally neutral, or that the impacts of the credits are larger than their 2 cycle credit values by the on-road gap. See TSD 5 for more details.

4.3.4.2 Reference Case

As described in RIA chapter 3 and Preamble III.D, we assume a flat reference case of MY 2016 standards. No additional compliance flexibilities which lead to environmental disbenefits were explicitly modeled for the MY 2016 standards. Compliance flexibilities such as the A/C credit and fleet averaging were included in the modeling. The EPA flexible fueled vehicle (FFV) credit expires before MY 2016.[DDDD] The Temporary Leadtime Allowance Alternative Standards (TLAAS), as analyzed in RIA chapter 5 of the MY 2012-2016 rule, is projected have an impact of approximately 0.1 g/mile in MY 2016, and (by rule) will expire afterwards. Therefore, no credits which lead to environmental disbenefits are projected to be available to the reference case. Off-cycle credits, which are designed to be environmentally neutral, would only lower costs. In a change from the proposal, as in the

[DDDD] The credit available for producing FFVs will have expired, although the real world usage credits will be available.

control case, two off-cycle credits were made available to vehicle manufacturers in our OMEGA modeling of the reference case (active aerodynamics and start-stop technology). These credits are considered environmentally neutral in our analysis, and are not modeled as having an impact on emissions or fuel savings.

Consistent with the MYs 2012-2016 rule analysis, EPA did not allow EVs and PHEVs (maximum penetration caps of zero) in the reference case. While the penetration of EVs and PHEVs in MY 2016 will like be non-zero, as they are being sold in MY 2011, EPA chose not to include these technologies in the reference case assessment due to their cost-distorting effects on the smallest companies. For further discussion see RIA Chapter 3.

As discussed above, no credits with environmental disbenefit are projected to be used after MY 2016 in the reference case. As manufacturers must comply with the EPA program[EEEE], the projected emission rates are simply the footprint of the projected fleet against the standard curves.[FFFF] CO_2 emission rates for MY 2016, 2021 and 2025 were taken from fleet projections against the curves. Two cycle CO_2 emission rates for the reference case are shown below, and continue changing on a fleet basis due to mix shifts (Table 4.3-9). As no EVs were modeled, there is no increase in electricity consumption in the reference case. The air conditioning impacts as discussed in Section 4.3.4.1 were also incorporated.

Table 4.3-9 – Reference Case Two Cycle CO_2

MY	Car	Truck	Fleet
2017	234	308	262
2018	234	308	261
2019	234	308	261
2020	234	308	260
2021	234	308	260
2022	234	308	260
2023	234	307	259
2024	234	307	259
2025	234	307	258

4.3.4.3 Control Case

MY 2017-2025 CO2 emission estimates were derived from the curves that determine the targets and from projected credit usage on an industry wide basis. These values slightly differ from those produced by the OMEGA modeling, which includes credit transfer between car and truck fleet, but the results should be environmentally equivalent due to the VMT- and sales-weighted components of that transfer. A/C refrigerant and efficiency credit estimates are discussed in Section4.3.4.1, while the methodology used to estimate the impact of the EV/PHEV/FCV multiplier credit and pickup related credits are discussed in following

[EEEE] There is no option for voluntary non-compliance (fine payment) under the EPA program.
[FFFF] These reference case rates are slightly more stringent than those modeled in the proposal, which were based on OMEGA model runs and had a slight shortfall (approximately 1 gram) relative to the standard.

sections. These estimates of total credit usage are summarized in Table 4.3-10 through Table 4.3-12. In the impacts modeling, off-cycle credits are modeled as environmentally neutral, or in other words, the credits were modeled so that the environmental benefits of the credits are larger than their 2 cycle values by the on-road gap.

The following three tables, Table 4.3-10 through Table 4.3-12, summarize EPA's projections of overall projected CO_2 emissions averages for passenger cars, light trucks, and the overall fleet combining passenger cars and light trucks for projected MYs 2017-2025 under the emission control case – ie the final rule. It is important to emphasize that these projections are based on technical assumptions by EPA about various matters, including the mix of cars and trucks, as well as the mix of vehicle footprint values, in the fleet in varying years. It is of course possible that the actual CO_2 emissions values, as well as the actual utilization of incentives and credits, will be either higher or lower than the EPA projections.[GGGG]

In each of these tables, the column "Projected CO_2 Compliance Target" represents our projected fleetwide average CO_2 compliance target value based on the CO_2-footprint curve standards as well as the projected mixes of cars and trucks and vehicle footprint distributions.

The columns under "Incentives" represent the projected emissions impact of the advanced technology multiplier incentive[HHHH], as well as the incentives for use of advanced technologies (both so-called 'game changing' technologies, and technologies providing comparable emission reductions) on pickup trucks. Also shown under incentives is the projected impact of the flexibilities provided to intermediate volume manufacturers (additional lead time to meet the early model year standards). These incentives allow manufacturers to meet their compliance targets with CO_2 emissions levels slightly higher than otherwise required , but do not reflect actual real-world CO_2 emissions reductions. As such they reduce the emissions reductions that the main CO_2 standards would otherwise be expected to achieve.

The column "Projected Achieved CO_2" is the sum of the CO_2 Compliance Target and the values in the "Incentive" columns. This Achieved CO_2 value is a better reflection of the CO_2 emissions benefits of the standards, since it accounts for the incentive programs.

One incentive that is not reflected in these tables is the 0 gram per mile compliance value for EV/PHEV/FCVs. The 0 gram per mile value accurately reflects the tailpipe CO_2 gram per mile achieved by these vehicles; however, fuel use from these vehicles will impact the overall GHG reductions associated with the standards due to fuel production and distribution-related upstream GHG emissions which are projected to be greater than the upstream GHG emissions associated with gasoline from oil. The combined impact of the 0

[GGGG] All EPA projections in the this chapter are relative to the MY 2008 market forecast ; see the EPA Regulatory Impact Analysis Chapter 10 for projections relative to a 2010-based reference fleet.
[HHHH] The advanced technology multiplier incentive applies to EVs, PHEVs, FCVs, and CNG vehicles. The projections reflect the use of EVs and PHEVs for MYs 2017-2021. It is, of course, possible that there will be FCVs and CNG vehicles during this timeframe as well.

gram per mile compliance value for EV/PHEV/FCVs and the advanced technology multiplier on overall program GHG emissions is discussed in more detail below in Preamble Section III.C.2.

The columns under "Credits" quantify the projected CO_2 emissions credits that we project manufacturers will generate through improvements in air conditioner leakage (including refrigerant substitution) and efficiency, as well as certain off-cycle technologies. These credits reflect real world emissions reductions, so they do not raise the levels of the Achieved CO_2 values, but they do allow manufacturers to meet their compliance targets with 2-cycle test CO_2 emissions values higher than otherwise apply. For the off-cycle credit program, values are projected for two technologies—active aerodynamics and stop-start systems—EPA is not quantifying the use of additional off-cycle technologies at this time because of a lack of information with respect to the likely use of additional off-cycle technologies. The off-cycle credits, like A/C credits, reflect real world reductions, so they would not change the Achieved CO_2 values.

In the MYs 2012-2016 rule, we estimated the impact of the Temporary Leadtime Allowance Alternative Standards credit in MY 2016 to be 0.1 gram/mile. Due to the small magnitude, we have not included this flexibility in the following tables for the MY 2016 base year.

The column "Projected 2-cycle CO_2" is the projected fleetwide 2-cycle CO_2 emissions values that manufacturers would have to achieve in order to be able to comply with the standards. This value is the sum of the projected fleetwide credit, incentive, and Compliance Target values. Table 4.3-10 EPA Projections for Fleetwide Tailpipe Emissions Compliance with CO_2 Standards – Passenger Cars[IIII]
(grams per mile)

		Incentives[JJJJ]		Projected	Credits			
Model Year	Projected CO_2 Compliance Target	Advanced Technology Multiplier	Intermediate Volume Provisions	Achieved CO_2	Off Cycle Credit	A/C Refrigerant	A/C Efficiency	Projected 2-cycle CO_2
2017	212	0.6	0.1	213	0.5	7.8	5.0	226
2018	202	1.1	0.3	203	0.6	9.3	5.0	218
2019	191	1.6	0.1	193	0.7	10.8	5.0	210
2020	182	1.5	0.1	183	0.8	12.3	5.0	201
2021	172	1.2	0.0	173	0.8	13.8	5.0	193
2022	164	0.0	0.0	164	0.9	13.8	5.0	184
2023	157	0.0	0.0	157	1.0	13.8	5.0	177
2024	150	0.0	0.0	150	1.1	13.8	5.0	170
2025	143	0.0	0.0	143	1.4	13.8	5.0	163

[IIII] Projected results using 2008-based fleet projection analysis. These values differ slightly from those shown in the proposal because of revisions to the MY 2008-based fleet and updates to the analysis.
[JJJJ] An incentive not reflected in this table is the 0 gram per mile compliance value for EV/PHEV/FCVs. See text for explanation.

Table 4.3-11 EPA Projections for Fleetwide Tailpipe Emissions Compliance with CO_2 Standards – Light Trucks[KKKK] (grams per mile)

		Incentives[LLLL]		Projected	Credits			
Model Year	Projected CO_2 Compliance Target	Pickup Mild HEV + Strong HEV	Intermediate Volume Provisions	Achieved CO_2	Off Cycle Credit	A/C Refrigerant	A/C Efficiency	Projected 2-cycle CO_2
2017	295	0.1	0.2	295	0.9	7	5	308
2018	286	0.2	0.3	287	1.0	11	5	304
2019	277	0.3	0.2	278	1.2	13.4	7.2	299
2020	269	0.4	0.2	270	1.4	15.3	7.2	294
2021	249	0.5	0.0	250	1.5	17.2	7.2	276
2022	237	0.6	0.0	238	2.2	17.2	7.2	264
2023	225	0.6	0.0	226	2.9	17.2	7.2	253
2024	214	0.7	0.0	214	3.6	17.2	7.2	242
2025	203	0.8	0.0	204	4.3	17.2	7.2	233

Table 4.3-12 EPA Projections for Fleetwide Tailpipe Emissions Compliance with CO2 Standards – Combined Passenger Cars and Light TrucksMMMM (grams per mile)

		Incentives[NNNN]			Projected	Credits			
Model Year	Projected CO_2 Compliance Target	Advanced Technology Multiplier	Pickup Mild HEV + Strong HEV	Intermediate Volume Provision	Achieved CO_2	Off Cycle Credit	A/C Refrigerant	A/C Efficiency	Projected 2-cycle CO_2
2017	243	0.4	0.0	0.1	243	0.6	7.5	5.0	256
2018	232	0.7	0.1	0.3	234	0.8	9.9	5.0	249
2019	222	1.0	0.1	0.1	223	0.9	11.7	5.8	242
2020	213	1.0	0.1	0.1	214	1.0	13.4	5.8	234
2021	199	0.8	0.2	-	200	1.1	15.0	5.8	222
2022	190	0.0	0.2	-	190	1.4	15.0	5.8	212
2023	180	0.0	0.2	-	181	1.7	15.0	5.8	203
2024	171	0.0	0.2	-	172	1.9	14.9	5.7	194
2025	163	0.0	0.3	-	163	2.3	14.9	5.7	186

[KKKK] Projected results using 2008-based fleet projection analysis. These values differ slightly from those shown in the proposal because of revisions to the MY 2008-based fleet and updates to the analysis.
[LLLL] An incentive not reflected in this table is the 0 gram per mile compliance value for EV/PHEV/FCVs. See text for explanation.
[MMMM] Projected results using 2008-based fleet projection analysis. These values differ slightly from those shown in the proposal because of revisions to the MY 2008-based fleet and updates to the analysis.
[NNNN] The one incentive not reflected in this table is the 0 gram per mile compliance value for EV/PHEV/FCVs. See text for explanation.

Mild and Strong HEV Pickup Credits

Between MY 2017 and MY 2025, full-size pickup sales vary as a fraction of the fleet sales as well as a fraction of light truck sales in the MY 2008 based market forecast.

Table 4.3-13 Pickup Trucks as a Fraction of the Fleet

Model Year	Projected Sales of Full Size Pickup Trucks	Pickup Trucks (of Trucks)	Pickup Trucks (of Fleet)	Trucks (of fleet)
2017	1,218,829	21%	8%	37%
2018	1,163,965	21%	8%	36%
2019	1,110,802	20%	7%	36%
2020	1,134,230	20%	7%	35%
2021	1,100,818	19%	7%	35%
2022	1,082,815	19%	7%	35%
2023	1,026,579	18%	6%	34%
2024	993,161	17%	6%	34%
2025	983,954	17%	6%	33%

Based on these fleet fractions, and the credit available, the maximum potential credit can be calculated.

Table 4.3-14 Maximum Potential Impact of Pickup Credits on Truck Fleet

Model Year	Mild HEV Credit	Mild HEV Maximum Potential Impact (Trucks)	Strong HEV Credit	Strong HEV Maximum Potential Impact (Trucks)
2017	10.0	2.1	20.0	4.2
2018	10.0	2.1	20.0	4.1
2019	10.0	2.0	20.0	4.0
2020	10.0	2.0	20.0	4.0
2021	10.0	1.9	20.0	3.9
2022	0.0	0.0	20.0	3.8
2023	0.0	0.0	20.0	3.6
2024	0.0	0.0	20.0	3.5
2025	0.0	0.0	20.0	3.4

Not every pickup truck will get these credits. Unlike in the proposal, where we post-processed these credits, we calculated these credits directly in the OMEGA model, based on the cost effectiveness of the full size pickup HEV packages (with full consideration of credits). See the earlier tables Table 4.3-10 through Table 4.3-12 used for the estimated values.

In the OMEGA runs conducted for this final rulemaking, we did not model the fleet minimums for either strong or mild HEV. This change would mildly overstate the impact of the credit. However, total usage of pickup truck credits had less than 1 gram of impact on the truck fleet achieved values in any given MY (Table 4.3-11).

Consumption of Electricity

Based on the OMEGA model outputs, we estimated electricity consumption and emission impacts from the consumption of electricity due to the electric vehicles and plug-in electric hybrids. EPA accounts for all electricity consumed by the vehicle. For calculations of GHG emissions from electricity generation, the total energy consumed from the battery is divided by 0.9 to account for charging losses, and by 0.93 to account for losses during transmission. Both values were discussed in the MYs 2012-2016 rule as well as in the Interim Joint TAR, and the final rule (and proposal) is unchanged from those analyses. The estimate of charging losses is based upon engineering judgment and manufacturer CBI. The estimate of transmission losses is consistent, although not identical to the 8% estimate used in GREET, as well as the 6% estimate in eGrid 2010.[51,52] The upstream emission factor is applied to total electricity production, rather than simply power consumed at the wheel.[OOOO] It is assumed that electrically powered vehicles drive the same drive schedule as the rest of the fleet.[PPPP]

Table 4.3-15 Average Electricity Consumption

	Average 2 cycle Electricity Consumption for the fleet (kwh/mile)	
Model Year	Cars	Trucks
2017	0.001	0.000
2018	0.001	0.000
2019	0.002	0.000
2020	0.002	0.000
2021	0.003	0.000
2022	0.004	0.000
2023	0.004	0.000
2024	0.005	0.000
2025	0.006	0.001

[OOOO] By contrast, consumer electricity costs would not include the power lost during transmission. While consumers indirectly pay for this lost power through higher rates, this power does not appear on their electric meter.

[PPPP] The validity of this assumption will depend on the use of electric vehicles by their purchasers.

EV/PHEV/FCVs multipliers

As discussed in Section III.B of the preamble, the compliance cap for EVs and PHEVs at zero g/mile is related to the standard level. For purposes of this modeling, we assume that this cap is never reached. This does not imply that EPA has finalized a cap based on this criteria. A discussion of the potential impacts of these credits can be found in preamble section III.C.2 and Section 4.5.2 of the RIA. Costs beyond MY 2025 assume no technology changes on the vehicles, and implicitly assume EVs used for compliance receive their tailpipe measurement of zero gram/mile.[QQQQ] Upstream emissions from electric vehicles, regardless of the zero-gram mile credit, are always modeled in this analysis.

For the analysis of impacts, we assumed the following penetration of electric vehicles, where the MY 2021 and MY 2025 values come from OMEGA, with the earlier and later values interpolated. As modeled, 2016 EV penetrations were set at 0% of the fleet.[RRRR] PHEV sales, as projected by OMEGA, are not significant.[SSSS]

Table 4.3-16 – EV Fraction of the MY Fleets

Model Year	Cars	Truck	EV multiplier
2017	0.3%	0.0%	2
2018	0.5%	0.0%	2
2019	0.8%	0.0%	2
2020	1.1%	0.0%	1.75
2021	1.4%	0.0%	1.5
2022	1.8%	0.1%	0
2023	2.2%	0.2%	0
2024	2.6%	0.2%	0
2025	3.0%	0.3%	0

The EV multiplier credit was calculated by following formula

Equation 10 – Impact of EV multiplier

GHG Target with multiplier = (GHG Target without multiplier * (Total MY Sales + Multiplier * Number of EV sales))/Total sales

[QQQQ] The costs for PHEVs and EVs in this rule reflect those costs discussed in Joint TSD Chapter 3, and do not reflect any tax incentives, as the availability of those tax incentives in this time frame is uncertain.
[RRRR] While the actual real world penetration of electric vehicles will be greater than 0% in 2016, for purposes of this rulemaking, we do not model any EVs or PHEVs in the reference case, as they are generally not needed for compliance. For further details, see EPA RIA Chapter 3.
[SSSS] Please note that the OMEGA technology projection for EVs and PHEVs does not include the multiplier provision. Including that provision would presumably increase EV penetration in the MYs 2017-2021 timeframe.

So for MY 2021, which had car sales of 10.5 million and a car GHG target of 172.8, the formula would yield

Equation 11 – Impact of EV multiplier: example

GHG Target with multiplier =

(172.1 * (10.5 million+ 1.5 * 1.4% EV sales * 10.5 million sales))/10.5 million sales

= 173.2 or a delta of 1.2 grams.

4.3.5 Emission Results

4.3.5.1 Calendar Year Analyses

Table 4.3-17 Detailed Impacts of Program on GHG Emissions (MMT CO2eq)

Calendar Year:	2020	2030	2040	2050
Net Delta[*]	-27	-271	-455	-569
Net CO_2	*-23*	*-247*	*-417*	*-522*
Net other GHG	*-4*	*-25*	*-38*	*-47*
Downstream	-22	-223	-374	-467
CO_2 (excluding A/C)	*-18*	*-201*	*-341*	*-428*
A/C – indirect CO_2	*-1*	*-3*	*-4*	*-5*
A/C – direct HFCs	*-3*	*-19*	*-28*	*-35*
CH_4 (rebound effect)	*0*	*0*	*0*	*0*
N_2O (rebound effect)	*0*	*0*	*0*	*0*
Gasoline Upstream	*-5*	*-57*	*-96*	*-121*
CO_2	*-5*	*-50*	*-84*	*-105*
CH_4	*-1*	*-7*	*-12*	*-15*
N_2O	*0*	*0*	*0*	*-1*
Electricity Upstream	1	9	15	19
CO_2	*1*	*7*	*13*	*16*
CH_4	*0*	*1*	*2*	*3*
N_2O	*0*	*0*	*0*	*0*

Table 4.3-18 Impacts of Program on GHG Emissions in all CYs

CY	CO2 (MMT)	HFC134a (MMT CO2eq)	CH4 (MMT CO2eq)	N2O (MMT CO2eq)	Total (MMT CO2eq)
2017	-2	0	0	0.0	-2
2018	-7	-1	0	0.0	-8
2019	-14	-2	0	0.0	-16
2020	-23	-3	-1	0.0	-27
2021	-37	-5	-1	0.0	-43
2022	-54	-7	-1	0.0	-63
2023	-75	-8	-2	0.0	-85
2024	-99	-10	-2	0.0	-111
2025	-125	-12	-3	-0.1	-140
2026	-151	-13	-4	-0.1	-167
2027	-176	-15	-4	-0.1	-195
2028	-200	-16	-5	-0.1	-221
2029	-224	-17	-5	-0.1	-247
2030	-247	-19	-6	-0.1	-271
2031	-268	-20	-6	-0.1	-295
2032	-289	-21	-7	-0.1	-317
2033	-309	-22	-7	-0.1	-338
2034	-327	-23	-8	-0.1	-358
2035	-344	-24	-8	-0.2	-377
2036	-361	-25	-8	-0.2	-394
2037	-376	-26	-9	-0.2	-411
2038	-391	-27	-9	-0.2	-427
2039	-404	-27	-9	-0.2	-441
2040	-417	-28	-10	-0.2	-455
2041	-429	-29	-10	-0.2	-468
2042	-440	-29	-10	-0.2	-480
2043	-451	-30	-10	-0.2	-492
2044	-462	-31	-11	-0.2	-504
2045	-472	-31	-11	-0.2	-515
2046	-482	-32	-11	-0.2	-526
2047	-492	-33	-11	-0.2	-537
2048	-502	-33	-12	-0.2	-548
2049	-512	-34	-12	-0.2	-558
2050	-522	-35	-12	-0.2	-569

Table 4.3-19 Annual Criteria Pollutant Emission Impacts of Program (short tons)

		CY 2020		CY 2030	
	Pollutant	Impacts (Short Tons)	% of Total US Inventory	Impacts (Short Tons)	% of Total US Inventory
Total	VOC	-11,712	-0.1%	-123,070	-1.0%
	CO	14,164	0.0%	224,875	0.4%
	NO_X	-904	0.0%	-6,509	-0.1%
	PM2.5	-136	0.0%	-1,254	0.0%
	SO_X	-1,270	0.0%	-13,377	-0.2%
Downstream	VOC	249	0.0%	4,835	0.0%
	CO	14,414	0.0%	227,250	0.4%
	NO_X	498	0.0%	8,281	0.1%
	PM2.5	40	0.0%	568	0.0%
	SO_X	-420	0.0%	-4,498	-0.1%
Fuel Production and Distribution	VOC	-12,043	-0.1%	-128,823	-1.0%
	CO	-749	0.0%	-8,009	0.0%
	NO_X	-1,757	0.0%	-18,795	-0.2%
	PM2.5	-280	0.0%	-3,000	-0.1%
	SO_X	-1,198	0.0%	-12,813	-0.2%
Electricity	VOC	81	0.0%	917	0.0%
	CO	499	0.0%	5,634	0.0%
	NO_X	355	0.0%	4,005	0.0%
	PM2.5	104	0.0%	1,179	0.0%
	SO_X	348	0.0%	3,933	0.0%

Table 4.3-20 Annual Air Toxic Emission Impacts of Program (short tons)

		CY 2020		CY 2030	
	Pollutant	Impacts (Short Tons)	% of Total US Inventory	Impacts (Short Tons)	% of Total US Inventory
Total	1,3- Butadiene	1	0.0%	25	0.2%
	Acetaldehyde	3	0.0%	57	0.1%
	Acrolein	0	0.0%	2	0.0%
	Benzene	-16	0.0%	-101	0.0%
	Formaldehyde	-7	0.0%	-43	0.0%
Downstream	1,3- Butadiene	1	0.0%	28	0.2%
	Acetaldehyde	4	0.0%	70	0.1%
	Acrolein	0	0.0%	3	0.0%
	Benzene	8	0.0%	160	0.1%
	Formaldehyde	3	0.0%	66	0.0%
Fuel Production and Distribution	1,3- Butadiene	0	0.0%	-2	0.0%
	Acetaldehyde	-1	0.0%	-14	0.0%
	Acrolein	0	0.0%	-2	0.0%
	Benzene	-24	0.0%	-261	-0.1%
	Formaldehyde	-10	0.0%	-110	-0.1%
Electricity	1,3- Butadiene	0	0.0%	0	0.0%
	Acetaldehyde	0	0.0%	1	0.0%
	Acrolein	0	0.0%	1	0.0%
	Benzene	0	0.0%	0	0.0%
	Formaldehyde	0	0.0%	1	0.0%

4.3.5.2 Model Year Lifetime Analyses

Table 4.3-21 Projected Net GHG Deltas (MMTCO$_2$eq per model year lifetime)

MY	Downstream	Upstream (Gasoline)	Electricity	Total CO2e
2017	-25	-6	1	**-30**
2018	-58	-14	2	**-70**
2019	-89	-21	3	**-108**
2020	-124	-29	4	**-149**
2021	-178	-43	5	**-216**
2022	-222	-55	7	**-270**
2023	-262	-66	9	**-320**
2024	-304	-78	11	**-371**
2025	-347	-90	14	**-423**
Total	-1,610	-402	57	**-1,956**

Table 4.3-22 Projected Net Non-GHG Deltas

Criteria Emission Impacts of Program (short tons)					
MY	VOC	CO	NOx	PM2.5	SO2[TTTT]
2017	-12,972	36,172	-258	-102	-1,446
2018	-28,424	78,396	-625	-245	-3,247
2019	-44,042	120,847	-991	-384	-5,047
2020	-61,383	167,694	-1,404	-539	-7,042
2021	-90,206	243,828	-2,366	-884	-10,672
2022	-115,470	311,003	-2,861	-1,075	-13,471
2023	-138,798	372,813	-3,216	-1,219	-15,947
2024	-163,022	436,805	-3,561	-1,358	-18,479
2025	-187,348	500,822	-3,871	-1,484	-20,972
Sum	-841,664	2,268,380	-19,151	-7,292	-96,322
Model Year Lifetime Air Toxic Emissions (short tons)					
MY	Benzene	1,3 Butadiene	Formaldehyde	Acetaldehyde	Acrolein
2017	7	5	2	13	1
2018	14	12	3	27	1
2019	21	18	5	42	2
2020	29	25	6	58	2
2021	38	36	8	84	3
2022	48	46	10	107	4
2023	58	55	11	128	5
2024	69	64	13	150	6
2025	79	73	14	171	7
Sum	364	332	72	778	33

4.3.6 Fuel Consumption Impacts

The fuel consumption analyses relied on the same set of fleet and activity inputs as the emission analysis. Because the OMEGA modeled penetrations of diesel technology are small (<1% in MY 2025), EPA modeled the entire fleet as using petroleum gasoline, and used a conversion factor of 8887 grams of CO_2 per gallon petroleum gasoline in order to determine the quantity of fuel savings. The term petroleum gasoline is used here to mean fuel with 115,000 BTU/gallon. This is different than retail fuel, which is typically blended with ethanol and has a lower energy content.[UUUU] This topic is further discussed in Joint TSD 4. A brief memorandum discussing the differences in the agencies' calendar year analyses have been placed in the EPA docket.

[TTTT] Note that one source of SO_2 emission reductions are a result of the reduction in gasoline fuel use. Existing EPA regulations require that highway gasoline fuel must not contain more than 80ppm sulfur, and the average content must be 30ppm sulfur.

[UUUU] EPA similarly assumes a value of 10,180 grams of CO2 per gallon of diesel fuel.

Table 4.3-23 Calendar Year Fuel Consumption Impacts

CY	Fuel Delta (Billion Gallons petroleum gasoline)	Fuel Delta (Billion Barrels petroleum gasoline)	Electricity Delta (Billion kwh)
2017	0	0.0	0
2018	-1	0.0	0
2019	-1	0.0	1
2020	-2	-0.1	1
2021	-3	-0.1	2
2022	-5	-0.1	3
2023	-7	-0.2	4
2024	-9	-0.2	6
2025	-12	-0.3	7
2026	-14	-0.3	9
2027	-16	-0.4	10
2028	-19	-0.4	12
2029	-21	-0.5	14
2030	-23	-0.5	15
2031	-25	-0.6	17
2032	-27	-0.6	18
2033	-29	-0.7	19
2034	-30	-0.7	20
2035	-32	-0.8	22
2036	-34	-0.8	23
2037	-35	-0.8	24
2038	-36	-0.9	25
2039	-38	-0.9	26
2040	-39	-0.9	27
2041	-40	-1.0	27
2042	-41	-1.0	28
2043	-42	-1.0	29
2044	-43	-1.0	29
2045	-44	-1.0	30
2046	-45	-1.1	31
2047	-46	-1.1	31
2048	-47	-1.1	32
2049	-48	-1.1	33
2050	-49	-1.2	33
Sum 2017-2050	-903	-22	607

Table 4.3-24 Model Year Fuel Consumption Impacts

MY	Fuel Delta (Billion Gallons petroleum gasoline)	Fuel Delta (Billion Barrels petroleum gasoline)	Electricity Delta (Billion kwh)
2017	-3	-0.1	2
2018	-5	-0.1	3
2019	-9	-0.2	5
2020	-12	-0.3	7
2021	-17	-0.4	9
2022	-22	-0.5	13
2023	-27	-0.6	16
2024	-31	-0.7	20
2025	-36	-0.9	24
Sum	-163	-3.9	100

4.3.7 GHG and Fuel Consumption Impacts from Alternatives

Table 4.3-25 Calendar Year Impacts of Alternative Scenarios

	GHG Delta (MMT2 CO2eq)				Fuel Savings (B. Gallons petroleum gasoline)			
Scenario	2020	2030	2040	2050	2020	2030	2040	2050
Primary	-27	-271	-455	-569	-2	-23	-39	-49
A - Cars +20 g/mile	-19	-223	-382	-480	-1	-18	-32	-40
B - Cars -20 g/mile	-34	-311	-514	-641	-3	-28	-46	-58
C - Trucks +20 g/mile	-27	-249	-420	-526	-2	-21	-36	-45
D - Trucks -20 g/mile	-36	-294	-484	-604	-3	-25	-42	-53

Table 4.3-26 Model Year Lifetime Impacts of Alternative Scenarios (Summary of MY 2017-MY2025)

	Total CO2e	Fuel Delta (b gal petroleum gasoline)	Fuel Delta (b. barrels petroleum gasoline)
Primary	-1,956	-163	-3.9
A - Cars +20 g/mile	-1,537	-122	-2.9
B - Cars -20 g/mile	-2,314	-200	-4.8
C - Trucks +20 g/mile	-1,781	-146	-3.5
D - Trucks -20 g/mile	-2,231	-189	-4.5

4.4 Safety Analysis

As described in Preamble Section II.G and RIA Chapter 3, EPA used the OMEGA model to conduct a similar analysis of the impacts of mass reduction on vehicle safety. After applying these percentage increases to the estimated weight reductions per vehicle size by model year assumed in the OMEGA model, Table 6-6 shows the results of EPA's safety analysis separately for each model year. These are estimated increases or decreases in fatalities over the lifetime of the model year fleet. A positive number means that fatalities are projected to increase; a negative number means that fatalities are projected to decrease. For details, see the EPA RIA Chapter 3.

Table 4.4-1 – Summary of Fatality Analysis

		MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	Total
Reference Case	Passenger cars	61	61	63	66	69	71	73	76	78	618
	Light trucks	-105	-101	-99	-99	-100	-100	-100	-100	-101	-905
	Total	-44	-40	-36	-33	-31	-29	-27	-24	-22	-286
Control Case	Passenger cars	65	71	78	86	95	101	108	115	123	842
	Light trucks	-110	-112	-115	-121	-128	-141	-152	-164	-178	-1,222
	Total	-45	-41	-38	-35	-34	-40	-45	-49	-55	-381
Delta	Passenger cars	5	9	14	20	26	30	35	40	45	223
	Light trucks	-5	-11	-16	-22	-29	-40	-52	-64	-77	-317
	Total	-1	-1	-2	-2	-3	-10	-18	-25	-32	-94

4.5 Sensitivity Cases

4.5.1 Rebound

EPA conducted a sensitivity analysis regarding the GHG and fuel savings benefits of the program under different rebound rates.

As discussed in TSD 4, the rebound effect refers to the increase in vehicle use that results if an increase in fuel efficiency lowers the cost per mile of driving, which can encourage people to drive slightly more. The rebound effect is measured directly by estimating the change in vehicle use, often expressed in terms of vehicle miles traveled (VMT), with respect to changes in vehicle fuel efficiency.[VVVV] However, it is a common practice in the literature to measure the rebound effect by estimating the change in vehicle use with respect to the fuel cost per mile driven, which depends on both vehicle fuel efficiency and fuel prices.[WWWW] When expressed as a positive percentage, these two parameters give the ratio of the percentage increase in vehicle use that results from a percentage increase in fuel efficiency or reduction in fuel cost per mile, respectively. For example, the 10 percent rebound effect we assume in this final rulemaking means that a 10 percent decrease in fuel cost per mile is expected to result in a 1 percent increase in VMT.[XXXX]

Table 4.5-1 – Rebound Sensitivity Results

	MY Lifetime 2017-2025		CY 2030	
Rebound Rate	GHG Benefits (MMT CO2e)	Fuel Savings (B. Gallons)	GHG Benefits (MMT CO2e)	Fuel Savings (B. Gallons)
0%	2,115	176	292	25
5%	2,035	169	282	24
10%	1,956	163	271	23
15%	1,877	156	261	22
20%	1,798	149	250	21

4.5.2 EV impacts

In section III.C.2 of the preamble, as in the NPRM, EPA presents an analysis of the GHG impacts of the EV zero gram/mile and EV/PHEV multiplier impacts on the cumulative

[VVVV] Vehicle fuel efficiency is more often measured in terms of fuel consumption (gallons per mile) rather than fuel economy (miles per gallon) in rebound estimates.

[WWWW] Fuel cost per mile is equal to the price of fuel in dollars per gallon divided by fuel economy in miles per gallon (or multiplied by fuel consumption in gallons per mile), so this figure declines when a vehicle's fuel efficiency increases.

[XXXX] Please note that increasing VMT by 1% in response to a 10% decrease in fuel cost per mile is not equivalent to decreasing the benefits from the rule by 1% due to the decreased fuel consumption and GHG emissions in the control case. To a lesser extent, the issue is also complicated due to compliance strategies that do not directly impact fuel cost per mile, such as HFC emission reduction strategies, and the use of electric vehicles for compliance, which do not reduce cost per mile to the same extent that gasoline technologies do.

GHG savings from the fleet. This projection of the impact of the EV/PHEV/FCV incentives on the overall program GHG emissions reductions assumes that EPA would have finalized exactly the same standard if the 0 gram per mile compliance value were not allowed for any EV/PHEV/FCVs. While EPA has not analyzed such a scenario, not allowing a 0 gram per mile compliance value would change the technology mix and cost projected for the standard.

To conduct this analysis, EPA first ran the OMEGA model post-processor assuming that no vehicles operated on wall electricity. The OMEGA scenario results were drawn from the primary analysis, but were adjusted as for a different ratio of EVs and PHEVs, as discussed below. The sensitivity scenario, involving 2 million EVs and PHEVs sold from 2022-2025, was modeled through the same method as the proposal. The EV phase in schedule from the primary scenario was multiplied by ~1.82 in order to produce the phase-in corresponding to 2.0 million EVs sold in 2022-2025. 2 cycle performance was then adjusted accordingly for the multiplier credits and electricity usage was included in the accounting.

As in the proposal, for this analysis, we assumed that 50% of the plug-in vehicles would be PHEVs, and subtracted 25% from the total impacts of the EVs and PHEVs in order to approximate the lesser reliance of PHEVs on electric power.

If EPA established the exact same tailpipe standards, and provided no additional flexibilities, the program impacts would be estimated at 2,032 MMT between MY 2017 and MY 2025 if there were no electric vehicles or plug-in electric vehicles used for compliance.

Scenario	Cumulative EV/PHEV sales MYs 2017-2025	Cumulative EV/PHEV sales MYs 2022-2025	Cumulative Decrease in GHG Emission Reductions MYs 2017-2025	Percentage Decrease in GHG Emission Reductions MYs 2017-2025
No EV/PHEVs	0	0	0	0
EPA OMEGA model Projection	1.5 million	1.1 million	56 MMT	2.7%
Sensitivity Scenario	2.8 million	2.0 million	101 MMT	5.0%

4.6 Inventories Used for Non-GHG Air Quality Modeling

Because air quality analysis requires emission inventories with greater geographical resolution than the national inventories described above, these air quality inventories were developed separately. For this analysis, we needed three air quality inventories: a 2005 baseline inventory, a 2030 reference inventory and a 2030 control inventory. As described above, the sectors that are impacted by the rule are the “downstream” emissions from light-duty onroad vehicles affected directly by the regulations and the “upstream” emissions that are affected by changes in fuel usage. Other sectors are not changed by the rule and are described in a technical support document.[53]

4.6.1 Onroad Vehicles

As summarized in Section 4.3.1, non-GHG emissions from light duty vehicles are affected by rebound VMT and by reduced fuel consumption. For the air quality inventories (except refueling as described below), we modeled these effects using existing air quality inventories created for the Heavy Duty Greenhouse Gas rule signed August 9, 2011.[54] This allowed us to account for the impacts of the HDGHG rule in both our control and reference case. In particular, for the 2005 base case, we used the 2005 base case emissions from the HDGHG analysis and for the 2030 reference case, we used the control case from the HDGHG analysis. For the 2030 control case for this rule, we modified the HDGHG control case to account for rebound and fuel consumption effects.

To model the effect of rebound on non-GHG emissions, we started with the VMT changes by model year and vehicle type as predicted in the VMT equation in Section4.3.2.3. For each model year and vehicle type, the multiplicative change in VMT due to rebound was multiplied by emissions by model year (from a 2030 national default run of the MOVES2010a model) to estimate the predicted new emissions for each pollutant. These original emissions and the new emissions were summed across all model years and the ratio of the two totals was computed for each pollutant and vehicle type. This ratio was then applied to the grid-level reference inventory for running emissions, start emissions, brake wear and tire wear. No rebound effect was applied to vapor venting, permeation or liquid leak emissions.

Similarly, the effect of reduced fuel consumption on emissions of sulfate and sulfur dioxide was estimated by model year and applied to MOVES2010b results by model year. The emissions were summed and the ratio of the resulting emissions was applied to the grid-level reference inventories for these pollutants.

The effect of reduced fuel consumption on refueling emissions was calculated separately. A modified draft version of MOVES2010b was run to generate reference and control refueling emissions at the national level, The reference case emissions were generated using VMT and energy consumption estimates from the analysis for the rule. The calculated effects of these changes at the national level were then applied to county-level emissions calculated by running a draft version of MOVES2010b at the county-month level.

These impacts are summarized in Table 4.6-1 below.

Table 4.6-1 Air Quality Inventory Impacts for Vehicle Emissions (2030)

Pollutant	Reference	Control	Difference	Percent Difference
$PM_{2.5}$	58100	56794	-1306	-2.2%
PM_{10}	121011	120504	-507	-0.4%
NO_X	1609568	1618449	8881	0.6%
VOC	935118	941090	5972	0.6%
CO	18023434	18278399	254965	1.4%
SO_X	22742	18625	-4117	-18.1%
NH_3	95331	96909	1578	1.7%
Acetaldehyde	9677	9752	75	0.8%
Acrolein	746	750	3	0.5%
Benzene	19284	19483	199	1.0%
1,3-Butadiene	3064	3098	34	1.1%
Formaldehyde	15713	15785	72	0.5%

4.6.2 Fuel Production and Distribution

In addition to the effects of improved fuel economy on emissions from vehicles and equipment, and EGU emissions associated with increases in electric vehicles, there are reductions in emissions associated with domestic crude production and transport, petroleum refineries, production of energy for refinery use, vapor losses from transfer and storage of gasoline and gasoline/ethanol blends, and combustion emissions associated with transport of gasoline from refineries to bulk terminals and bulk terminals to service stations. The air quality inventories for this rule account for all these impacts except for combustion emissions associated with transport of crude oil.

4.6.2.1 Domestic Crude Production and Losses During Transport to Refineries

To obtain the reference case inventory, we applied adjustments to emissions from the version 4 2005-based EPA air quality modeling platform,[YYYY] to account for the impacts of medium- and heavy-duty greenhouse gas emissions and fuel efficiency standards. The

[YYYY] The air quality modeling platform represents a structured system of connected modeling-related tools and data that provide a consistent and transparent basis for assessing the air quality response to projected changes in emissions. The 2005-based CMAQ modeling platform was developed by the U.S. EPA's Office of Air Quality Planning and Standards in collaboration with the Office of Research and Development and is intended to support a variety of regulatory and research model applications and analyses.

platform assumed implementation of 2012-2016 light-duty vehicle fuel economy standards. The control case inventory reflects the emission standards being finalized in this rule.[ZZZZ]

Consistent with the regulatory impact analysis for the recent EPA final rule establishing greenhouse gas emissions standards for medium- and heavy-duty engines and vehicles,[55] we assumed 50% of the change in gasoline and diesel supply was projected to come from domestic refineries, and (b) 10% of the change in crude being used by domestic refineries would be domestic crude. Using the assumption that 1.0 gallon less of gasoline equates to approximately 1.0 gallon less crude throughput, the reduction in crude extraction and transport from this rule would equal about 5% of the change in gasoline volume. Since the reduction in fuel consumption is estimated at 6.02 billion gallons for the medium- and heavy-duty greenhouse gas rule and 31.6 billion gallons for this rule, the reduction in crude production is about 0.3 billion gallons for the medium and heavy-duty rule and 1.58 billion gallons for this rule. To generate the emission inventory adjustment factors for air quality modeling these reductions were applied to the projected crude supply of 230 billion gallons to US refineries in 2030, per AEO 2011.[56] Thus, the adjustment factors are 0.13% and 0.68% for the two rules, respectively.

4.6.2.2 Petroleum Production and Refining Emissions

The petroleum refinery inventory in the modeling platform was adjusted to account for the impacts of ethanol production due to EISA and medium- and heavy-duty greenhouse gas emissions and fuel efficiency standards. The impacts spreadsheet, originally developed for the RFS2 rule, was used to develop these adjustments.[57,58] This spreadsheet uses emission factors and changes in fuel volumes and energy throughput to estimate total nationwide emission impacts on refinery emissions associated with gasoline and diesel production. This spreadsheet estimated that refinery emissions associated with gasoline and diesel production would decrease by 12% as a result of the greenhouse gas emissions standards and fuel efficiency standards for medium- and heavy-duty engines and vehicles, and another 21% as a result of the standards in this rule. 76% of refinery emissions in the modeling platform were estimated to be the result of gasoline and diesel production, based on petroleum refinery output estimates from Energy Information Administration and emission rates associated with producing various refinery products obtained from GREET 2011.[59,60] The impacts of decreased production were applied only to the portion of refinery emissions associated with gasoline and diesel production. They were also assumed to be spread evenly across all U. S. refineries.

4.6.2.3 Production of Energy for Refinery Use

The fuel efficiency standards being finalized in this rule not only impact on-site refinery emissions, but also emissions upstream of refineries associated with producing the

[ZZZZ] The reference case inventories for these sources do not account for the increased ethanol production impacts of EISA. However, these sources are a minor portion of gasoline and diesel related air emissions, and do not meaningfully impact the delta between the cases.

energy they use. Refineries rely on upstream energy from residual oil, natural gas, coal and electricity.

GREET 1.8.c was used to adjust emission factors for refinery upstream emissions in the impacts spreadsheet, with adjustments to emission rates for electricity to reflect the incremental mix of EGU energy feedstocks assumed in the IPM analysis discussed in Section 4.6.3. Table 4.6-2 summarizes the emission rates for refinery upstream emissions in the impacts spreadsheet, and percent of emission rates attributable to each type of input energy.

Table 4.6-2 Refinery Energy Use

		Percent of Emission Rates from Energy Feedstocks			
Pollutant	Emission Rate (g/mmBTU)	Residual Oil	Natural Gas	Coal	Electric
VOC	0.622	5	45	26	24
CO	1.069	5	38	5	52
NO_x	2.960	7	40	11	42
PM_{10}	4.445	0	1	85	14
$PM_{2.5}$	1.158	1	2	81	16
SO_x	2.398	4	28	8	60

Table 4.6-3 presents the emission impacts for upstream refinery emissions. Along with nationwide emissions for sources associated with producing these energy feedstocks in the modeling platform, these impacts were used to develop nationwide scalars which were applied to county and facility level emission estimates. The scalars used are given in Table 4.6-3 as well. It should be noted that the emission totals in the platform that scalars were applied to reflect only point and nonpoint sources directly associated with producing these energy feedstocks, and do not include emissions upstream of the feedstocks or from nonroad equipment used in mining or natural gas extraction that may be accounted for in the impacts spreadsheet.

Table 4.6-3 Upstream Refinery Emission Impacts in Tons and Inventory Scalars

	Residual Oil Production		Natural Gas Production		Coal Production		Electricity Production	
Pollutant	Impact	Scalar	Impact	Scalar	Impact	Scalar	Impact	Scalar
VOC	-51	0.9992	-474	0.9883	-270	0.9026	-252	0.9951
CO	-93	0.9990	-676	0.9758	-97	0.9817	-932	0.9991
NO_x	-351	0.9943	-2010	0.9583	-551	0.9136	-2070	0.9989
PM_{10}	-36	0.9997	-51	0.9199	-6366	0.7195	-1027	0.9966
$PM_{2.5}$	-17	0.9990	-39	0.9353	-1584	0.7874	-309	0.9987
SO_x	-179	0.9913	-1168	0.9753	-325	0.8947	-2482	0.9988

4.6.2.4 Gasoline Transport, Storage and Distribution Emissions

Non-Combustion Emissions

VOC and benzene emissions are produced by transfer and storage activities associated with distribution of gasoline. These are referred to as Stage I emissions. Stage I distribution begins at the point the fuel leaves the production facility and ends when it is loaded into the storage tanks at dispensing facilities. It does not include emissions associated with refueling vehicles.

There are five types of facilities that make up this distribution chain for gasoline. Bulk gasoline terminals are large storage facilities that are either collocated at refineries or receive gasoline directly from the refineries via pipelines, barges, or tankers. Gasoline from the bulk terminal storage tanks is loaded into cargo tanks (tank trucks or railcars) for distribution to smaller intermediate storage facilities (bulk plants), or directly to gasoline dispensing facilities (retail public service stations and private service stations). When ethanol is blended into gasoline it usually occurs in the pipes which supply cargo tanks at bulk terminals.

Bulk plants are intermediate storage and distribution facilities that normally receive gasoline or gasoline/ethanol blends from bulk terminals via tank trucks or railcars. Gasoline and gasoline/ethanol blends from bulk plants are subsequently loaded into tank trucks for transport to local dispensing facilities.

Gasoline and gasoline/ethanol blend dispensing facilities include both retail public outlets and private dispensing operations such as rental car agencies, fleet vehicle refueling centers, and various government motor pool facilities. Dispensing facilities receive gasoline and gasoline/ethanol blends via tank trucks from bulk terminals or bulk plants. Inventory estimates for this source category only include the delivery of gasoline at dispensing facilities and does not include the vehicle or equipment refueling activities.

Emissions from a version of the platform inventory adjusted to account for ethanol production impacts of EISA were used to develop the reference and control case inventories. Emissions were first partitioned into a refinery to bulk terminal component (RBT), a bulk plant storage (BPS) component, and a bulk terminal to gasoline dispensing pump (BTP) component. One set of scalars was applied to RBT/BPS emissions and another to BTP emissions. These scalars are provided in Table 4.6-4. The scalars for BTP emissions reflect the change in total gasoline plus ethanol volume in gasoline and gasoline/ethanol blends. However, it does not account for changes in gasoline/ethanol blends used. Impacts were assumed to be spread evenly across the U. S.

Table 4.6-4 Scalars Applied to Base Inventory (2005 Platform with EISA Impacts) to Obtain Reference and Control Case Gasoline Storage, Transport and Distribution Emissions

Process	Reference Case (Impacts of Medium- and Heavy-Duty Greenhouse Gas Rule)	Control Case (Impacts of Medium- and Heavy-Duty Greenhouse Gas Rule Plus this Rule)
Refinery to Bulk Terminal/ Bulk Plant Storage	0.9972	0.7944
Bulk Terminal to Pump	0.9976	0.8234

Combustion Emissions

In addition to non-combustion emissions associated with storage, transport and distribution, there are combustion emissions associated with transport of gasoline by pipeline, commercial marine vessel, rail, and tanker truck. Overall impacts of the rule on combustion emissions associated with transport were estimated using the impacts spreadsheet. The overall impacts were allocated to transport mode using nationwide emission fractions from GREET 1.8.c. GREET provides emission fractions by transport mode for conventional gasoline, Federal reformulated gasoline, and California reformulated gasoline. These were weighted together using fuel sales volumes developed for highway vehicle modeling based on data from the Energy Information Administration.[61]

Emission impacts by transport mode were then applied to total emissions from transport sources to develop scaling factors. However, SO_x emission impacts for heavy-duty trucks, commercial marine vessels and locomotives were unreasonably high relative to the total inventory; thus, we estimated scalars for this pollutant based on the average scalars for other pollutants.

For pipelines, due to the difficulty in isolating the emissions along pipelines from pumps and other equipment by SCC, we assigned impacts to refinery and bulk terminal SCCs. Rail transport impacts were assigned to emissions from Class I and II line-haul locomotives, commercial marine impacts to C1 and C2 marine vessels, and tanker truck impacts to Class 8 heavy-duty diesel vehicle emissions. Emission inventory impacts and inventory scalars are given in Table 4.6-5.

Table 4.6-5 Gasoline Transport Combustion Emission Impacts in Tons and Inventory Scalars

	Commercial Marine Vessels		Pipelines		Rail		Truck	
Pollutant	Impact	Scalar	Impact	Scalar	Impact	Scalar	Impact	Scalar
VOC	-159	0.9776	-287	0.9959	-46	0.9966	-84	0.9979
CO	-532	0.9962	-1447	0.9864	-377	0.9979	-241	0.9988
NO_x	-1989	0.9933	-6137	0.9192	-859	0.9976	-609	0.9985
PM_{10}	-76	0.9926	-241	0.9895	-30	0.9958	-61	0.9936
$PM_{2.5}$	-63	0.9936	-130	0.9932	-22	0.9969	-31	0.9968
SO_x	-32	0.9907	-1292	0.9890	-1	0.9969	-172	0.9971

4.6.2.5 Fuel Production and Distribution Summaries

Table 4.6-6 provides 2030 air quality inventory impacts for fuel production and distribution. Table 4.6-7 and Table 4.6-8 provide the percentage of these impacts by source category. These impacts do not include combustion emission reductions for tanker trucks; those impacts are reflected in the highway vehicle inventory totals. They also do not include impacts on emissions from production of electricity used at refineries.

Table 4.6-6 Air Quality Inventory Impacts for Fuel Production and Distribution (2030)

Pollutant	**Tons**	**Percent of Total Upstream Inventory**
$PM_{2.5}$	-3663	0.2
PM_{10}	-8509	0.4
NO_X	-18391	0.3
VOC	-149398	1.7
CO	-13918	0.1
SO_X	-14748	0.3
NH_3	0	0
Acetaldehyde	-22	0.05
Acrolein	-1	0.02
Benzene	-1503	1.3
1,3-Butadiene	-2	0.04
Formaldehyde	-720	0.2

Table 4.6-7 Percent Contribution by Source Category to Reduction in Fuel Production and Distribution Emissions by Source Category in 2030

Source	VOC	CO	NO_x	PM_{10}	$PM_{2.5}$	SO_x	NH_3
Crude Oil Production and Transport	0.9	0	0	0	0	0	0
Petroleum Production and Refining	4.8	89.3	75.0	30.4	56.6	89.7	0
Production of Energy for Refinery Use	0.3	4.0	8.6	68.5	41.1	10.1	0
Gasoline Transport, Storage and Distribution, Non-Combustion	93.9	0	0	0	0	0	0
Gasoline Transport, Storage and Distribution, Combustion from Locomotive and Marine Engines	0.1	6.7	16.4	1.1	2.3	0.2	0

Table 4.6-8 Percent Contribution by Source Category to Reduction in Fuel Production and Distribution Emissions by Source Category in 2030 (continued)

Source	1,3-Butadiene	Acetaldehyde	Acrolein	Benzene	Formaldehyde
Crude Oil Production and Transport	0	**0.1**	**0**	0.7	0.1
Petroleum Production and Refining	90.4	10.8	24.8	26.5	93.2
Production of Energy for Refinery Use	1.1	12	1.2	0.6	1.5
Gasoline Transport, Storage and Distribution, Non-Combustion	0	0	0	71.8	0
Gasoline Transport, Storage and Distribution, Combustion from Locomotive and Marine Engines Combustion	8.5	77.1	74.0	0.3	5.3

4.6.3 Estimate of Emissions from Changes in Electricity Generation

4.6.3.1 The IPM model

As is typical in EPA air quality modeling, we used the Integrated Planning Model (IPM) to estimate upstream emissions from electric power plants. In this case, we ran two scenarios, with a reference scenario based upon the IPM Final Mercury and Air Toxics Standards (MATS)[62] and another with additional load associated with electric vehicle charging in the FRM. This differs from the NPRM, where we estimated impacts based on national average emissions.[63]

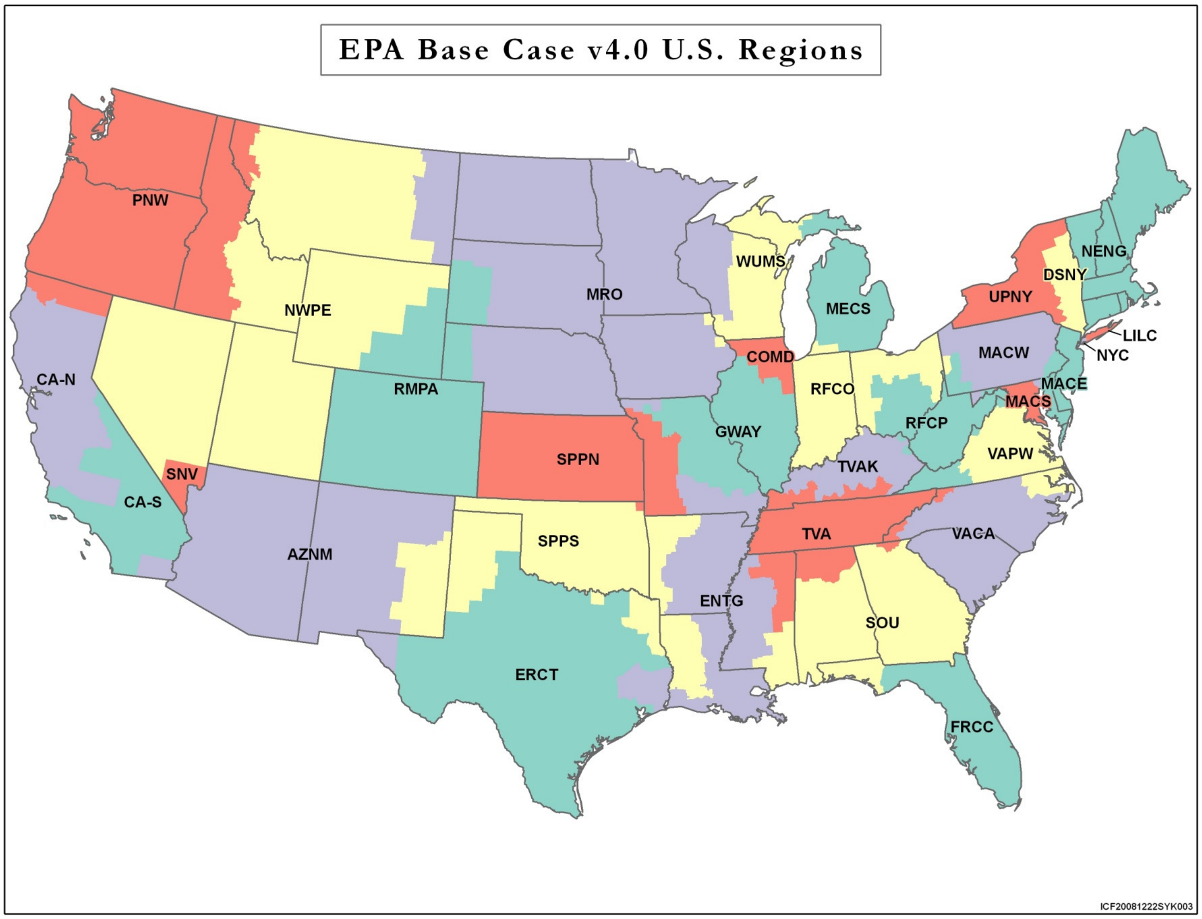
While this section is not intended to be a thorough discussion of the IPM, additional information can be seen at the EPA IPM website, and in the model documentation.[64]

EPA uses IPM to analyze the projected impact of environmental policies on the electric power sector in the 48 contiguous states and the District of Columbia. IPM is a multi-regional, dynamic, deterministic linear programming model of the U.S. electric power sector. It provides forecasts of least-cost capacity expansion, electricity dispatch, and emission control strategies for meeting energy demand and environmental, transmission, dispatch, and reliability constraints. IPM can be used to evaluate the cost and emissions impacts of proposed policies to limit emissions of sulfur dioxide (SO2), nitrogen oxides (NOx), carbon dioxide (CO2), and mercury (Hg) from the electric power sector. The model is used by EPA for rulemaking purposes and has been used to support analysis for the Cross-State Air Pollution Rule (CSAPR),[65], as well as the proposed EGU GHG NSPS[66], Final Mercury and Air Toxics Standards (MATS),[67] and Climate Change and Multi-Pollutant Legislative Proposals.[68]

IPM generates optimal decisions under the assumption of perfect foresight, determining the least-cost method of meeting energy and peak demand requirements over a specified period (e.g. 2010 to 2030). In its solution, the model considers a number of key operating or regulatory constraints (e.g. emission limits, transmission capabilities, renewable generation requirements, fuel market constraints) that are placed on the power, emissions, and fuel markets.

IPM represents the U.S. electric power grid through 32 model regions that are geographical entities with distinct characteristics (See Figure 4.6-9). For example, the model regions representing the U.S. power market correspond broadly to regions and sub-regions constituting the North American Electric Reliability Council (NERC) regions as well as with the organizational structures of the Regional Transmission Organizations (RTOs) and Independent System Operators, which handle dispatch on most of the U.S. grid. In some cases, these NERC regions are further subdivided in IPM into sub-regions to provide higher resolution. For instance, NERC depicts much of the Western U.S. as a single region, the Western Electricity Coordinating Council (WECC), whereas IPM depicts this region as several distinct sub-regions, such as Northern California, Southern California, the Pacific Northwest, and Arizona and New Mexico. Each of these IPM region have its own set of unique electric power generations characteristics and electricity transmission limitations. For instance, unlike neighboring regions, much electricity generated in the Pacific Northwest comes from hydroelectric power plants. As such, this region is modeled differently than Southern California, which imports much of its electricity from Arizona and Nevada. However, electricity transmission from Nevada to Southern California is limited by number and size of high voltage electric power lines strung across the adjacent mountain ranges.

Figure 4.6-9 IPM regions comprising the U.S.



4.6.3.2 Dispatch method as compared to a national average method

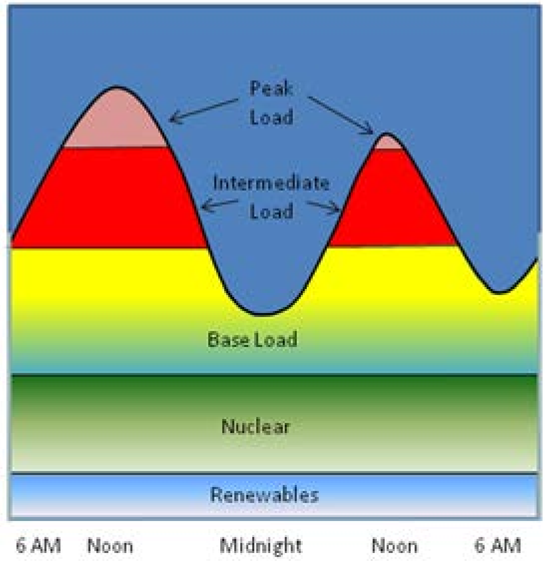
IPM estimates the electric demand, generation, transmission, and distribution within each region as well as the inter-regional transmission grid. All existing utility power generation units, including renewable resources, are modeled, as well as independent power producers and cogeneration facilities that sell electricity to the grid.

To accomplish this, the model incorporates detailed representations of new and existing resource options, including fossil generating options (coal steam, gas-fired simple cycle combustion turbines, combined cycles, and oil/gas steam), nuclear generating options, and renewable and non-conventional (e.g., fuel cells) resources. Renewable resource options include wind, geothermal, solar thermal, solar photovoltaic and biomass. With these inputs, IPM selects the least-cost method for meeting energy and peak demand subject to the constraints specified above, providing estimates of the associated electric power plant emissions and costs. The least cost method may include generating power from existing plants, or making the decision to dispatch (or build) new plants.

This least-cost approach to estimating upstream emissions from electric power plants differs from the approach used in the NPRM, which was based on national average emissions.[69] There are several shortcomings are associated with the use of national average emissions. First, it is not a least-cost approach. Electric utilities typically employ least-cost approaches to dispatch electric power plants to meet the electric power demands of the ratepayer. With a least-cost approach like IPM, the model selects from thousands of candidate electric power plants to meet the demand imposed by charging electric vehicles. Some selections may be above the national average for emissions – such as coal-fired electric power plants – while others may be considerably below the national average for emissions, such as wind turbines. Regardless of the relative emissions, the selection made by IPM is the least-cost selection and, thereby, minimizing costs to the ratepayer. Not using a least-cost approach is economically inefficient since it does not minimize costs to the ratepayer and implies higher-than-necessary electricity prices.

Secondly, demand for electricity varies with time; daytime peaks in electricity demand are considerably higher than nighttime demand. Likewise, the electric power plants tasked to meet this demand will vary considerably with time as will the emissions from these plants (See Figure 4.7-2). Base Load plants, such as coal and nuclear, have limited ability and/or incentive to vary electric power output. Therefore, these plants typically run at full capacity with little variation in emissions. Renewable electric power plants, such as wind turbines, also run at full capacity whenever available, but have no emissions. Depending upon the time of day, it is possible that emissions associated with a charging PHEV/EVs may be non-existent, as in the case of nuclear or wind power plants, or high, as in the case of coal-fired electric power plants. Similarly, the ability to vary electric power output for Intermediate Load and Peak Load power plants vary considerably with time as does their associated emissions. As such, a national average emissions approach fails to capture the time-varying nature of electricity demand.

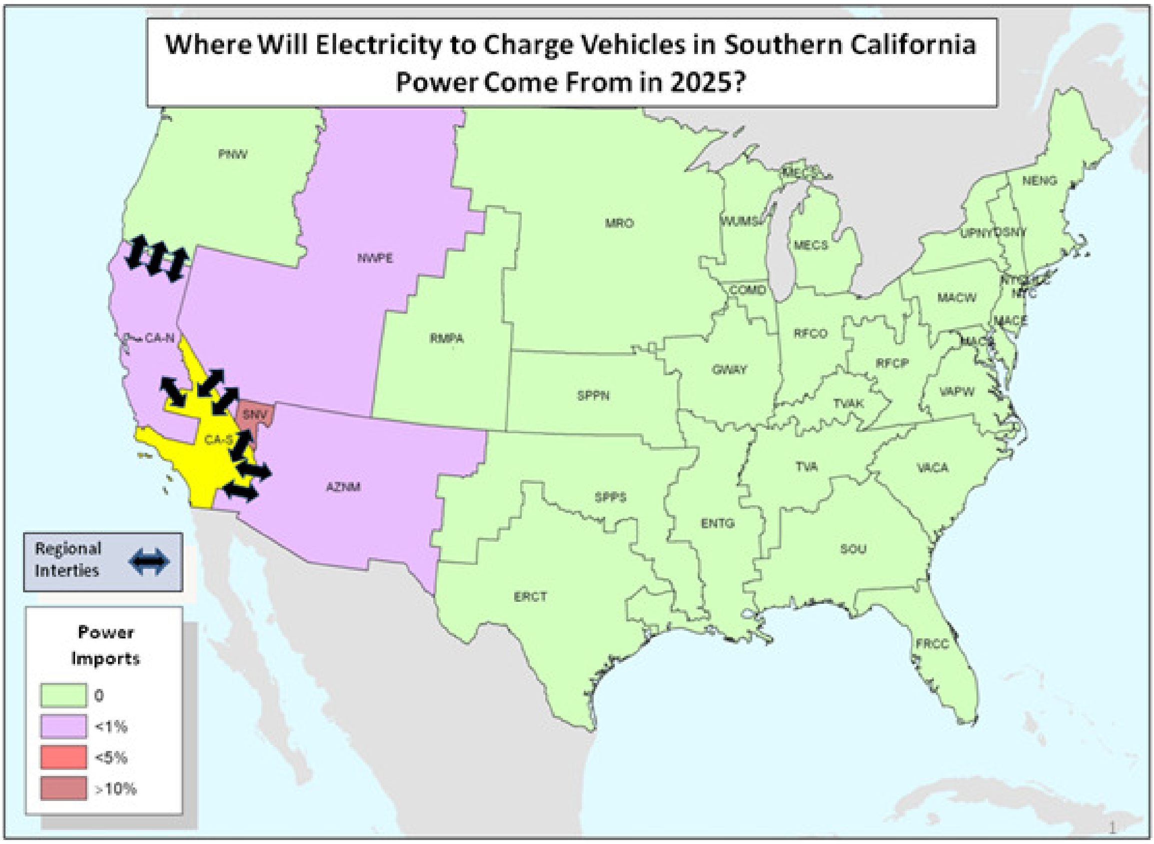
Figure 4.6-10 Time-varying nature of electric power generation



Thirdly, a national average emissions approach fails to capture the location-varying nature of electricity generation; the location of electric power plants – and their associated emissions – varies with the availability of fuel sources. Coal-fired electric power plants in Appalachia, for instance, will have considerable higher emissions that electricity generated in hydroelectric power plants in the Pacific Northwest. This is relevant because PHEV/EV distribution – as with fuel sources – are not uniform across the nation. As such, PHEV/EVs in one region of the nation will be typically charged from electric power plants within that region. A location-varying approach to estimating upstream emissions from electric power plants can capture the impact of such variations whereas a national average approach, by definition, cannot.

Finally, a national average emissions approach fails to capture regional constraints within the high-voltage transmission system. Despite the interconnected nature of much of the U.S. electric power grid, electricity generated in one region may not necessarily leave the region in which it was generated due to the location and capacity of high-voltage transmission lines. If it does, the flow of that power is greatly limited by the location and capacity of high-voltage transmission lines, called "regional interties". For instance, southern California (designated as "CA-S" in Figure 4.7-3) is connected to southern Nevada ("SNV"), Arizona ("AZNM"), the Northwest Power Pool - East ("NWPE"), and northern California (CA-N) by way of regional interties. However, the availability of unused generation capacity, coupled with congestion on the regional interties, can severely limit the importation of electricity. For these reasons, electricity is often imported to southern California from southern Nevada. As such, the electric power plant emissions associated with electricity consumed in southern California is physically deferred to southern Nevada. In the U.S. electric power grid, there exist several similar examples of deferred electric power plant emissions. For instance, the electric power plant emissions from the regions that comprise New York City are deferred to other regions simply because there is not enough generation capacity within New York City to meet its demand.

Figure 4.6-11 Regional constraints in high-voltage transmission for southern California



4.6.3.3 Estimating Nationwide Power Estimates for PHEV/EVs

To estimate upstream electric power plant emissions associated with electric vehicle charging, we used OMEGA to estimate the nationwide PHEV/EV energy requirements for a total of eight OMEGA vehicle types considered likely candidates for electrification as electric vehicles or as PHEVs years 2011-2025 and 2025-2050. For years 2011-2025, we interpolated from a PHEV/EV fleet size of zero vehicles in 2011 to a 2025 sales volume size estimated by OMEGA using the NPRM estimates (approximately 3%).[70] We used the NPRM modeling of electricity demand as an input to the IPM modeling. For 2025-2050, this method assumed that the degree of PHEV/EV technology penetration stabilized at 2025 levels, so that electric vehicle fleet growth between the years 2025-2050 are attributed to the turnover of electrified and non-electrified portions of the vehicle fleet.

In the NPRM analysis, eight OMEGA NPRM vehicle types – subcompact (type 1), small car (type 2 & 3), large car (type 5 & 6), minivan and small truck (types 4 & 8), and minivan and and large truck (types 7 & 15) – were considered potential candidates as electric vehicles or as PHEVs. The energy demand associated with each of these vehicles is discussed in joint TSD 3. Larger vehicles, such as pickup trucks with heavy-duty towing packages capable of hauling large travel trailers or power boats, were not considered potential candidates for electrification in the NPRM analysis, and were not projected as a portion of the electric vehicle demand. As such, we did not make an attempt to model the electric power consumption of these vehicle types. The OMEGA output yielded estimates for nationwide electric power demand associated with charging vehicles (See Table 4.6-12).

Table 4.6-12 OMEGA NPRM projections for incremental PHEV/EV charging loads

IPM Model Run Year	Total Electricity for PHEV/EV Charging (kwh)
2017	123,800,453
2020	1,265,251,557
2030	26,126,391,091
2040	45,558,246,553
2050	54,971,493,663

4.6.3.4 Distribution of Nationwide Power Estimates to IPM Regions

We distributed the nationwide estimates of PHEV/EV energy requirements across each of the 32 IPM model regions on the basis of publically-available annual HEV sales for 2006-2009 from Polk and Wards.[71] EPA judged this a reasonable proxy for the initial distribution of electric vehicles. These vehicles are unlikely to be evenly distributed with population, given their particular attributes, and the HEV distribution offers likely parallels. There was little PHEV/EV sales data when our modeling efforts started, and as of 2012, few models are on the market. As such, we used annual HEV sales data to provide a reasonable state-by-state basis for a distribution of EVs and PHEVs across the country.

However, it was necessary to apportion the sales across IPM regions. If a state resides completely within an IPM region, all of the annual HEV sales for 2006-2009 were attributed to that particular IPM region. For instance, all of Minnesota resides within the IPM region MRO (Midwest Regional Planning Organization). As such, all annual HEV sales for 2006-2009 for the state of Minnesota were attributed to the MRO region for modeling purposes.

However, state boundaries did not necessarily coincide with IPM region boundaries. In cases in which a state resides in more than one IPM region, the vehicles were assumed to be located in the counties that comprised the state's top Metropolitan Statistical Areas (MSA) as of 2008. These vehicles were allocated based upon the number of counties in the MSA that resides in each of the IPM regions. For instance, Chicago-Joliet-Naperville is the top MSA in Illinois. It consists of 14 counties and spans the IPM regions of COMD (Commonwealth

Edison), RFCO (Reliability First Corporation), and WUMS (Wisconsin-Upper Michigan). Nine of the fourteen counties fall into the COMD region, four counties fall into the RFCO region, and one county falls into the WUMS region. The annual HEV sales for 2006-2009 for the Chicago-Joliet-Naperville MSA was then apportioned based upon the county's population density. In this case, 9/14th of the MSA's vehicle sales attributed to the COMD region, 4/14th of the MSA's vehicle sales attributed to the RFCO region, and 1/14th of the MSA's vehicle sales attributed to the WUMS region. Similar proportions were developed for each of the remaining IPM regions. These proportions were applied to the nationwide PHEV/EV energy requirements developed in OMEGA.

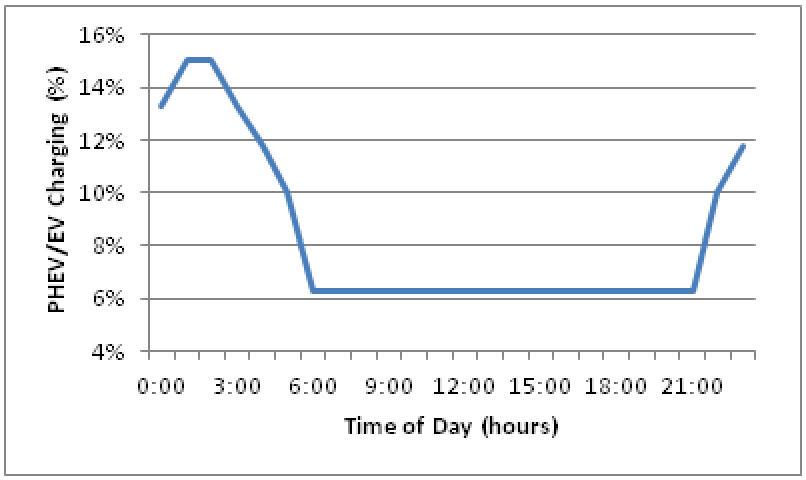
Table 4.6-13 Distribution of nationwide power estimates to IPM regions

IPM Region	Average Annual HEV Sales (2006-2009)
AZNM	9,793
CA-N	32,401
CA-S	42,654
COMD	6,016
ENTG	5,539
ENTG	5,539
ERCT	14,562
FRCC	17,727
GWAY	3,266
LILC	1,673
MACE	19,023
MACS	6,637
MACW	4,834
MECS	7,477
MRO	7,218
NENG	15,652
NWPE	2,264
NYC	4,182
PNW	16,515
RFCO	10,976
RFCP	4,813
RMPA	7,387
SNV	1,623
SOU	7,393
SPPN	2,689
SPPS	3,267
TVA	3,575
TVAK	2,051
UPNY	2,904
VACA	12,483
VAPW	9,740

4.6.3.5 Generation of PHEV/EV Charging Profiles

The charging of PHEV/EV varies by time of day. However, very little historic data on the time of day that electric vehicle owners charged their vehicles was available when this analysis was first started. As such, we developed an electric vehicle charging profile which varies by time of day assuming that 25% of the charging will occur between the hours of 6:00 AM and 7:00 PM. We term this period the “on-peak” period. Charging rate during this time is assumed to be uniform; that is, the same amount of charging is expected to occur for the one-hour period starting at, say, 6:00 AM as would be expected to occur for a one-hour period starting at 4:00 PM. The remaining 75% of PHEV/EV charging is expected to occur between the hours of 7:00 PM and 6:00 AM. We term this period as the “off-peak” period and this charging profile is distributed as a Gaussian-like distribution (See Figure 1-6). In this way, both the on-peak and off-peak charging profiles were mathematically defined; should charging profiles based upon historical data be found to differ from this profile, the impact of these real-life deviations could be better diagnosed.

Figure 4.6-14 PHEV/EV Charging Profile by Time of Day



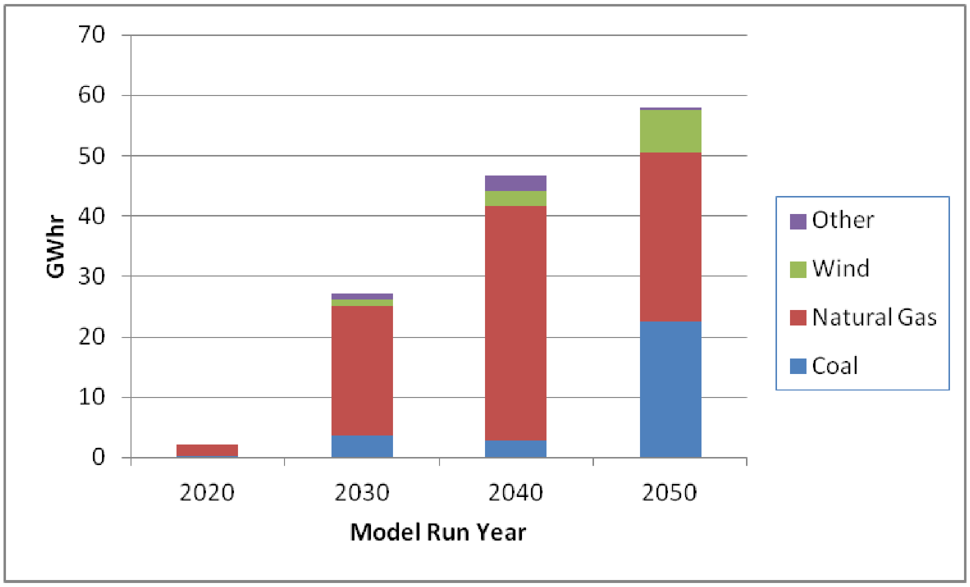
Subsequent to our analysis, electric vehicle and charging infrastructure data for DOE’s “EV Project” became available. This actual charging data was found to be were largely consistent (within a few percent) with both of the on-peak and off-peak charging profiles developed for our analysis.[72] These charging profiles are input into IPM, which uses the profiles to estimate associated incremental emissions and price impacts.

4.6.3.6 Results

IPM uses these charging profiles and total demand to estimate associated incremental emissions and price impacts associated with electric power plant emissions. In these IPM runs,[73] natural gas is generally projected to offset coal as the primary fuel used in electric power plants in future years. As such, the expected fuel mix for all national electric power plant generation is expected to change significantly over the years analyzed.

Correspondingly, the electric power plant generation resulting from electric vehicle charging is expected to similarly shift towards natural gas and away from coal-fired generation (Figure 4.6-15).

Figure 4.6-15 Fuel mix for electric power plants providing electricity to charging vehicles



For instance, the use of coal to fuel electric power plants for all end-users is expected to decrease from approximately 45% in 2020[AAAAA] to 41% in 2050 while the use of nuclear power is expected to decrease from roughly 20% in 2020 to just over 5% in 2050. During this time, the use of natural gas to fuel electric power plants is expected in increase from roughly 20% in 2020 to over 41% in 2050 (See Figure 4.6-15).

The fuel mix for electric power plants that produce electricity for electric vehicle charging is expected to be similar to the overall trend towards natural gas. During this time, the use of natural gas to fuel all electric power plants is expected in increase from roughly 42% in 2020 to over 48% in 2050. In 2030, it is 80% natural gas, 14% coal, and 6%wind and other sources, with similar numbers in 2040

[AAAAA] The incremental power demand in 2020 is very small, near negligible, and should not be ascribed significance.

Figure 4.6-16 Projected fuel mix for PHEV/EV charging in 2030

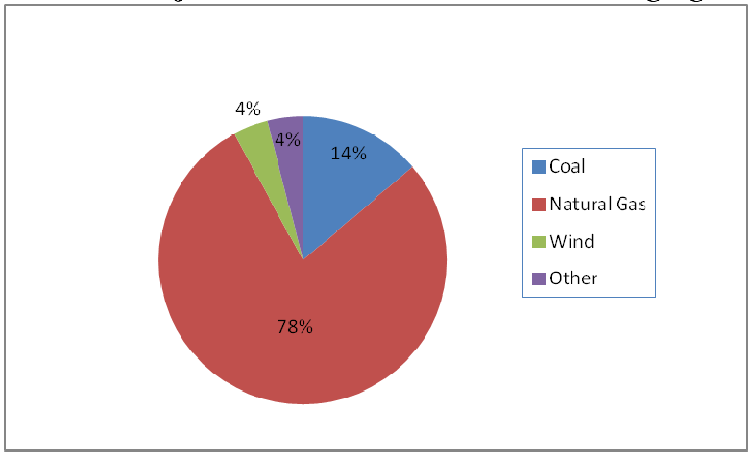
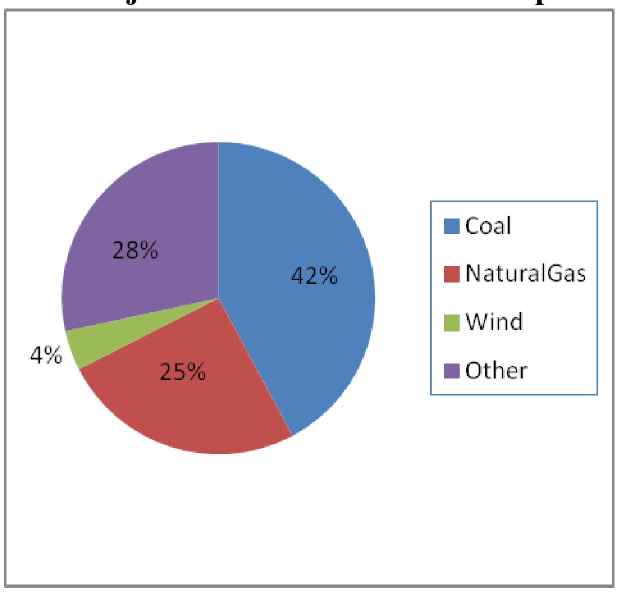
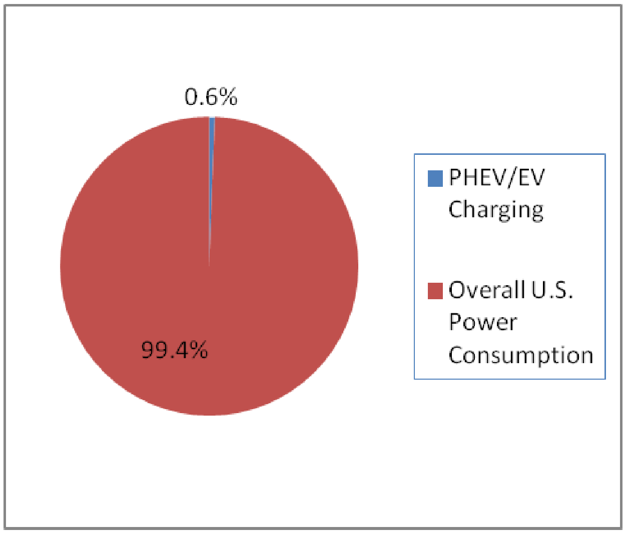


Figure 4.6-17 Projected fuel mix for all electric power in 2030



In this analysis, the overall portion of electricity consumed by charging PHEV/EVs is projected to be small; as compared to all electric expected to be generated, the portion of electricity earmarked for electric vehicle charging is expected to constitute 0% in 2020, 0.6% in 2030, 0.9% in 2040, and just over 1% in 2050 (see Figure 1-10).

Figure 4.6-18 Electric power consumption for PHEV/EVs charging compared to total U.S. electric power consumption in 2030



In 2030, based on the NPRM OMEGA runs, CO_2 emissions related to electric vehicle charging are expected to be 12 MMT. As compared to electricity generated in coal-fired power plants for purposes of electric vehicle charging, mercury emissions are expected to be virtually negligible, as natural gas is virtually mercury-free. NOx emissions are estimated to be 3 M Tons while SO2 emissions are estimated to be 6 M Tons nationwide. In both of these cases, the contribution of emissions from electric power plants related to electric vehicle charging will be on the order of a few tenths of a percent as compared to overall emissions of these pollutants. PM10 and PM2.5 emissions from electric power plants fueled by natural gas- are also expected to decrease relative to coal-fired power plants, in this case, on the order of 67 tons and 172 tons, respectively (Table 4.6-19).

Table 4.6-19 Electric power plant emissions due to charging PHEV/EVs

	2020	2030	2040	2050
CO2 [MM Tonnes]	0	12	17	29
NOx [M Tons]	-2	3	1	2
SO2 [M Tons]	-4	6	4	6
Hg [Tons]	0	0	0	0
PM 2.5 [Tons]	15	172	322	846
PM 10 [Tons]	16	67	360	837

4.6.3.7 Air Quality Inventory

More detailed emission data was post-processed out of the emission data for 2030. This more detailed data, which includes VOC and CO, was not available for all years, and these inventories were used for air quality modeling. Due to the difficulty related to geographic apportionment, the air quality modeling analyses did not consider the feedstock gathering aspects of the power generation.

Table 4.6-20 – Air Quality Inventory.

	Calendar year 2030 Impacts	% Impact relative to total IPM emissions
Annual CO (Tons)	8,544	0.8%
Annual NOx (Tons)	2,528	0.1%
Annual VOC (Tons)	245	0.5%
Annual SO2 (Tons)	5,612	0.3%
Annual Primary PM10 (Tons)	67	0.0%
Annual Primary PM25 (Tons)	172	0.1%

4.6.3.8 Costs

EPA has prepared a memo to the docket on the cost analysis contained from the IPM runs.[74]

4.6.3.9 Additional impacts from reduction in refinery electricity consumption

In addition to the impacts from electric vehicles and plug-in electric vehicles, there are additional impacts on electric power plant emissions from reductions in energy used to supply petroleum refineries. These impacts were accounted for in air quality inventories as well, and methods used to estimate these impacts are discussed in Section 4.7.2.3. Table 4-43 presents total air quality inventory impacts on electric power plants emissions when these impacts are included (Table 4.6-21).

Table 4.6-21 - Total Air Quality Inventory Impacts on Electric Power Plants from Electric and Electric Plug-in Vehicles, and Reductions in Production of Electricity for Refinery Use.

Pollutant	Tons	Percent of Total Upstream Inventory
$PM_{2.5}$	--136	-0.06
PM_{10}	-923	-0.31
NO_X	459	0.02
VOC	-7	1.7
CO	7618	0.72
SO_X	3131	0.15
NH_3	541	1.10
Acetaldehyde	0	0
Acrolein	0	0
Benzene	-12	0.24
1,3-Butadiene	0	0
Formaldehyde	112	1.25

4.6.4 Comparison of inventories used in air quality modeling and FRM (short tons)

A comparison of the inventories used for AQ modeling and this FRM analysis is shown below (Table 4.6-22). The AQ modeling and FRM inventories are highly similar, with some updates made to the FRM modeling (such as the updates due to AEO 2012 ER, reduced number of EVs from the FRM technology analysis, and inclusion of updated power plant feedstock gathering emission factors) which were not included in the AQ inventories due to the lead time required for the air quality modeling.[BBBBB]

Table 4.6-22 – Comparison of Inventories

	AQ			FRM
Pollutant	Reference	Control	Delta	Delta
CO	43,939,504	44,190,468	250,963	224,875
NOX	9,160,190	9,150,007	-10,183	-6,509
PM2_5	2,888,030	2,883,315	-4,715	-1,254
SO2	4,870,847	4,854,965	-15,882	-13,377
VOC	10,805,700	10,658,356	-147,344	-123,070

[BBBBB] The difference between the FRM and AQ deltas for two air toxics, benzene and formaldehyde, are larger, and are attributable to modeling artifacts in the AQ inventories. This difference would not have a significant effect on our AQ modeling results, as this rule does not have a significant impact on the ambient level of these air toxics.

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[44]EPA MOVES 2010a. August 2010. http://www.epa.gov/otaq/models/moves/index.htm. (Docket No. EPA-HQ-OAR-2010-0799-1105)

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5 Vehicle Program Costs and Fuel Savings

In this chapter, EPA presents our estimate of the costs associated with the final vehicle program. The presentation here summarizes the vehicle level costs associated with the new technologies expected to be added to meet the MYs 2017-2025 GHG standards, including hardware costs to comply with the A/C credit program. The analysis summarized here provides our estimate of incremental costs on a per vehicle basis and on an annual total basis.[75]

The presentation here summarizes the outputs of the OMEGA model that were discussed in some detail in Chapter 3 of this RIA. For details behind the analysis, such as the OMEGA model inputs and the estimates of costs associated with individual technologies, the reader is directed to Chapter 1 of this RIA, and Chapter 3 of the Joint TSD. Note that the cost analysis is based on a fixed vehicle fleet, as discussed in Chapter 1 of the Joint TSD. For the cost analysis, then, the implicit demand elasticities are zero.

New for this final rule relative to the proposal are the inclusion of maintenance costs associated with the new technologies and a discussion of potential repair costs. In the proposal, we requested comment on maintenance and repair costs and received comments from two commenters (see Chapter 5.2.2 below).

5.1 Technology Costs per Vehicle

To develop technology costs per vehicle, EPA has used the same methodology as that used in the MYs 2012-2016 final rule, the 2010 TAR and the proposal for this rule. Individual technology direct manufacturing costs have been estimated in a variety of ways—vehicle and technology tear down, models developed by outside organizations, and literature review—and indirect costs have been estimated using the updated and revised indirect cost multiplier (ICM) approach that was first developed for the MYs 2012-2016 final rule.[CCCCC] All of these individual technology costs are described in detail in Chapter 3 of the joint TSD. Also described there are the ICMs used in this rule and the ways the ICMs have been updated and revised since the MYs 2012-2016 final rule which results in considerably higher indirect costs in this rule than estimated in the MYs 2012-2016 final rule. Further, we describe in detail the adjustments to technology costs to account for manufacturing learning and the cost reductions that result from that learning. We note here that learning impacts are applied only to direct manufacturing costs. This approach differs from the MYs 2012-2016 final rule which applied learning to both direct and indirect costs. Learning effects in this final rule are applied exactly as was done in the proposal. Lastly, we have included costs associated with stranded capital (i.e., capital investments that are not fully recaptured by auto makers because they would be forced to update vehicles on a more rapid schedule than they may have intended absent this final rule). Again, this is detailed in Chapter 3 of the joint TSD.

[CCCCC] The ICM approach was updated for the proposal and has not changed for this final rule.

EPA used the technology costs to build GHG and fuel consumption reducing packages of technologies for each of 19 different vehicle types meant to fully represent the range of baseline vehicle technologies in the marketplace (i.e., number of cylinders, valve train configuration, vehicle class, etc.). This package building process as well as the process we use to determine the most cost effective packages for each of the 19 vehicle types is detailed in Chapter 1 of this RIA. These packages are then used as inputs to the OMEGA model to estimate the most cost effective means of compliance with the final standards giving due consideration to the timing required for manufacturers to implement the needed technologies. That is, we assume that manufacturers cannot add the full suite of needed technologies in the first year of implementation. Instead, we expect them to add technologies to vehicles during the typical 4 to 5 year redesign cycle. As such, we expect that every vehicle can be redesigned to add significant levels of new technology every 4 to 6 years. Further, we do not expect manufacturers to redesign vehicles at a pace more rapid than the standard industry four to five year cycle.

We then ran the OMEGA model for the 2021 and 2025 MYs as described in detail in Chapter 3 of this RIA. The control case OMEGA cost outputs for the 2021 and 2025 MYs were presented there and are repeated here in Table 5.1-1.

Table 5.1-1 2021MY & 2025MY Control Case OMEGA Costs, including AC-Related Costs but no Stranded Capital (2010$)

Company	2021MY			2025MY		
	Car	Truck	Combined	Car	Truck	Combined
Aston Martin	$6,688	$0	$6,688	$7,463	$0	$7,463
BMW	$936	$499	$821	$2,137	$1,240	$1,900
Chrysler/Fiat	$657	$772	$709	$1,601	$2,372	$1,934
Daimler	$1,962	$637	$1,633	$3,002	$1,275	$2,607
Ferrari	$6,672	$0	$6,672	$7,843	$0	$7,843
Ford	$659	$854	$725	$1,803	$2,497	$2,017
Geely	$2,102	$705	$1,668	$3,166	$1,492	$2,670
GM	$501	$702	$600	$1,505	$2,223	$1,847
Honda	$519	$816	$611	$1,505	$1,903	$1,622
Hyundai	$764	$866	$785	$1,658	$2,253	$1,777
Kia	$583	$866	$646	$1,548	$1,953	$1,634
Lotus	$3,727	$0	$3,727	$3,556	$0	$3,556
Mazda	$921	$1,208	$972	$1,966	$2,436	$2,044
Mitsubishi	$572	$1,089	$752	$1,926	$2,157	$2,003
Nissan	$631	$890	$711	$1,604	$2,378	$1,833
Porsche	$4,851	$577	$3,844	$4,793	$1,259	$4,029
Spyker	$3,005	$593	$2,659	$3,566	$950	$3,224
Subaru	$967	$1,579	$1,114	$1,921	$2,491	$2,050
Suzuki	$1,018	$1,196	$1,049	$2,101	$1,837	$2,056
Tata-JLR	$3,895	$1,040	$2,474	$5,058	$1,427	$3,370
Tesla	$79	$0	$79	$70	$0	$70
Toyota	$469	$581	$512	$1,215	$1,675	$1,383
Volkswagen	$1,467	$484	$1,268	$2,408	$1,232	$2,176
Fleet	$748	$744	$746	$1,711	$2,044	$1,821

Note: Results correspond to the 2008 baseline fleet.

To get the costs per vehicle for the intervening years 2017-2020 and 2022-2024, we have interpolated costs based on target CO_2 levels for each individual company. For this final rule, those target CO_2 levels, excluding AC impacts, were presented in Chapter 3 of this RIA and are repeated here for cars in Table 5.1-2 and for trucks in Table 5.1-3.

Table 5.1-2 Target CO_2 Levels, excluding AC, by MY for Cars (g/mi)

Company	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	232.7	223.3	214.3	205.6	197.4	189.4	181.8	174.4	167.4	160.7
BMW	238.5	228.9	219.7	210.8	202.3	194.2	186.4	178.8	171.6	164.7
Chrysler/Fiat	243.0	230.6	221.0	211.9	204.0	195.3	186.9	179.4	171.8	164.9
Daimler	243.1	234.1	224.8	215.9	207.2	198.6	190.6	183.1	175.9	168.7
Ferrari	245.1	235.2	225.7	216.6	207.9	199.5	191.5	183.8	176.4	169.3
Ford	239.5	230.6	221.2	212.2	204.0	195.8	187.9	180.3	173.0	166.1
Geely	242.6	232.4	223.0	214.0	205.4	197.1	189.2	181.5	174.1	167.1
GM	238.6	227.4	218.1	209.2	200.8	192.5	184.7	177.4	170.0	163.1
Honda	233.1	223.6	214.5	205.8	197.5	189.5	181.9	174.7	167.6	160.8
Hyundai	232.4	223.6	214.5	205.9	197.5	189.5	181.8	174.6	167.5	160.7
Kia	227.8	219.8	210.8	202.3	194.0	186.1	178.5	171.4	164.4	157.7
Lotus	216.3	207.5	199.2	191.1	183.4	176.0	169.0	162.1	155.6	149.3
Mazda	229.0	220.6	211.8	203.3	195.3	187.5	180.1	172.9	165.8	159.0
Mitsubishi	229.7	220.0	211.1	202.5	194.4	186.6	179.0	171.9	164.9	158.2
Nissan	236.0	227.1	217.9	209.0	200.7	192.7	185.0	177.6	170.4	163.6
Prosche	216.3	216.3	216.3	199.2	191.1	176.0	169.0	162.1	155.6	149.3
Spyker	229.0	219.7	210.9	202.4	194.2	186.4	178.9	171.7	164.8	158.1
Subaru	221.2	212.2	203.6	195.4	187.6	180.0	172.8	165.9	159.2	152.8
Suzuki	217.8	217.8	217.8	200.7	192.5	177.3	170.1	163.3	156.7	150.4
Tata-JLR	260.2	260.2	260.2	239.7	230.0	211.8	203.3	195.1	187.2	179.7
Tesla	216.3	207.5	199.2	191.1	183.4	176.0	169.0	162.1	155.6	149.3
Toyota	231.8	222.4	213.4	204.7	196.5	188.5	181.0	173.7	166.7	159.9
Volkswagen	227.3	218.1	209.3	200.9	192.8	185.0	177.5	170.4	163.5	156.9
Fleet	234.5	225.3	216.3	207.4	199.2	190.9	183.2	175.9	168.7	161.9

Note: Results correspond to the 2008 baseline fleet.

Table 5.1-3 Target CO_2 Levels, excluding AC, by MY for Trucks (g/mi)

Company	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BMW	294.1	295.1	289.1	284.4	277.7	260.6	249.2	238.4	228.0	218.0
Chrysler/Fiat	306.6	305.1	300.5	295.9	288.8	270.8	258.9	247.3	236.2	225.7
Daimler	305.8	310.8	306.3	301.1	294.6	277.0	265.0	253.5	242.6	232.0
Ferrari	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ford	316.6	315.8	311.4	307.4	303.4	285.2	272.7	259.9	247.3	236.1
Geely	291.7	290.4	283.7	278.9	272.3	255.3	244.0	233.2	223.0	213.1
GM	324.4	321.0	316.4	311.4	305.8	286.2	273.3	260.7	248.7	237.5
Honda	292.2	292.1	287.1	282.4	275.4	258.5	247.0	236.3	225.6	215.7
Hyundai	289.9	288.9	283.2	278.5	271.8	254.9	243.6	233.0	222.5	212.8
Kia	300.9	300.9	296.7	292.0	284.7	267.2	255.4	244.3	233.4	223.2
Lotus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mazda	282.4	283.8	276.9	272.3	266.6	250.9	240.5	230.3	219.9	210.1
Mitsubishi	280.7	277.9	271.5	267.0	260.6	244.3	233.5	223.3	213.4	204.0
Nissan	306.7	305.1	300.2	295.1	288.6	272.4	260.4	248.4	236.7	226.0
Porsche	298.4	298.4	298.4	291.7	286.7	262.4	250.8	239.8	229.2	219.1
Spyker	291.0	289.6	283.0	278.2	271.5	254.6	243.3	232.6	222.4	212.6
Subaru	268.9	263.5	257.4	253.2	247.0	231.6	221.4	211.7	202.3	193.4
Suzuki	283.4	283.4	283.4	274.1	269.4	246.6	235.7	225.3	215.4	205.9
Tata-JLR	284.0	284.0	284.0	275.2	270.4	247.4	236.4	225.9	215.9	206.4
Tesla	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Toyota	306.2	304.5	299.2	294.3	288.8	271.0	259.0	247.2	235.9	225.3
Volkswagen	304.2	306.8	301.4	296.2	289.7	272.2	260.4	249.2	238.0	227.5
Fleet	308.6	306.8	302.3	297.7	292.0	273.8	261.6	249.7	238.1	227.5

Note: Results correspond to the 2008 baseline fleet.

Interpolating the costs shown in Table 5.1-1 by CO_2 targets shown in

Table 5.1-2 and Table 5.1-3 is straight forward enough, but the costs shown in Table 5.1-1 include our estimated AC-related costs (see Chapter 5 of the joint TSD). Because 2-cycle CO_2 targets do not include AC-related GHG controls, we first backed out the AC-related costs prior to conducting the interpolations. The non-AC Costs were interpolated first between 2016MY costs (set to $0 for the Control case) and 2021MY costs, and were interpolated again between 2021MY and 2025MY costs. Also included in this step was a scalar that was applied to costs in an effort to estimate the effects of learning on costs for the intervening years. This scalar was generated by simply averaging package costs year-over-year using the ranked-set of packages used for our 2021MY OMEGA runs and the ranked-set of OMEGA packages for our 2025MY OMEGA runs. We note that ranked-sets of packages and how they were developed is described in detail in Chapter 1 of this RIA. These averaged package costs were then expressed as a percentage of the 2021MY costs and then 2025MY costs, respectively. The former scalar was used for the interpolations between 2016 and 2021 model years while the latter scalar was used for the interpolations between 2021 and 2025 model years. These scalars are shown in Table 5.1-4.

Table 5.1-4 Scalars Applied to Interpolated Costs to Reflect Learning Effects

Scaler	2017	2018	2019	2020	2021	2022	2023	2024	2025
Costs as % of 2021	118%	114%	105%	102%	100%				
Costs as % of 2025	133%	129%	120%	116%	114%	113%	111%	110%	100%

Note that scalars exclude AC-related costs.

AC-related costs as presented in Chapter 5 of the joint TSD were then added back in to the interpolated costs by year. Note that the same cost for AC was used for each manufacturer as we do not have unique AC-related costs by manufacturer.

The final step was to include our estimates of stranded capital. The stranded capital costs used were based on those presented in Chapter 3 of this RIA where we presented estimates of stranded capital for the 2016, 2021 and 2025 MYs. To estimate stranded capital for the intervening years, we have done straight line interpolations to arrive at the stranded capital costs shown in

Table 5.1-5. Note that the same stranded capital costs were used for both cars and trucks except that no truck stranded capital costs were included for those manufacturers with no truck sales (Aston Martin, Ferrari, Lotus and Tesla).

Table 5.1-5 Interpolated Estimates of Stranded Capital Costs (2010$)

Company	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	$60	$54	$48	$41	$35	$31	$26	$21	$17
BMW	$16	$20	$23	$27	$31	$26	$21	$16	$11
Chrysler/Fiat	$53	$45	$38	$31	$24	$22	$20	$18	$16
Daimler	$18	$19	$20	$21	$22	$19	$16	$13	$10
Ferrari	$9	$16	$24	$32	$40	$35	$31	$26	$22
Ford	$16	$17	$19	$20	$21	$18	$15	$12	$9
Geely	$16	$20	$23	$26	$30	$25	$21	$16	$12
GM	$18	$18	$18	$18	$18	$17	$16	$15	$14
Honda	$12	$12	$13	$13	$13	$15	$17	$19	$21
Hyundai	$7	$8	$8	$8	$9	$11	$12	$14	$15
Kia	$14	$21	$28	$36	$43	$38	$34	$29	$25
Lotus	$26	$23	$20	$16	$13	$12	$11	$11	$10
Mazda	$17	$22	$28	$33	$38	$32	$26	$20	$13
Mitsubishi	$15	$21	$27	$33	$39	$32	$26	$19	$13
Nissan	$12	$12	$13	$13	$13	$14	$14	$14	$14
Porsche	$19	$21	$23	$25	$27	$24	$21	$18	$15
Spyker	$36	$30	$25	$20	$14	$14	$15	$15	$15
Subaru	$8	$10	$11	$13	$15	$12	$10	$7	$5
Suzuki	$28	$25	$21	$18	$14	$14	$13	$12	$11
Tata-JLR	$17	$18	$19	$20	$21	$21	$20	$20	$20
Tesla	$1	$1	$1	$0	$0	$0	$0	$0	$0
Toyota	$5	$9	$12	$16	$19	$21	$22	$24	$25
Volkswagen	$14	$17	$19	$22	$25	$20	$15	$10	$5
Fleet	$14	$16	$17	$18	$20	$19	$18	$17	$16

Note: Results correspond to the 2008 baseline fleet.

The end results are presented in Table 5.1-6 for cars, Table 5.1-7 for trucks and Table 5.1-8 for the combined fleet.

Table 5.1-6 Control Case Costs by Manufacturer by MY including AC & Stranded Capital Costs -- Cars (2010$)

Company	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	$1,778	$3,296	$4,438	$5,588	$6,724	$7,173	$7,546	$7,854	$7,480
BMW	$261	$475	$643	$804	$967	$1,351	$1,700	$2,024	$2,147
Chrysler/Fiat	$256	$390	$491	$577	$681	$993	$1,257	$1,520	$1,617
Daimler	$495	$944	$1,288	$1,633	$1,985	$2,358	$2,687	$2,981	$3,011
Ferrari	$1,720	$3,250	$4,403	$5,565	$6,712	$7,280	$7,763	$8,174	$7,864
Ford	$180	$334	$455	$564	$680	$1,042	$1,369	$1,676	$1,811
Geely-Volvo	$577	$1,054	$1,414	$1,771	$2,132	$2,511	$2,851	$3,162	$3,177
GM	$164	$272	$358	$435	$519	$834	$1,114	$1,389	$1,518
Honda	$151	$266	$359	$443	$532	$843	$1,124	$1,396	$1,525
Hyundai	$200	$373	$510	$640	$773	$1,066	$1,329	$1,578	$1,673
Kia	$153	$295	$409	$516	$625	$928	$1,200	$1,459	$1,572
Lotus	$987	$1,831	$2,469	$3,107	$3,739	$3,811	$3,850	$3,866	$3,566
Mazda	$244	$460	$634	$795	$959	$1,288	$1,591	$1,877	$1,979
Mitsubishi	$170	$303	$409	$508	$611	$1,026	$1,407	$1,765	$1,939
Nissan	$171	$316	$430	$535	$644	$954	$1,234	$1,501	$1,618
Porsche	$44	$61	$2,210	$3,120	$4,878	$5,018	$5,114	$5,176	$4,807
Spyker-Saab	$810	$1,488	$2,000	$2,511	$3,019	$3,286	$3,513	$3,709	$3,580
Subaru	$262	$482	$652	$815	$982	$1,295	$1,578	$1,842	$1,926
Suzuki	$54	$65	$496	$679	$1,032	$1,388	$1,711	$2,009	$2,112
Tata-JLR	$43	$58	$1,777	$2,506	$3,916	$4,392	$4,809	$5,176	$5,077
Tesla[DDDDD]	$26	$41	$57	$66	$79	$77	$72	$71	$69
Toyota	$130	$238	$325	$404	$488	$726	$942	$1,147	$1,239
Volkswagen	$395	$729	$986	$1,238	$1,492	$1,816	$2,104	$2,369	$2,412
Fleet	$206	$374	$510	$634	$767	$1,079	$1,357	$1,622	$1,726

Note: Results correspond to the 2008 baseline fleet; MY 2017-2018 costs for Porsche, Suzuki and Tata-JLR reflect AC and stranded capital even though EPA assumed for purposes of this analysis that these companies would use the intermediate volume manufacturer provisions allowing the MY 2016 standards to continue through MY 2018. However, for Porsche, we note that this analysis was already completed before EPA learned that, as of August 1, 2012, Volkswagen purchased 100% ownership of Porsche and, thus, EPA expects that in actuality the Porsche fleet will be combined with the Volkswagen fleet for purposes of compliance with the MYs 2017-2025 standards.

[DDDDD] While costs related to air-conditioning are shown for Tesla, as a manufacturer of solely electric vehicles, Tesla can comply with reference, control, and alternative standards without incurring additional costs from this regulation.

Table 5.1-7 Control Case Costs by Manufacturer by MY including AC & Stranded Capital Costs -- Trucks (2010$)

Company	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	$0	$0	$0	$0	$0	$0	$0	$0	$0
BMW	$5	$136	$220	$310	$529	$1,095	$1,189	$1,274	$1,250
Chrysler/Fiat	$89	$223	$324	$455	$796	$1,222	$1,713	$2,166	$2,388
Daimler	-$91	$55	$186	$316	$659	$1,851	$1,695	$1,541	$1,284
Ferrari	$0	$0	$0	$0	$0	$0	$0	$0	$0
Ford	$42	$207	$327	$426	$875	$1,235	$1,764	$2,272	$2,505
Geely-Volvo	$43	$218	$321	$438	$734	$2,024	$1,892	$1,759	$1,504
GM	$84	$209	$307	$400	$720	$1,057	$1,551	$2,008	$2,237
Honda	$18	$184	$307	$460	$829	$978	$1,365	$1,739	$1,923
Hyundai	$35	$224	$346	$497	$875	$1,259	$1,683	$2,086	$2,268
Kia	$16	$176	$315	$492	$908	$1,062	$1,443	$1,805	$1,977
Lotus	$0	$0	$0	$0	$0	$0	$0	$0	$0
Mazda	-$40	$292	$477	$683	$1,246	$1,430	$1,851	$2,270	$2,449
Mitsubishi	$106	$354	$492	$672	$1,127	$1,112	$1,552	$1,965	$2,169
Nissan	$59	$232	$367	$521	$904	$1,184	$1,689	$2,165	$2,391
Porsche	$21	$67	$191	$266	$604	$3,964	$3,067	$2,205	$1,274
Spyker-Saab	$60	$202	$283	$372	$607	$2,510	$2,001	$1,511	$964
Subaru	$263	$577	$742	$978	$1,594	$1,482	$1,919	$2,326	$2,495
Suzuki	$31	$71	$389	$526	$1,210	$1,323	$1,567	$1,792	$1,848
Tata-JLR	$20	$65	$330	$457	$1,061	$3,314	$2,708	$2,121	$1,447
Tesla	$0	$0	$0	$0	$0	$0	$0	$0	$0
Toyota	$36	$165	$258	$342	$600	$873	$1,220	$1,543	$1,700
Volkswagen	-$20	$102	$194	$283	$508	$1,476	$1,433	$1,386	$1,237
Fleet	$57	$196	$304	$415	$763	$1,186	$1,562	$1,914	$2,059

Note: Results correspond to the 2008 baseline fleet; MY 2017-2018 costs for Porsche, Suzuki and Tata-JLR reflect AC and stranded capital even though EPA assumed for purposes of this analysis that these companies would use the intermediate volume manufacturer provisions allowing the MY 2016 standards to continue through MY 2018. However, for Porsche, we note that this analysis was already completed before EPA learned that, as of August 1, 2012, Volkswagen purchased 100% ownership of Porsche and, thus, EPA expects that in actuality the Porsche fleet will be combined with the Volkswagen fleet for purposes of compliance with the MYs 2017-2025 standards; negative entries are due to shifts in compliance values due to the sales projections used (see Chapter 1 of the Joint TSD for details on our sales projections).

Table 5.1-8 Control Case Costs by Manufacturer by MY including AC & Stranded Capital Costs – Combined Fleet (2010$)

Company	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	$1,778	$3,296	$4,438	$5,588	$6,724	$7,173	$7,546	$7,854	$7,480
BMW	$193	$386	$531	$673	$852	$1,283	$1,565	$1,826	$1,910
Chrysler/Fiat	$180	$314	$416	$521	$733	$1,092	$1,454	$1,799	$1,950
Daimler	$349	$723	$1,014	$1,305	$1,655	$2,242	$2,460	$2,652	$2,616
Ferrari	$1,720	$3,250	$4,403	$5,565	$6,712	$7,280	$7,763	$8,174	$7,864
Ford	$133	$291	$412	$517	$746	$1,102	$1,491	$1,860	$2,025
Geely-Volvo	$412	$794	$1,075	$1,357	$1,698	$2,366	$2,567	$2,746	$2,681
GM	$125	$241	$333	$418	$619	$940	$1,322	$1,684	$1,861
Honda	$110	$241	$343	$448	$624	$883	$1,194	$1,497	$1,642
Hyundai	$166	$343	$477	$611	$794	$1,105	$1,400	$1,679	$1,792
Kia	$123	$269	$388	$511	$689	$957	$1,251	$1,532	$1,658
Lotus	$987	$1,831	$2,469	$3,107	$3,739	$3,811	$3,850	$3,866	$3,566
Mazda	$193	$430	$606	$775	$1,010	$1,312	$1,634	$1,942	$2,057
Mitsubishi	$148	$321	$438	$565	$791	$1,055	$1,455	$1,831	$2,015
Nissan	$136	$290	$411	$531	$725	$1,022	$1,369	$1,697	$1,847
Prosche	$39	$62	$1,734	$2,447	$3,871	$4,790	$4,672	$4,534	$4,044
Spyker-Saab	$703	$1,304	$1,754	$2,205	$2,674	$3,185	$3,315	$3,422	$3,238
Subaru	$262	$505	$673	$854	$1,128	$1,337	$1,655	$1,951	$2,054
Suzuki	$50	$66	$477	$651	$1,064	$1,377	$1,686	$1,972	$2,066
Tata-JLR	$31	$61	$1,057	$1,486	$2,495	$3,891	$3,832	$3,756	$3,390
Tesla	$26	$41	$57	$66	$79	$77	$72	$71	$69
Toyota	$94	$210	$299	$380	$532	$780	$1,043	$1,291	$1,407
Volkswagen	$311	$602	$825	$1,044	$1,293	$1,749	$1,972	$2,176	$2,181
Fleet	$154	$311	$438	$557	$766	$1,115	$1,425	$1,718	$1,836

Note: Results correspond to the 2008 baseline fleet; MY 2017-2018 costs for Porsche, Suzuki and Tata-JLR reflect AC and stranded capital even though EPA assumed for purposes of this analysis that these companies would use the intermediate volume manufacturer provisions allowing the MY 2016 standards to continue through MY 2018. However, for Porsche, we note that this analysis was already completed before EPA learned that, as of August 1, 2012, Volkswagen purchased 100% ownership of Porsche and, thus, EPA expects that in actuality the Porsche fleet will be combined with the Volkswagen fleet for purposes of compliance with the MYs 2017-2025 standards.

These costs per vehicle are then carried forward for future MYs to arrive at the costs presented in Table 5.1-9, including costs associated with the air conditioning program and estimates of stranded capital.

Table 5.1-9 Industry Average Vehicle Costs Associated with the Final Standards (2010$)

Model Year	2017	2018	2019	2020	2021	2022	2023	2024	2025	2030	2040	2050
$/car	$206	$374	$510	$634	$767	$1,079	$1,357	$1,622	$1,726	$1,710	$1,710	$1,710
$/truck	$57	$196	$304	$415	$763	$1,186	$1,562	$1,914	$2,059	$2,044	$2,044	$2,044
Combined	$154	$311	$438	$557	$766	$1,115	$1,425	$1,718	$1,836	$1,818	$1,816	$1,816

Note: Results correspond to the 2008 baseline fleet.

5.2 Costs of the MY 2017-2025 GHG Standards

5.2.1 Technology Costs

The costs presented here represent the costs for newly added technology to comply with the program incremental to the costs of the MYs 2012-2016 standards. Together with the projected increases in car and truck sales, the increases in per-car and per-truck average costs shown in Table 5.1-9 above result in the total annual technology costs presented in Table 5.2-1 below. Note that the costs presented in Table 5.2-1 do not include the fuel savings that consumers would realize as a result of driving a vehicle with improved fuel economy. Those impacts are presented in Chapter 5.4 below. Similarly, the costs presented in Table 5.2-1 do not include the maintenance costs that we have estimated in this final rule. Maintenance costs, presented below, were not included in the proposal. Note also that the costs presented here represent costs estimated to occur presuming that the MY 2025 standards would continue in perpetuity. In other words, the standards do not apply only to 2017-2025 model year vehicles - they do, in fact, apply to all 2025 and later model year vehicles.

Table 5.2-1 Undiscounted Annual Technology Costs & Costs Discounted back to 2012 at 3% and 7% Discount Rates (2010 dollars)

Calendar Year	Sales		$/unit		$Million/year		
	Cars	Trucks	$/car	$/truck	Cars	Trucks	Combined
2017	9,987,667	5,818,655	$206	$57	$2,060	$334	$2,440
2018	9,905,364	5,671,046	$374	$196	$3,700	$1,110	$4,850
2019	9,995,696	5,582,962	$510	$304	$5,100	$1,700	$6,820
2020	10,291,562	5,604,377	$634	$415	$6,530	$2,320	$8,860
2021	10,505,165	5,683,902	$767	$763	$8,060	$4,340	$12,400
2022	10,735,777	5,703,996	$1,079	$1,186	$11,600	$6,760	$18,300
2023	10,968,003	5,687,486	$1,357	$1,562	$14,900	$8,880	$23,700
2024	11,258,138	5,675,949	$1,622	$1,914	$18,300	$10,900	$29,100
2025	11,541,560	5,708,899	$1,726	$2,059	$19,900	$11,800	$31,700
2030	12,535,870	5,986,092	$1,710	$2,044	$21,400	$12,200	$33,700
2040	14,097,092	6,505,226	$1,710	$2,044	$24,100	$13,300	$37,400
2050	15,822,370	7,301,371	$1,710	$2,044	$27,100	$14,900	$42,000
NPV, 3%					$336,000	$186,000	$521,000
NPV, 7%					$149,000	$81,900	$231,000

Note: Results correspond to the 2008 baseline fleet.

Note that costs are estimated to decrease slightly in years beyond 2025. This represents the elimination of stranded capital that is included in the costs for 2017 through 2025. These costs are described in detail in Chapter 3 of the Joint TSD.

Looking at these costs by model year gives us the technology costs as shown in Table 5.2-2.

Table 5.2-2 Model Year Lifetime Present Value Technology Costs, Discounted back to the 1st Year of each MY at 3% and 7% Discount Rates (millions of 2010 dollars)

NPV at		2017	2018	2019	2020	2021	2022	2023	2024	2025	Sum
3%	Car	$2,030	$3,650	$5,020	$6,430	$7,940	$11,400	$14,700	$18,000	$19,600	$88,800
	Truck	$330	$1,100	$1,670	$2,290	$4,280	$6,670	$8,750	$10,700	$11,600	$47,400
	Fleet	$2,400	$4,780	$6,720	$8,730	$12,200	$18,100	$23,400	$28,700	$31,200	$136,000
7%	Car	$1,990	$3,580	$4,930	$6,320	$7,800	$11,200	$14,400	$17,700	$19,300	$87,200
	Truck	$323	$1,080	$1,640	$2,250	$4,200	$6,540	$8,590	$10,500	$11,400	$46,500
	Fleet	$2,360	$4,690	$6,590	$8,570	$12,000	$17,700	$23,000	$28,100	$30,600	$134,000

Note: Results correspond to the 2008 baseline fleet.

5.2.2 Maintenance & Repair Costs

New for this final rule are consideration and quantification of maintenance costs associated with the new technologies added to comply with the standards. To make clear, we distinguish maintenance from repair costs as follows: maintenance costs are those costs that are required to keep a vehicle properly maintained and, as such, are usually recommended by auto makers to be conducted on a regular, periodic schedule. Examples of maintenance costs are oil and air filter changes, tire replacements, etc. Repair costs are those costs that are unexpected and, as such, occur randomly and uniquely for every driver, if at all. Examples of repair costs would be parts replacement following an accident, turbocharger replacement following a mechanical failure, etc.

5.2.2.1 Maintenance Costs

In the joint TSD (see Chapter 3.6), we present our estimates for maintenance cost impacts along with how we derived them. For most technologies that we expect will be added to comply with the final standards, we expect no impact on maintenance costs. In other words, the new technologies have identical maintenance intervals and identical costs per interval as the technologies they will replace. However, for a few technologies, we do expect some maintenance cost changes. As detailed in the Joint TSD, those technologies expected to result in a change in maintenance costs are low rolling resistance tires levels 1 and 2 since they cost more than traditional tires and must be replaced at similar intervals, diesel fuel filters since they must be replaced more frequently and at higher cost than gasoline fuel filters, and several items for full EVs reflecting both reduced costs (oil changes, air filter changes, engine coolant flushes, spark plug replacements, etc.) since they do not need to be done on full EVs and increased costs (related to battery maintenance). Table 5.2-3 presents the maintenance costs and maintenance intervals used in this analysis for those technologies expected to result in expenditure changes.

Table 5.2-3 Maintenance Event Costs & Intervals (2010 dollars)

New Technology	Reference Case	Cost per Maintenance Event	Maintenance Interval (mile)
Low rolling resistance tires level 1	Standard tires	$6.44	40,000
Low rolling resistance tires level 2	Standard tires	$43.52	40,000
Diesel fuel filter replacement	Gasoline vehicle	$49.25	20,000
EV oil change	Gasoline vehicle	-$38.67	7,500
EV air filter replacement	Gasoline vehicle	-$28.60	30,000
EV engine coolant replacement	Gasoline vehicle	-$59.00	100,000
EV spark plug replacement	Gasoline vehicle	-$83.00	105,000
EV/PHEV battery coolant replacement	Gasoline vehicle	$117.00	150,000
EV/PHEV battery health check	Gasoline vehicle	$38.67	15,000

Note that many of the maintenance event costs for EVs are negative. The negative values represent savings since EVs do not incur these costs while their gasoline counterparts do. Note also that the MYs 2012-2016 rule is expected to result in widespread use of low rolling resistance tires level 1 (LRRT1) on the order of 85 percent penetration. Therefore, as the MYs 2017-2025 rule results in increasing use of low rolling resistance tire level 2 (LRRT2), there is a corresponding decrease in the use of LRRT1. As such, as LRRT2 maintenance costs increase with increasing market penetration, LRRT1 maintenance costs decrease. There is further discussion of this point below.

Using the maintenance costs and intervals presented in Table 5.2-3, we can estimate the annual maintenance cost increases/decreases associated with each of these technologies relative to their reference cases counterparts. We have done this by using the VMT schedules discussed in Chapter 4 of the joint TSD to determine when the maintenance events would occur on the average vehicle. These maintenance intervals by mileage throughout the average 2017MY car lifetime are shown in Table 5.2-4.

Table 5.2-4 Maintenance Intervals for the Average 2017MY Car (Events/CY)

CY	MY	Age	Cumulative VMT (with rebound)	LRRT1	LRRT2	Diesel fuel filter	EV oil change	EV air filter	EV engine coolant	EV spark plugs	EV battery coolant	EV battery health
2017	2017	1	15,692	0.4	0.4	0.8	2.1	0.5	0.2	0.1	0.1	1.0
2018	2017	2	30,772	0.4	0.4	0.8	2.0	0.5	0.2	0.1	0.1	1.0
2019	2017	3	45,473	0.4	0.4	0.7	2.0	0.5	0.1	0.1	0.1	1.0
2020	2017	4	59,579	0.4	0.4	0.7	1.9	0.5	0.1	0.1	0.1	0.9
2021	2017	5	73,244	0.3	0.3	0.7	1.8	0.5	0.1	0.1	0.1	0.9
2022	2017	6	86,486	0.3	0.3	0.7	1.8	0.4	0.1	0.1	0.1	0.9
2023	2017	7	99,160	0.3	0.3	0.6	1.7	0.4	0.1	0.1	0.1	0.8
2024	2017	8	110,378	0.3	0.3	0.6	1.5	0.4	0.1	0.1	0.1	0.7
2025	2017	9	121,074	0.3	0.3	0.5	1.4	0.4	0.1	0.1	0.1	0.7
2026	2017	10	131,168	0.3	0.3	0.5	1.3	0.3	0.1	0.1	0.1	0.7
2027	2017	11	140,558	0.2	0.2	0.5	1.3	0.3	0.1	0.1	0.1	0.6
2028	2017	12	149,235	0.2	0.2	0.4	1.2	0.3	0.1	0.1	0.1	0.6
2029	2017	13	157,170	0.2	0.2	0.4	1.1	0.3	0.1	0.1	0.1	0.5
2030	2017	14	164,353	0.2	0.2	0.4	1.0	0.2	0.1	0.1	0.0	0.5
2031	2017	15	170,782	0.2	0.2	0.3	0.9	0.2	0.1	0.1	0.0	0.4
2032	2017	16	176,433	0.1	0.1	0.3	0.8	0.2	0.1	0.1	0.0	0.4
2033	2017	17	181,264	0.1	0.1	0.2	0.6	0.2	0.0	0.0	0.0	0.3
2034	2017	18	185,279	0.1	0.1	0.2	0.5	0.1	0.0	0.0	0.0	0.3
2035	2017	19	188,503	0.1	0.1	0.2	0.4	0.1	0.0	0.0	0.0	0.2
2036	2017	20	191,044	0.1	0.1	0.1	0.3	0.1	0.0	0.0	0.0	0.2
2037	2017	21	192,993	0.0	0.0	0.1	0.3	0.1	0.0	0.0	0.0	0.1
2038	2017	22	194,488	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.1
2039	2017	23	195,661	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.1
2040	2017	24	196,582	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1
2041	2017	25	197,316	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
2042	2017	26	197,933	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
2043	2017	27	198,461	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
2044	2017	28	198,902	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
2045	2017	29	199,277	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
2046	2017	30	199,604	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2047	2017	31	199,736	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2048	2017	32	199,856	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2049	2017	33	199,960	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2050	2017	34	200,049	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2051	2017	35	200,122	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2052	2017	36	200,178	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2053	2017	37	200,218	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2054	2017	38	200,218	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2055	2017	39	200,218	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2056	2017	40	200,218	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note: Results correspond to the 2008 baseline fleet.

Note that the table presents fractional maintenance intervals. Obviously, a given car cannot undergo a fractional maintenance interval. However, some cars will undergo the maintenance while others will not and, on average, the intervals would occur as shown. Similar tables could be shown for a 2017MY truck which, because the VMT is higher, would show more maintenance intervals. Tables for 2018 through 2025MY cars and trucks would also differ as the VMT schedule changes by MY. However, since the information is very similar and conceptually identical, we have not shown all of those tables but have placed them in the docket.[76]

Importantly, the maintenance intervals shown are generated using a survival adjusted VMT schedule, so the maintenance intervals are adjusted by survival rates. Further, the VMT used includes rebound miles driven since the costs we are estimating here are societal costs (in Section 5.5 we exclude rebound miles since the maintenance costs considered there are private costs). Further, including rebound miles helps to ensure that our estimates remain conservative since more miles means more maintenance and, therefore, more costs.[EEEEE]

Using the information shown in Table 5.2-4, we can easily calculate the maintenance costs using the cost per event information presented in Table 5.2-3. However, we also need to consider the penetrations of each technology. For example, our OMEGA modeling predicts that no gasoline sales will be converted to diesel sales making the diesel fuel filter maintenance costs essentially moot for our maintenance analysis. Similarly, our EV penetration rates are on the order of 1-3% so, while an EV could provide considerable maintenance savings relative to a gasoline vehicle, those savings have little impact in our analysis because so few gasoline sales are expected to be converted to EVs. Note that PHEVs would be expected to incur the battery coolant and battery health check costs, as do EVs, but would not see the savings that EVs see since most of the typical gasoline maintenance would probably be required on a PHEV. The penetration rates used in this analysis are those presented in Chapter 3.8 of this RIA and are shown in Table 5.2-5 for the relevant technologies.

Table 5.2-5 Fleet Mix and Penetration Rates used for Maintenance Costs

MY	Fleet Mix		LRRT1		LRRT2		Diesel		EV		PHEV	
	Car	Truck	Car	Truck	Car	Truck	Car	Truck	Car	Truck	Car	Truck
2016			85.0%	85.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2017	63%	37%	0.6%	0.2%	14.4%	14.8%	-0.4%	-0.1%	0.2%	0.0%	0.0%	0.0%
2018	64%	36%	-13.9%	-14.6%	28.9%	29.6%	-0.8%	-0.2%	0.4%	0.0%	0.0%	0.0%
2019	64%	36%	-28.3%	-29.3%	43.3%	44.3%	-1.2%	-0.3%	0.7%	0.0%	0.1%	0.0%
2020	65%	35%	-42.7%	-44.1%	57.7%	59.1%	-1.7%	-0.4%	0.9%	0.0%	0.1%	0.0%
2021	65%	35%	-57.2%	-58.9%	72.2%	73.9%	-2.1%	-0.5%	1.1%	0.0%	0.1%	0.0%
2022	65%	35%	-63.2%	-65.2%	78.2%	80.2%	-2.1%	-0.5%	1.5%	0.1%	0.1%	0.0%
2023	66%	34%	-69.2%	-71.6%	84.2%	86.6%	-2.1%	-0.5%	1.9%	0.2%	0.1%	0.0%
2024	66%	34%	-75.2%	-77.9%	90.2%	92.9%	-2.1%	-0.5%	2.3%	0.2%	0.1%	0.0%
2025	67%	33%	-81.2%	-84.3%	96.2%	99.3%	-2.1%	-0.6%	2.7%	0.3%	0.1%	0.0%

Note: The penetration rates shown reflect results of our OMEGA runs and represent our estimated response to the 2017-2025 GHG standards, not necessarily the true fleet penetration; results correspond to the 2008 baseline fleet.

Now, using the maintenance event costs, the maintenance intervals and the technology penetration rates, we can estimate the maintenance cost changes resulting from the new standards. For a 2017MY car, those costs are shown in Table 5.2-6.

[EEEEE] Of course, more miles means more savings in the case of EVs. However, since EV penetration rates are quite low in our analysis which minimizes their influence.

Table 5.2-6 Sales Weighted Maintenance Costs for a 2017MY Car (2010 dollars)

CY	MY	Age	Cumulative VMT (with rebound)	LRRT1	LRRT2	Diesel fuel filter	EV (all items)	PHEV (all items)	Total
2017	2017	1	15,692	$0.01	$2.47	-$0.16	-$0.14	$0.01	$2.19
2018	2017	2	30,772	$0.01	$2.37	-$0.15	-$0.14	$0.01	$2.10
2019	2017	3	45,473	$0.01	$2.31	-$0.15	-$0.13	$0.01	$2.05
2020	2017	4	59,579	$0.01	$2.21	-$0.14	-$0.13	$0.01	$1.96
2021	2017	5	73,244	$0.01	$2.15	-$0.14	-$0.12	$0.01	$1.91
2022	2017	6	86,486	$0.01	$2.08	-$0.14	-$0.12	$0.01	$1.85
2023	2017	7	99,160	$0.01	$1.99	-$0.13	-$0.11	$0.01	$1.77
2024	2017	8	110,378	$0.01	$1.76	-$0.11	-$0.10	$0.01	$1.56
2025	2017	9	121,074	$0.01	$1.67	-$0.11	-$0.10	$0.01	$1.48
2026	2017	10	131,168	$0.01	$1.59	-$0.10	-$0.09	$0.01	$1.41
2027	2017	11	140,558	$0.01	$1.47	-$0.10	-$0.08	$0.01	$1.30
2028	2017	12	149,235	$0.01	$1.36	-$0.09	-$0.08	$0.01	$1.21
2029	2017	13	157,170	$0.01	$1.25	-$0.08	-$0.07	$0.00	$1.11
2030	2017	14	164,353	$0.01	$1.13	-$0.07	-$0.06	$0.00	$1.00
2031	2017	15	170,782	$0.01	$1.01	-$0.07	-$0.06	$0.00	$0.90
2032	2017	16	176,433	$0.01	$0.89	-$0.06	-$0.05	$0.00	$0.79
2033	2017	17	181,264	$0.00	$0.76	-$0.05	-$0.04	$0.00	$0.67
2034	2017	18	185,279	$0.00	$0.63	-$0.04	-$0.04	$0.00	$0.56
2035	2017	19	188,503	$0.00	$0.51	-$0.03	-$0.03	$0.00	$0.45
2036	2017	20	191,044	$0.00	$0.40	-$0.03	-$0.02	$0.00	$0.35
2037	2017	21	192,993	$0.00	$0.31	-$0.02	-$0.02	$0.00	$0.27
2038	2017	22	194,488	$0.00	$0.24	-$0.02	-$0.01	$0.00	$0.21
2039	2017	23	195,661	$0.00	$0.19	-$0.01	-$0.01	$0.00	$0.16
2040	2017	24	196,582	$0.00	$0.14	-$0.01	-$0.01	$0.00	$0.13
2041	2017	25	197,316	$0.00	$0.12	-$0.01	-$0.01	$0.00	$0.10
2042	2017	26	197,933	$0.00	$0.10	-$0.01	-$0.01	$0.00	$0.09
2043	2017	27	198,461	$0.00	$0.08	-$0.01	$0.00	$0.00	$0.07
2044	2017	28	198,902	$0.00	$0.07	$0.00	$0.00	$0.00	$0.06
2045	2017	29	199,277	$0.00	$0.06	$0.00	$0.00	$0.00	$0.05
2046	2017	30	199,604	$0.00	$0.05	$0.00	$0.00	$0.00	$0.05
2047	2017	31	199,736	$0.00	$0.02	$0.00	$0.00	$0.00	$0.02
2048	2017	32	199,856	$0.00	$0.02	$0.00	$0.00	$0.00	$0.02
2049	2017	33	199,960	$0.00	$0.02	$0.00	$0.00	$0.00	$0.01
2050	2017	34	200,049	$0.00	$0.01	$0.00	$0.00	$0.00	$0.01
2051	2017	35	200,122	$0.00	$0.01	$0.00	$0.00	$0.00	$0.01
2052	2017	36	200,178	$0.00	$0.01	$0.00	$0.00	$0.00	$0.01
2053	2017	37	200,218	$0.00	$0.01	$0.00	$0.00	$0.00	$0.01
2054	2017	38	200,218	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2055	2017	39	200,218	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2056	2017	40	200,218	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00

Note: Results correspond to the 2008 baseline fleet.

Again, similar tables could be generated for trucks and for each MY. Note the small costs for LRRT1. This is because the MYs 2017-2025 rule is expected to result in a very low penetration of LRRT1. Table 5.2-5 shows only a 1% penetration rate for the 2017MY after which the penetration starts to fall as LRRT2 replaces LRRT1. The analogous information for a 2025MY car makes this clear, as shown in Table 5.2-7.

Table 5.2-7 Sales Weighted Maintenance Costs for a 2025MY Car (2010 dollars)

CY	MY	Age	Cumulative VMT (with rebound)	LRRT1	LRRT2	Diesel fuel filter	EV (all items)	PHEV (all items)	Total
2025	2025	1	16,906	-$2.21	$17.70	-$0.87	-$1.87	$0.07	$12.82
2026	2025	2	33,154	-$2.13	$17.00	-$0.84	-$1.80	$0.07	$12.30
2027	2025	3	48,996	-$2.07	$16.50	-$0.82	-$1.75	$0.07	$11.93
2028	2025	4	64,197	-$1.99	$15.90	-$0.79	-$1.68	$0.06	$11.51
2029	2025	5	78,924	-$1.92	$15.40	-$0.76	-$1.63	$0.06	$11.15
2030	2025	6	93,196	-$1.87	$14.90	-$0.74	-$1.58	$0.06	$10.77
2031	2025	7	106,862	-$1.79	$14.30	-$0.71	-$1.51	$0.06	$10.35
2032	2025	8	118,950	-$1.58	$12.70	-$0.63	-$1.34	$0.05	$9.20
2033	2025	9	130,479	-$1.51	$12.00	-$0.60	-$1.28	$0.05	$8.66
2034	2025	10	141,359	-$1.42	$11.30	-$0.56	-$1.20	$0.05	$8.16
2035	2025	11	151,483	-$1.32	$10.60	-$0.52	-$1.12	$0.04	$7.68
2036	2025	12	160,840	-$1.23	$9.81	-$0.48	-$1.04	$0.04	$7.10
2037	2025	13	169,397	-$1.12	$8.95	-$0.44	-$0.95	$0.04	$6.48
2038	2025	14	177,144	-$1.01	$8.11	-$0.40	-$0.86	$0.03	$5.88
2039	2025	15	184,078	-$0.91	$7.25	-$0.36	-$0.77	$0.03	$5.24
2040	2025	16	190,173	-$0.80	$6.38	-$0.32	-$0.68	$0.03	$4.62
2041	2025	17	195,381	-$0.68	$5.45	-$0.27	-$0.58	$0.02	$3.94
2042	2025	18	199,707	-$0.57	$4.53	-$0.23	-$0.48	$0.02	$3.28
2043	2025	19	203,178	-$0.45	$3.64	-$0.18	-$0.38	$0.01	$2.64
2044	2025	20	205,912	-$0.36	$2.86	-$0.14	-$0.30	$0.01	$2.07
2045	2025	21	208,008	-$0.27	$2.19	-$0.11	-$0.23	$0.01	$1.58
2046	2025	22	209,612	-$0.21	$1.68	-$0.08	-$0.18	$0.01	$1.22
2047	2025	23	210,870	-$0.16	$1.32	-$0.07	-$0.14	$0.01	$0.96
2048	2025	24	211,856	-$0.13	$1.03	-$0.05	-$0.11	$0.00	$0.75
2049	2025	25	212,640	-$0.10	$0.82	-$0.04	-$0.09	$0.00	$0.59
2050	2025	26	213,298	-$0.09	$0.69	-$0.03	-$0.07	$0.00	$0.50
2051	2025	27	213,860	-$0.07	$0.59	-$0.03	-$0.06	$0.00	$0.43
2052	2025	28	214,329	-$0.06	$0.49	-$0.02	-$0.05	$0.00	$0.35
2053	2025	29	214,727	-$0.05	$0.42	-$0.02	-$0.04	$0.00	$0.30
2054	2025	30	215,073	-$0.05	$0.36	-$0.02	-$0.04	$0.00	$0.26
2055	2025	31	215,210	-$0.02	$0.14	-$0.01	-$0.02	$0.00	$0.10
2056	2025	32	215,333	-$0.02	$0.13	-$0.01	-$0.01	$0.00	$0.09
2057	2025	33	215,440	-$0.01	$0.11	-$0.01	-$0.01	$0.00	$0.08
2058	2025	34	215,532	-$0.01	$0.10	$0.00	-$0.01	$0.00	$0.07
2059	2025	35	215,607	-$0.01	$0.08	$0.00	-$0.01	$0.00	$0.06
2060	2025	36	215,664	-$0.01	$0.06	$0.00	-$0.01	$0.00	$0.04
2061	2025	37	215,705	-$0.01	$0.04	$0.00	$0.00	$0.00	$0.03
2062	2025	38	215,705	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2063	2025	39	215,705	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2064	2025	40	215,705	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00

Note: Results correspond to the 2008 baseline fleet.

Doing this for all model years and adding up costs across given calendar years matched with the appropriate sales provides the annual maintenance costs shown in Table 5.2-8.

Table 5.2-8 Undiscounted Sales Weighted Annual Maintenance Costs & Costs Discounted back to 2012 at 3% and 7% Discount Rates (millions of 2010 dollars)

CY	LRRT1		LRRT2		Diesel		EV		PHEV		Total		
	Car	Truck	Car	Truck	Car	Truck	Car	Truck	Car	Truck	Car	Truck	Vehicle
2017	$0	$0	$25	$16	-$2	$0	-$1	$0	$0	$0	$22	$16	$37
2018	-$3	-$2	$73	$45	-$5	-$1	-$4	$0	$0	$0	$61	$43	$103
2019	-$11	-$7	$146	$88	-$10	-$1	-$8	$0	$1	$0	$118	$80	$199
2020	-$22	-$13	$250	$146	-$16	-$2	-$14	$0	$1	$0	$199	$131	$330
2021	-$37	-$22	$381	$221	-$25	-$3	-$22	$0	$1	$0	$298	$196	$494
2022	-$55	-$32	$526	$299	-$34	-$4	-$32	$0	$2	$0	$408	$262	$670
2023	-$75	-$42	$685	$379	-$42	-$5	-$46	-$1	$3	$0	$525	$331	$856
2024	-$97	-$52	$862	$462	-$52	-$6	-$63	-$2	$3	$0	$654	$402	$1,060
2025	-$121	-$64	$1,050	$554	-$61	-$8	-$84	-$3	$4	$0	$792	$479	$1,270
2030	-$234	-$119	$1,940	$976	-$103	-$13	-$183	-$9	$8	$0	$1,430	$836	$2,260
2040	-$396	-$193	$3,190	$1,540	-$160	-$20	-$331	-$17	$13	$0	$2,320	$1,310	$3,630
2050	-$493	-$247	$3,950	$1,970	-$195	-$25	-$417	-$22	$16	$0	$2,860	$1,680	$4,540
NPV, 3%	-$4,140	-$2,070	$34,100	$17,000	-$1,770	-$223	-$3,350	-$163	$135	$0	$24,900	$14,500	$39,500
NPV, 7%	-$1,600	-$807	$13,400	$6,710	-$706	-$89	-$1,270	-$60	$53	$0	$9,830	$5,760	$15,600

Note: Costs include maintenance incurred during rebound miles; results correspond to the 2008 baseline fleet.

We can also look at the costs on a model year basis by looking at the net present value of costs and savings over the full lifetime of each model year of vehicles. The net present value lifetime costs and savings for each MY 2017-2025 are shown in Table 5.2-9 using a 3% discount rate and in Table 5.2-10 using a 7% discount rate.

Table 5.2-9 Model Year Lifetime Present Value Maintenance Costs and Savings, Discounted to the 1st Year of each MY at 3% (millions of 2010 dollars)

MY	Tires		Diesel		EV		PHEV		Total			$Million per MY		
	$/c	$/t	$/c	$/t	$/c	$/t	$/c	$/t	$/c	$/t	$/veh	$/c	$/t	$/veh
2017	$25	$27	-$2	$0	-$1	$0	$0	$0	$22	$26	$24	$222	$153	$375
2018	$47	$50	-$3	-$1	-$3	$0	$0	$0	$41	$49	$44	$406	$279	$684
2019	$69	$74	-$5	-$1	-$4	$0	$0	$0	$60	$72	$65	$600	$404	$1,000
2020	$92	$97	-$7	-$2	-$6	$0	$0	$0	$80	$95	$85	$819	$534	$1,350
2021	$115	$123	-$8	-$2	-$7	$0	$0	$0	$99	$121	$107	$1,040	$686	$1,730
2022	$125	$134	-$9	-$2	-$10	-$1	$1	$0	$107	$131	$115	$1,150	$747	$1,890
2023	$135	$146	-$9	-$2	-$13	-$1	$1	$0	$114	$142	$124	$1,250	$810	$2,060
2024	$146	$157	-$9	-$2	-$16	-$2	$1	$0	$122	$153	$132	$1,380	$867	$2,240
2025	$157	$169	-$9	-$2	-$19	-$2	$1	$0	$130	$164	$141	$1,490	$936	$2,430
Sum	$911	$975	-$60	-$15	-$80	-$6	$4	$0	$775	$954	$836	$8,360	$5,420	$13,800

Note: Costs include maintenance incurred during rebound miles; results correspond to the 2008 baseline fleet.

Table 5.2-10 Model Year Lifetime Present Value Maintenance Costs and Savings, Discounted to the 1st Year of each MY at 7% (millions of 2010 dollars)

MY	Tires		Diesel		EV		PHEV		Total			$Million per MY		
	$/c	$/t	$/c	$/t	$/c	$/t	$/c	$/t	$/c	$/t	$/veh	$/c	$/t	$/veh
2017	$20	$21	-$1	$0	-$1	$0	$0	$0	$17	$20	$18	$172	$118	$290
2018	$36	$38	-$3	-$1	-$2	$0	$0	$0	$32	$38	$34	$314	$214	$528
2019	$54	$56	-$4	-$1	-$3	$0	$0	$0	$47	$56	$50	$465	$310	$775
2020	$71	$75	-$5	-$1	-$5	$0	$0	$0	$62	$73	$66	$634	$411	$1,050
2021	$89	$94	-$7	-$2	-$6	$0	$0	$0	$77	$92	$82	$812	$523	$1,330
2022	$97	$102	-$7	-$2	-$8	$0	$0	$0	$83	$100	$89	$887	$570	$1,460
2023	$106	$112	-$7	-$2	-$10	-$1	$0	$0	$89	$109	$96	$977	$620	$1,600
2024	$113	$121	-$7	-$2	-$12	-$1	$1	$0	$94	$118	$102	$1,060	$669	$1,730
2025	$122	$129	-$7	-$2	-$15	-$2	$1	$0	$101	$126	$109	$1,160	$718	$1,880
Sum	$707	$747	-$46	-$12	-$62	-$4	$3	$0	$601	$731	$646	$6,480	$4,150	$10,600

Note: Costs include maintenance incurred during rebound miles; results correspond to the 2008 baseline fleet.

5.2.2.2 Repair Costs

For repair costs, EPA has found it much more difficult to find transparent data upon which to base any estimated cost differences. Because repairs occur randomly and uniquely for individual vehicle owners, we have no clear schedules to compare as was done above for maintenance costs. While it is reasonable to assume that more expensive vehicles are more expensive to repair, we have no certain methodology of quantifying those costs.

Repair costs can be broken down into two primary types: those resulting from accidents or collisions, and those resulting from component failures. Some accidents/collisions result in the "totaling" of the vehicle. In those cases, our primary analyses already include in our benefit-cost analyses the cost associated with losing more expensive vehicles, since the new vehicle sales estimates include sales to replace totaled vehicles, and we apply marginal per vehicle costs to all new vehicle sales. In some other cases, accidents/collisions may not result in a repair. Especially as vehicles age, owners may decide that non-vital repairs are no longer justifiable. As a result, the accidents and collisions of interest to us are actually a subset of those that occur, since we would not want to include those that result in a "totaled" determination, or those that result in no additional cost of repair. For that subset of accidents and collisions, the key question is whether repair costs would increase or decrease as a result of this rule. We do not include those costs here, because we lack data on the effects of this rule on repair costs. For instance, it is possible that lighter-weight body components may be either more or less expensive to repair in the case of dents than current body components. In the absence of such data, we acknowledge this omission from our cost estimates. We note that our payback analysis includes increased costs associated with insurance premiums (higher insurance premiums for a higher priced vehicle), to reflect the out-of-pocket costs that vehicle buyers will face. The insurance premiums do not provide good measures of the increased repair costs for use in the benefit-cost analysis, though, because they include costs associated with "totaled" vehicles that, as noted, are already accounted for in the vehicle sales estimates.

The other type of repair costs, those for component failures, is similarly difficult to estimate. Our ICMs include a warranty factor that is generally higher than the average warranty level for some initial number of years. This increased level of warranty cost is meant to cover probable increases in warranty expenses incurred by auto makers as they introduce new technologies. Increased warranty expenses are typical in any industry when a new product or new technology is introduced. No matter what level of pre-production testing is done, not all failure modes can be predicted or accurately captured in that testing. As such, failure rates are generally higher than "typical" during some period following first introduction. Following this period of higher than normal warranty costs, our ICM warranty factor is reduced to reflect the "working out" of failure issues and a return to a normal level of warranty expense (i.e., suppliers and auto makers learn from experience and reduce costs). Importantly, our ICM factors continue to consider warranty costs indefinitely, they are not assumed to be $0 at any point in time.

For out-of-warranty repair costs, it could be argued that vehicles meeting the new standards will certainly be more complex than those meeting the reference case standards (e.g., turbocharged vehicles have a turbocharger and, by definition, their intake and exhaust systems are more complex than those on naturally aspirated engines). Increased complexity generally implies increased chances for failures. In an effort to shed light on this possibility, we searched for a reliable source of data that would show how vehicle repair rates differed for vehicles with traditional technology versus those with the types of technologies we project can be employed to comply with the new standards. Unfortunately, after a thorough search it was determined that there currently is no reliable source for data or a study on failure rates and changes in repair cost for the new technologies being forecast to be used in this rule.

EPA received only one comment[FFFFF] on this issue. NADA commented that the agencies should account for the cost of ownership and referred to the calculator provided on its website. Based on EPA's review of this tool, it appears that the NADA calculator considers the first 5 years of ownership. However, based on a search of several vehicles shown in Table 5.2-11, we have found no significant increase in repair when comparing hybrids with non-hybrid versions of the same vehicles. We also found no significant difference in repair cost when comparing vehicles with a manual transmission to one with an automatic transmission, or when comparing a vehicle with turbo charged engine vs. a naturally aspirated engine. There was a $455 dollar difference between the diesel vs. gasoline engine equipped vehicles. Though we did a thorough search of the NADA site, we were not able to determine the underlying data on which these projections are made. This means that the difference in repair cost could be due to factors other than powertrain components such as radio, lights, electric windows, or brakes, to name but a few examples.

[FFFFF] "The benefits analysis used in the proposal uses an oversimplified pay-back method that overstates potential fuel economy savings. Instead, for purposes of calculating any "pay-back," real-world finance, opportunity, and additional maintenance costs should be accounted for. In other words, the final rule should evaluate its potential impact on a vehicle's total cost of ownership. An example of such a calculator is found at http://www.nadaguides.com/Cars/Cost-to-Own. NADA would welcome the opportunity to discuss further with EPA and NHTSA how prospective purchasers of new light-duty customers would be better served by a total cost of ownership approach to understanding a given vehicle's future costs of operation."

Table 5.2-11 NADA Repair Cost Data Technology Being Compared

	Vehicle	Estimated 5 Year Repair Cost	Repair Cost Difference
Hybrid FWD to Non-Hybrid AWD	2012 Ford Fusion HEV FWD	$2,691	$71
	2012 Ford Fusion SEL AWD	$2,620	
Hybrid to Non-Hybrid	2012 Honda Civic Hybrid	$2,157	$24
	2012 Honda Civic LX	$2,133	
Hybrid to Non-Hybrid	2012 Toyota Camry Hybrid LE	$2,133	$0
	2012 Toyota Camry Auto LE	$2,133	
Hybrid to Non-Hybrid	2012 Ford Escape XLT FWD	$2,275	$0
	2012 Ford Escape Hybrid FWD	$2,275	
Turbo Diesel to Standard Gas	2012 Volkswagen Touareg TDI Sport	$3,298	$455
	2012 Volkswagen Touareg VR6 Sport	$2,843	
6 Speed Manual Trans (Base) to 6 Speed Auto Trans	2012 Kia Sorento I4 Base	$1,071	$0
	2012 Kia Sorento I4 LX	$1,071	
Hybrid to Non-Hybrid to Turbo Downsized Engine	2012 Hyundai Sonata 2.0T Auto Limited	$1,142	$71
	2012 Hyundai Sonata 2.4L Auto Hybrid	$1,071	$0
	2012 Hyundai Sonata 2.4L Auto Limited	$1,071	
Turbo Charged Engine to Natually Aspirated Engine	2012 Ford Taurus SHO (Turbo) AWD	$2,843	$0
	2012 Ford Taurus SEL AWD	$2,843	

While we did not find specific repair data on the projected technologies, data are available on vehicle reliability which we believe provides a reasonable basis to project no net increase in future failure rates. Both J. D. Power and Consumer Reports have annual dependability/reliability studies. We have examined these sources in detail.

The J.D. Power and Associates Vehicle Dependability Study (VDS) provides information about long-term vehicle quality after three years of ownership, when most vehicles reach the end of the warranty period and owners assume responsibility for repair costs. Owners rate vehicles based on problems experienced during the previous 12 months in a variety of categories, including ride/handling/braking, engine and transmission, and a broad range of vehicle quality problems. The VDS study has been an industry benchmark since 1990. The information we found is presented in Table 5.2-12.

Consumer Reports puts out an “Annual Auto Survey,” which is sent to Consumer Reports’ print and Web subscribers and conducted by the Consumer Reports National Research Center. Respondents report on their vehicles in any of the trouble spots during the previous 12 months, and each year’s survey is independent of the previous year’s survey. Consumer Reports’ most recent survey covered model year 2005 through 2010 models and focused on problems that the respondents considered serious because of cost, failure, safety, or downtime. At the time of their latest survey most 2010 models were less than 6 months old and were driven an average of 3,000 miles, while the 2005 models were about 5 years old.

Both the J. D. Power and the Consumer Reports surveys show positive results for vehicles with advanced technologies, specifically hybrid vehicles. We were not able to find a source for projecting failure rates for individual technologies.

Table 5.2-12 J. D. Power Vehicle Dependability Survey Data 2000 to 2009 Model Year Vehicles

JD Powers Survey Report	Vehicle Model Year Covered by Survey	Industry Average Repairs per 100 Vehicles
2012	2009	132
2011	2008	151
2010	2007	155
2009	2006	170
2008	2005	206
2007	2004	216
2006	2003	227
2005	2002	237
2004	2001	269
2003	2000	273

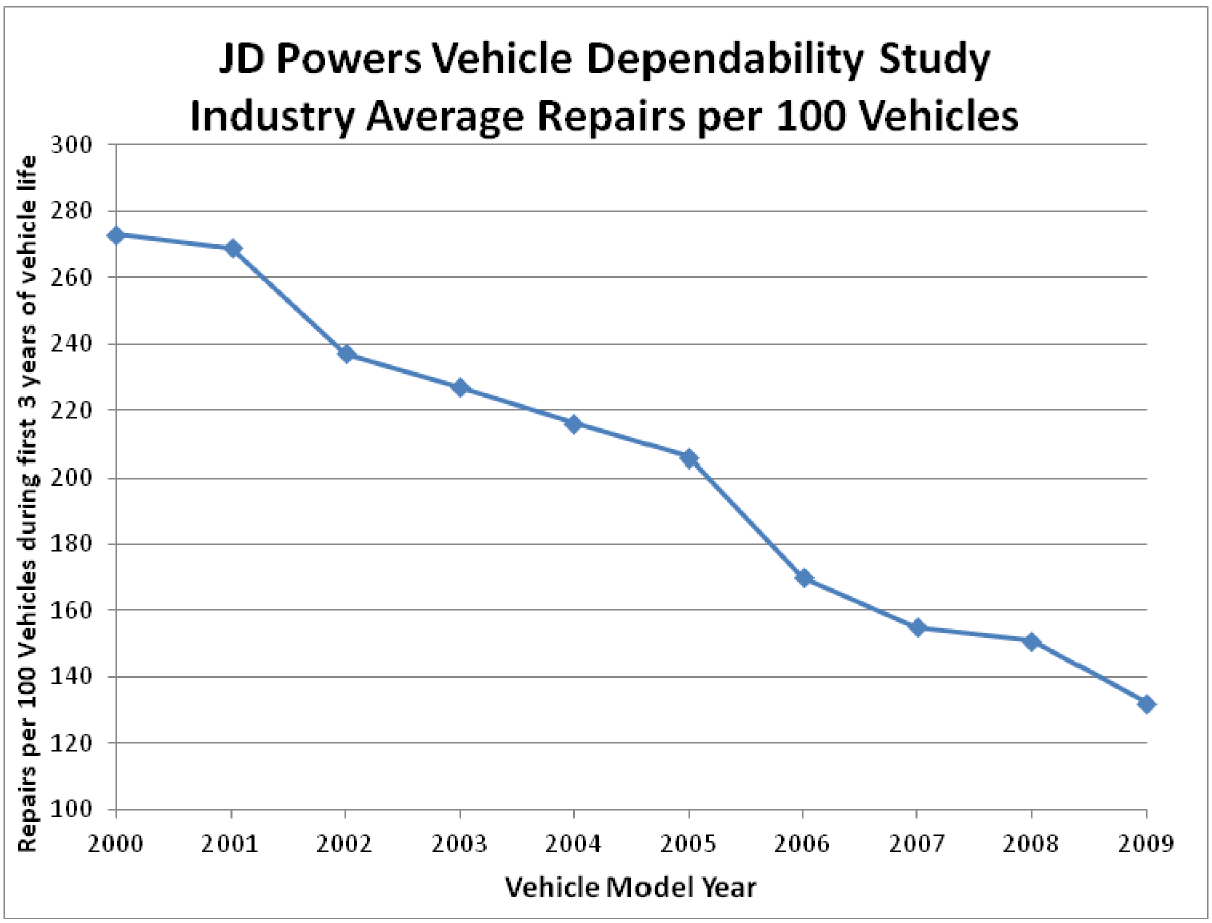

Figure 5-1 J. D. Power VDS Data 2000 Model Year to 2009 Model Year

For J. D. Power's VDS results we present here the industry average repairs per 100 vehicles with data starting in the 2000 model year (published in 2003) and ending in the 2009 model year (published in 2012). Table 5.2-12 and Figure 5-1 show the VDS results for 2000-2009 model years. One can see that there is a distinct trend toward decreased problems reported per 100 vehicles for model years 2000 to 2009. The repairs per 100 vehicles metric has roughly halved in the decade spanning 2003 to 2012 (i.e., for model years 2000 through 2009). This trend occurred concurrently with an increasing frequency of complex technologies added to vehicles. This complexity includes improvements in powertrain, safety, and many consumer related electronic features. Table 5.2-13 and Table 5.2-14 show Engine Characteristics and Transmission Characteristics, respectively, that have been added to 2000 to 2009 model year vehicles. The data in these tables are based on the EPA's 2010 Trends Report. The two tables show increased penetration in some of the more complex engine technologies such as GDI, VVT, CD (cylinder deactivation), Multi-Valve, Gasoline Hybrid, Turbocharged engines. There is also a significant penetration of advanced transmissions (CVTs and 6 speeds). All of these advanced technologies have been added while reliability has improved significantly as shown in FIGURE. The data definitely show that vehicle reliability has improved dramatically even as manufacturers are moving toward increasingly complex powertrains. While we do not have specific data on the change in other attributes, EPA is confident that 2009MY vehicles are also more complex than 2000MY vehicles in their use of navigation systems, entertainment systems, power-seats, and several safety related features (e.g. number of airbags and electronic stability control systems).

J.D. Power also stated in a February 15, 2012, press release that the Toyota Prius (a hybrid only vehicle) had the lowest problems per 100 score (80). The vehicle with the next closest score (93) in its segment was the Toyota Corolla, which happens to be the closest vehicle from Toyota to being a gasoline-only equivalent of the Prius.

Table 5.2-13 Engine Characteristics of MY 2000 to MY 2009 Light Duty Vehicles

Cars and Trucks		2000 Model Year	2009 Model Year
Powertrain	Gasoline	99.90%	97.20%
	Gasoline Hybrid	0.00%	2.30%
	Diesel	0.10%	0.50%
Fuel Injection Metering Method	Gasoline Direct Injection	-	4.2%
	Port Fuel Injection	99.80%	95.20%
	Throttle Body Injection	0.00%	-
	Diesel	0.10%	0.50%
Multi-Valve		44.80%	83.60%
Variable Valve Timing		15.00%	72.00%
Cylinder Deactivation		-	7.40%
Boosted (Turbocharged or Supercharged)		1.70%	3.50%

Table 5.2-14 Transmission and Drive Characteristics of MY 2000 to MY 2009 Light Duty Vehicles

Cars and Trucks	2000 Model Year	2009 Model Year
Manual	9.7%	4.7%
CVT	0.0%	9.5%
4 Gears or Fewer	83.8%	31.5%
5 Gears	15.8%	31.6%
6 Gears	0.5%	24.7%
7 Gears or More	-	2.6%

We also looked at information from Consumer Reports. Here we looked at both the April 2011 and the December 2011 monthly publications. The April issues covered reliability of individual models based on customer surveys, while the December issue analyzed and predicted future reliability of vehicles based on past trends.

In the April issue, it is clear that hybrid models consistently have equal or greater powertrain (engine and transmission) reliability than their non-hybrid counterparts. Hybrid models shown for which there exists a non-hybrid counterpart are the Ford Escape, Honda Civic, Lexus RX, Mercury Mariner, Nissan Altima, Toyota Highlander, and Toyota Camry. Each of the hybrid models has a significantly more complex powertrain than its non-hybrid counterpart while having equal or better reliability history.

In the December 2011 issue, Consumer Reports predicts future reliability rating in vehicle categories such as family cars, small hatchbacks, small SUVs, etc. In every category in which a hybrid was offered, the hybrid's reliability was the best or at least in the top 5 vehicles in the category. No hybrid was in the "not recommended" category for reliability. The Ford Fusion Hybrid was the family car with the best predicted reliability. The Toyota Prius was the fuel-efficient hatchback with the best predicted reliability of any other vehicle with sufficient data. The only vehicle that scored higher was also a hybrid, but did not have sufficient data to warrant mentioning.

Also in the 2011 issue was the first mention of Ford's EcoBoost engines. The EcoBoost engine is an example of a turbocharged and downsized engine with GDI. This type of engine is one of the most complex gasoline technologies used in the automotive industry, and our modeling projects widespread use in both the car and truck fleets to meet the standards. See preamble Tables III-49 and III-52. The Ford F150 with EcoBoost is a "recommended" vehicle by Consumer Reports. This means that Consumer Reports expects the vehicle to have above-average reliability. It is worth mentioning that the Ford Flex with EcoBoost is not recommended. EPA checked the Consumer Reports website[GGGGG] to determine if its concern was with the EcoBoost engine or other systems. The website showed

[GGGGG] The data is available on its website (http://www.consumerreports.org/) to subscribers.

the reliability of the EcoBoost engine is much better than average and there are other problems with that model that gave them reason to give it a “not recommended” rating.

Another source for information on turbo charged engines is Paul Tan’s Automotive News[HHHHH]. The site has an article on turbo charged engine failure rates that cites some data from an aftermarket warranty company in UK called Warranty Direct. The article states that (based on the Warranty Direct data) turbo charged engines are expected to have higher failure rates and repair costs than non turbo charged engines. It also states: "Of course, data such as this benefits companies like Warranty Direct, which sell extended warranty coverage which you can buy for your car when your manufacturer warranty expires. So there is a hidden motive in them delivering this message to the public. But if it is backed by data, it could warrant a little worry." The article hasn't verified that its source (Warranty Direct) has data to back up its numbers. If their numbers are really just based on the warranty claims it pays, it could simply be that more customers who have Turbo Charged vehicles elect their coverage. Since the article has not verified the data, they do not know the years the vehicle data are from, the types of vehicles (SUV, passenger cars, etc.), nor do they know the average age or average mileage of the vehicles being compared. At best, the data from Warrant Direct is speculative on the future failure rates of downsized engines based on past turbo charged engine vehicles, which were typically designed for performance versions of vehicles that are typically made in limited production vs. high production turbo downsized engines.

Furthermore, we believe that the evidence presented here suggests that the warranty portion of some of our indirect cost multipliers (ICM) may be slightly overstated. In developing our ICMs, warranty costs were generally estimated to increase over normal practice due to the move to new and, more significantly, more complex technologies. This may, in fact, not be the case; perhaps the warranty portion of the ICM should be lower than “normal” or, at least, on par with it. We have not made such a change for the final rule in order to keep costing methodology conservative (i.e., err on the side of estimating increased costs), but we intend to consider this in the future.

Over the last ten years, vehicle powertrain complexity has been on a steady rise. Vehicle manufacturers have stepped up efforts to improve powertrain quality, in part due to On Board Diagnostics (OBD). OBD has made powertrain issues more visible to consumers, and correcting these issues has made manufacturers’ warranty due to OBD components more visible. Almost every engine, transmission or hybrid component failure will cause the check engine indicator to light. In response to the increased warranty, manufacturers have increased their internal requirements for powertrain durability and now qualify most powertrain/OBD components to last 15 years or 150,000 miles. Due to the expense of paying for replacement parts for the most costly powertrains, such as hybrids or turbo downsized engines, we expect manufacturers will continue to improve quality. Also, with the industry making its most reliable vehicles in its history, reliability is the price of entry into a marketplace that will no longer accept less. Due to improved reliability of powertrains, the expected repair costs for powertrain systems are expected to decrease in the future, though in our analysis EPA has taken a conservative estimate of zero incremental costs. Furthermore, we believe that there is

[HHHHH] A free web based automotive news site. http://paultan.org/

evidence to show that EPA should consider adjusting the indirect cost multipliers based on these findings. We believe that there is evidence to show that the agency should adjust the maintenance and repair portion of the ICM such that it does not increase with added complexity. The agency will consider this for the mid-term evaluation.

5.2.3 Vehicle Program Costs

Annual costs of the vehicle program are the annual technology costs shown in Table 5.2-1 and the annual maintenance costs shown in Table 5.2-8. Those results are shown in Table 5.2-15.

Table 5.2-15 Undiscounted Annual Program Costs & Costs Discounted back to 2012 at 3% and 7% Discount Rates (2010 dollars)

Calendar Year	Car	Truck	Total Annual Costs
2017	$2,080	$350	$2,470
2018	$3,760	$1,150	$4,950
2019	$5,220	$1,780	$7,020
2020	$6,730	$2,450	$9,190
2021	$8,360	$4,530	$12,900
2022	$12,000	$7,030	$19,000
2023	$15,400	$9,210	$24,600
2024	$18,900	$11,300	$30,200
2025	$20,700	$12,200	$32,900
2030	$22,900	$13,100	$35,900
2040	$26,400	$14,600	$41,000
2050	$29,900	$16,600	$46,500
NPV, 3%	$361,000	$200,000	$561,000
NPV, 7%	$159,000	$87,700	$247,000

Note: Results correspond to the 2008 baseline fleet.

Model year lifetime costs of the vehicle program are the MY lifetime technology costs shown in Table 5.2-2 and the MY lifetime maintenance costs shown in Table 5.2-9 and Table 5.2-10. Those results are shown in Table 5.2-16.

Table 5.2-16 Model Year Lifetime Present Value Vehicle Program Costs Discounted to the 1st Year of each MY at 3% & 7% (millions of 2010 dollars)

NPV at	MY →	2017	2018	2019	2020	2021	2022	2023	2024	2025	Sum
3%	Cars	$2,250	$4,050	$5,620	$7,250	$8,990	$12,600	$15,900	$19,400	$21,100	$97,200
	Trucks	$483	$1,370	$2,070	$2,820	$4,960	$7,410	$9,560	$11,600	$12,500	$52,800
	Combined	$2,770	$5,460	$7,720	$10,100	$14,000	$19,900	$25,400	$30,900	$33,600	$150,000
7%	Cars	$2,170	$3,890	$5,400	$6,950	$8,610	$12,100	$15,400	$18,700	$20,400	$93,600
	Trucks	$441	$1,290	$1,950	$2,660	$4,720	$7,110	$9,210	$11,200	$12,100	$50,600
	Combined	$2,650	$5,220	$7,370	$9,610	$13,300	$19,200	$24,600	$29,900	$32,500	$144,000

Note: Results correspond to the 2008 baseline fleet.

5.3 Cost per Ton of Emissions Reduced

EPA has calculated the cost per ton of GHG reductions associated with the GHG standards on a CO_2eq basis using the costs and the emissions reductions described in Chapter 3. These values are presented in Table 5.3-1 for cars, trucks and the combined fleet. The cost per metric ton of GHG emissions reductions has been calculated in the years 2020, 2030, 2040, and 2050 using the annual vehicle compliance costs and emission reductions for each of those years. The value in 2050 represents the long-term cost per ton of the emissions reduced. EPA has also calculated the cost per metric ton of GHG emission reductions including the savings associated with reduced fuel consumption (presented below in Section 5.4). These cost effectiveness estimates are similar to the highly cost effective MYs 2012-2016 standards ($50 per ton CO_2e in 2030, see 75 FR 25515 (Table III.H.3-1); the delta becomes less in 2040 and 2050); the increase in cost effectiveness reflects the extra model years of the program. This latter calculation does not include the other benefits associated with this program such as those associated with energy security benefits as discussed later in Chapter 7. By including the fuel savings, the cost per ton is generally less than $0 since the estimated value of fuel savings considerably outweighs the program costs.

Table 5.3-1 Annual Cost per Metric Ton of CO_2eq Reduced (2010 dollars)

	Calendar Year	Undiscounted Annual Costs ($millions)	Undiscounted Annual Pre-tax Fuel Savings ($millions)	Annual CO_2eq Reduction (mmt)	$/ton (w/o fuel savings)	$/ton (w/ fuel savings
Cars	2020	$6,730	$6,000	21	$316	$34
	2030	$22,900	$56,700	179	$128	-$189
	2040	$26,400	$102,000	300	$88	-$252
	2050	$29,900	$138,000	374	$80	-$289
Trucks	2020	$2,450	$1,430	6	$430	$179
	2030	$13,100	$29,700	92	$142	-$180
	2040	$14,600	$53,400	155	$94	-$251
	2050	$16,600	$73,700	196	$85	-$292
Combined	2020	$9,190	$7,430	27	$340	$65
	2030	$35,900	$86,400	271	$132	-$186
	2040	$41,000	$155,000	455	$90	-$251
	2050	$46,500	$212,000	569	$82	-$291

Note: Results correspond to the 2008 baseline fleet.

5.4 Reduction in Fuel Consumption and its Impacts

5.4.1 What Are the Projected Changes in Fuel Consumption?

The final CO_2 standards will result in significant improvements in the fuel efficiency of affected vehicles. Drivers of those vehicles will see corresponding savings associated with reduced fuel expenditures. EPA has estimated the impacts on fuel consumption for both the tailpipe CO_2 standards and the A/C credit program. While gasoline consumption would decrease under the final GHG standards, electricity consumption would increase slightly due to the small penetration of EVs and PHEVs (<1% in MY 2021 and 2% in MY 2025). The fuel savings includes both the gasoline consumption reductions and the electricity consumption increases. Note that the total number of miles that vehicles are driven each year is different under the control case than in the reference case due to the "rebound effect," which is described in Chapter 4.2.5 of the joint TSD. EPA also notes that consumers who drive more than our average estimates for vehicle miles traveled (VMT) will experience more fuel savings; consumers who drive less than our average VMT estimates will experience less fuel savings.

The expected impacts on fuel consumption are shown in Table 5.4-1 . The gallons reduced and kilowatt hours increased (kWh) as shown in the tables reflect impacts from the final CO_2 standards, including the A/C credit program, and include the increased fuel consumption resulting from the rebound effect.

Table 5.4-1 Fuel Consumption Impacts of the Final Standards and A/C Credit Programs

Calendar Year	Petroleum-based Gasoline Reference (million gallons)	Petroleum-based Gasoline Reduced (million gallons)	Electricity Increased (million kWh)
2017	128,136	197	125
2018	126,732	620	370
2019	125,458	1,265	739
2020	124,513	2,149	1,242
2021	123,886	3,435	1,881
2022	123,530	5,055	2,743
2023	123,431	6,967	3,830
2024	123,596	9,158	5,148
2025	124,074	11,620	6,704
2030	129,995	22,986	14,026
2040	150,053	38,901	24,661
2050	177,323	48,743	30,943
Total	5,464,349	903,298	564,873

Note: The electricity increase shown is that needed to charge EVs/PHEVs, not that generated by power plants; results correspond to the 2008 baseline fleet.

5.4.2 What are the Fuel Savings to the Consumer?

Using the fuel consumption estimates presented in Section 5.4.1, EPA can calculate the monetized fuel savings associated with the final standards. To do this, we multiply reduced fuel consumption in each year by the corresponding estimated average fuel price in that year, using the reference case taken from the AEO 2012 Early Release.[IIIII] AEO is a

[IIIII] In the Executive Summary to AEO 2012 Early Release, the Energy Information Administration describes the reference case. They state that, "Projections…in the Reference case focus on the factors that shape U.S. energy markets in the long term, under the assumption that current laws and regulations remain generally unchanged throughout the projection period. The AEO2012 Reference case provides the basis for examination and discussion of energy market trends and serves as a starting point for analysis of potential changes in U.S. energy policies, rules, or regulations or potential technology breakthroughs."

standard reference used by NHTSA and EPA and many other government agencies to estimate the projected price of fuel. The agencies also used AEO as the source of fuel price projections for the 2012-2016 rulemaking.

However, these estimates do not account for the significant uncertainty in future fuel prices. AEO also provides a "low" fuel price case and a "high" fuel price case. The monetized fuel savings would be understated if actual fuel prices are higher, or overstated if fuel prices are lower, than estimated.[JJJJJ] In addition, since future fuel prices are not known with certainty, there could be a distribution of possible fuel price outcomes, as opposed to sets of known higher price- and lower price-pathways.

EPA's assessment uses both the pre-tax and post-tax gasoline prices. Since the post-tax gasoline prices are the prices paid at fuel pumps, the fuel savings calculated using these prices represent the savings consumers would see. The pre-tax fuel savings are those savings that society would see. Assuming no change in gasoline tax rates, the difference between these two columns represents the reduction in fuel tax revenues that will be received by state and federal governments - about $85 million in 2017 and $4.7 billion by 2025. These results are shown in Table 5.4-2 . Note that in Chapter 7 of this RIA, the overall benefits and costs of the final standards are presented and only the pre-tax fuel savings are presented there.

Table 5.4-2 Undiscounted Annual Fuel Savings & Fuel Savings Discounted back to 2012 at 3% and 7% Discount Rates (millions of 2010 dollars)

Calendar Year	Gasoline Savings (pre-tax)	Gasoline Savings (taxed)	Electricity Costs	Total Fuel Savings (pre-tax)	Total Fuel Savings (taxed)
2017	$662	$747	$11.5	$651	$735
2018	$2,110	$2,360	$34.1	$2,070	$2,330
2019	$4,370	$4,920	$67.9	$4,310	$4,850
2020	$7,540	$8,440	$114	$7,430	$8,320
2021	$12,200	$13,600	$175	$12,000	$13,400
2022	$17,900	$20,000	$258	$17,700	$19,700
2023	$24,700	$27,600	$366	$24,400	$27,200
2024	$32,800	$36,500	$499	$32,300	$36,000
2025	$42,300	$47,000	$658	$41,700	$46,300
2030	$87,900	$97,000	$1,450	$86,400	$95,500
2040	$158,000	$172,000	$2,800	$155,000	$169,000
2050	$216,000	$233,000	$3,800	$212,000	$229,000
NPV, 3%	$1,630,000	$1,780,000	$28,100	$1,600,000	$1,750,000
NPV, 7%	$617,000	$677,000	$10,600	$607,000	$666,000

Note: Annual values represent undiscounted values; net present values represent annual costs discounted to 2012; results correspond to the 2008 baseline fleet.

[JJJJJ] While EPA did not conduct an uncertainty analysis on the future price of fuel, NHTSA has conducted both a sensitivity analysis on fuel prices and a probabilistic uncertainty analysis where fuel price is one of the uncertain parameters (See Chapters X and XII of NHTSA's FRIA). Because the agencies' analyses are generally consistent and feature similar parameters, the results of NHTSA's sensitivity and uncertainty analyses are indicative of the uncertainty present in EPA's results.

Looking at these fuel savings by model year gives us the savings as shown in Table 5.4-3.

Table 5.4-3 Model Year Lifetime Present Value Fuel Savings Discounted to the 1st Year of each MY at 3% & 7% (millions of 2010 dollars)

NPV at		2017	2018	2019	2020	2021	2022	2023	2024	2025	Sum
3%	Car	$6,770	$12,800	$19,300	$26,600	$34,400	$43,000	$50,800	$59,400	$68,200	$321,000
	Truck	$275	$2,700	$4,950	$7,480	$16,000	$21,800	$27,600	$31,200	$39,300	$151,000
	Total	$7,050	$15,500	$24,300	$34,100	$50,400	$64,800	$78,400	$90,600	$108,000	$472,000
7%	Car	$5,200	$9,870	$14,900	$20,500	$26,500	$33,100	$39,100	$45,700	$52,400	$247,000
	Truck	$209	$2,050	$3,750	$5,670	$12,100	$16,600	$21,000	$23,900	$29,800	$115,000
	Total	$5,410	$11,900	$18,700	$26,200	$38,600	$49,700	$60,100	$69,600	$82,200	$362,000

Note: Results correspond to the 2008 baseline fleet.

As shown in Table 5.4-2 and Table 5.4-3, the agencies are projecting that consumers would realize very large fuel savings as a result of these standards. These calculations are based on the assumption, discussed in Preamble Section III.D.1.a, that the fuel economy of vehicles would be constant at MY 2016 levels in the absence of the rule. As discussed further in Chapter 8.1.2 of this RIA, it is a conundrum from an economic perspective that these large fuel savings have not been provided by automakers and purchased by consumers. A number of behavioral and market phenomena may lead to this disparity between the fuel economy that makes financial sense to consumers. See also preamble section III.H.1. Regardless of how consumers make their decisions on how much fuel economy to purchase, EPA expects that, in the aggregate, they will gain these fuel savings, which will result in actual money in consumers' pockets. Importantly, roughly 70% of discounted fuel savings occur within the first 10 years of a vehicle's lifetime and 90% occur within the first 15 years, at both 3% and 7% discount rates.

5.5 Consumer Cost of Ownership, Payback Period and Lifetime Savings on New and Used Vehicle Purchases

Here we look at the cost of owning a new vehicle complying with the standards and the payback period – the point at which savings exceed costs. For example, a new 2025 MY vehicle is estimated to cost roughly $1,800 more (on average, and relative to the reference case vehicle) due to the addition of new GHG reducing/fuel economy improving technology. This new technology will result in lower fuel consumption and, therefore, savings in fuel expenditures. But how many months or years would pass before the fuel savings exceed the cumulative costs?

Table 5.5-1 presents our estimate of increased costs associated with owning a new 2025MY vehicle.[77] The table uses annual miles driven (vehicle miles traveled, or VMT) and survival rates consistent with the emission and benefits analyses presented in Chapter 4 of the Joint TSD. The control case includes fuel savings associated with A/C controls. Newly included in this final rule compared to the proposal, are estimated maintenance costs that owners of these vehicles will likely incur (as explained above). Further, this analysis does not include other private impacts, such as reduced refueling events, or other societal impacts, such as the potential rebound miles driven or the value of driving those rebound miles, or noise, congestion and accidents, since the focus is meant to be on those factors consumers think about most while in the showroom considering a new car purchase and those factors that result in more or fewer dollars in their pockets. To estimate the cumulative vehicle costs, we have included not only the sales tax on the new car purchase but also the increased insurance premiums that would result from the more valuable vehicle (see Chapter 4.2.13 of the Joint TSD for details on how sales tax and increased insurance premiums were estimated). Car/truck fleet weighting is handled as described in Chapter 1 of the Joint TSD. The cumulative discounted costs are presented for both 3% and 7% discount rates with lifetime discounted costs shown in the last 2 rows of the table, again at both 3% and 7% discount rates.

Table 5.5-1 Increased Costs on a 2025 MY New Vehicle Purchase via Cash (2010 dollars)

Year of Ownership	Increased Purchase Costs[a]	Increased Insurance Costs [b]	Increased Maintenance Costs	Total Increased Costs	Cumulative Discounted Increased Costs at 3%	Cumulative Discounted Increased Costs at 7%
1	-$1,937	-$34	-$14	-$1,984	-$1,984	-$1,984
2	$0	-$33	-$13	-$46	-$2,029	-$2,027
3	$0	-$31	-$13	-$44	-$2,070	-$2,065
4	$0	-$29	-$12	-$41	-$2,108	-$2,099
5	$0	-$28	-$12	-$39	-$2,143	-$2,129
6	$0	-$26	-$11	-$38	-$2,175	-$2,156
7	$0	-$25	-$11	-$35	-$2,205	-$2,179
8	$0	-$23	-$10	-$33	-$2,232	-$2,200
↓	↓	↓	↓	↓	↓	↓
NPV, 3%	-$1,937	-$313	-$139	-$2,389	-$2,389	
NPV, 7%	-$1,937	-$254	-$109	-$2,300		-$2,300

[a] Increased vehicle cost due to the rule is $1,836; the value here includes nationwide average sales tax of 5.46.
[b] See 4.2.13 of the Joint TSD for information on how increased insurance costs were estimated.

However, most people purchase a new vehicle using credit rather than paying cash up front. A common car loan today is a five year, 60 month loan. As discussed in TSD Chapter 4.2.13, the national average interest rate for a 4 or 5 year new car loan is estimated to be 5.35 percent in 2025. For the credit purchase, the increased costs would look like that shown in Table 5.5-2 .

Table 5.5-2 Increased Costs on a 2025 MY New Vehicle Purchase via Credit (2010 dollars)

Year of Ownership	Increased Purchase Costs[a]	Increased Insurance Costs [b]	Increased Maintenance Costs	Total Increased Costs	Cumulative Discounted Increased Costs at 3%	Cumulative Discounted Increased Costs at 7%
1	-$452	-$34	-$14	-$500	-$500	-$500
2	-$452	-$33	-$13	-$497	-$982	-$964
3	-$452	-$31	-$13	-$495	-$1,449	-$1,397
4	-$452	-$29	-$12	-$493	-$1,900	-$1,799
5	-$452	-$28	-$12	-$491	-$2,337	-$2,174
6	$0	-$26	-$11	-$38	-$2,369	-$2,201
7	$0	-$25	-$11	-$35	-$2,399	-$2,224
8	$0	-$23	-$10	-$33	-$2,425	-$2,245
↓	↓	↓	↓	↓	↓	↓
NPV, 3%	-$2,131	-$313	-$139	-$2,583	-$2,583	
NPV, 7%	-$1,982	-$254	-$109	-$2,345		-$2,345

[a] This uses the same increased cost as Table 5.5-1 but spreads it out over 5 years assuming a 5 year car loan at 5.35 percent.
[b] See 4.2.13 of the Joint TSD for information on how increased insurance costs were estimated.

The above discussion covers costs, but what about the fuel savings side? Of course, fuel savings are the same whether a vehicle is purchased using cash or credit. Table 5.5-3 shows the fuel savings for a 2025MY vehicle (excluding rebound driving).

Table 5.5-3 Fuel Savings for a 2025MY Vehicle (2010 dollars)

Year of Ownership	Fuel Price	Miles Driven	Reference Fuel	Control Fuel	Fuel Savings	Cumulative Discounted Fuel Savings at 3%	Cumulative Discounted Fuel Savings at 7%
1	$3.87	16,779	$2,407	$1,702	$705	$695	$682
2	$3.91	16,052	$2,325	$1,644	$681	$1,347	$1,298
3	$3.94	15,539	$2,265	$1,601	$664	$1,964	$1,859
4	$3.96	14,902	$2,183	$1,543	$640	$2,541	$2,365
5	$4.00	14,424	$2,134	$1,508	$626	$3,089	$2,827
6	$4.04	13,941	$2,082	$1,471	$611	$3,608	$3,248
7	$3.96	13,106	$1,912	$1,350	$562	$4,072	$3,610
8	$3.96	11,866	$1,739	$1,229	$510	$4,480	$3,917
↓	↓	↓	↓	↓	↓	↓	↓
NPV, 3%			$25,261	$17,859	$7,402	$7,402	
NPV, 7%			$19,354	$13,680	$5,674		$5,674

Note: Fuel prices include taxes; miles driven exclude rebound miles.

We can now compare the cumulative discounted costs to the cumulative discounted fuel savings to determine the point at which savings begin to exceed costs. This comparison is shown in Table 5.5-4 for the 3% discounting case (see Table 5.5-5 for the 7% discounting case).

Table 5.5-4 Payback Period for 2025MY Cash & Credit Purchases – 3% discount rate (2010 dollars)

Year of Ownership	Cumulative Discounted Increased Costs - Cash purchase[b]	Cumulative Discounted Increased Costs - Credit purchase[b]	Cumulative Discounted Fuel Savings	Cumulative Discounted Net Savings – Cash purchase	Cumulative Discounted Net Savings – Credit purchase
1	-$1,984	-$500	$695	-$1,290	$195
2	-$2,029	-$982	$1,347	-$682	$365
3	-$2,070	-$1,449	$1,964	-$106	$515
4	-$2,108	-$1,900	$2,541	$433	$641
5	-$2,143	-$2,337	$3,089	$946	$752
6	-$2,175	-$2,369	$3,608	$1,433	$1,239
7	-$2,205	-$2,399	$4,072	$1,867	$1,673
8	-$2,232	-$2,425	$4,480	$2,249	$2,055
↓	↓	↓	↓	↓	↓
NPV, 3%	-$2,389	-$2,583	$7,402	$5,013	$4,819

Table 5.5-4 shows that, somewhere early in the 4th year of ownership (3.2 years), the savings have started to outweigh the costs of the cash purchase. More interestingly, the savings immediately outweigh costs for the credit purchase case and, in fact, this is true even in the first month of ownership, when the increased costs are $42 and the first month's fuel savings are $59 and, presumably, no maintenance costs have yet been incurred (none of these values are shown since the tables present annual values).[78] So, for a new car purchaser who does not keep the vehicle for the full lifetime, the increased costs will pay back within 4 years. When considering the vehicle over its full life, the payback period could be considered as that point at which the savings outweigh the full lifetime costs, which occurs somewhat later since the costs associated with future years are being included.[KKKKK] For this case, referring again to Table 5.5-4, we want the point at which the cumulative discounted fuel savings exceed the discounted full lifetime costs of $2,389 or $2,583 for cash and credit purchases, respectively. Those payback periods would be 3.7 years for the cash purchase and 4.1 years for the credit purchase. Note that the full lifetime net savings amount to $5,013 for the cash purchase and $4,819 for the credit purchase.[79] These very large net savings may not be realized by many individual owners since very few people keep vehicles for their full lifetime. However, those savings would be realized in combination by all owners of the vehicle. Figure 5-2 shows this information for the cash purchase, while Figure 5-3 shows the analogous information for the credit purchase.

[KKKKK] Note that payback of the full lifetime costs are what we estimated in the draft RIA. In this final RIA, we have focused on a payback period defined as a "breakeven" point – the point at which cumulative savings equal cumulative costs or, said another way, the point at which owners start to save more than they spend.

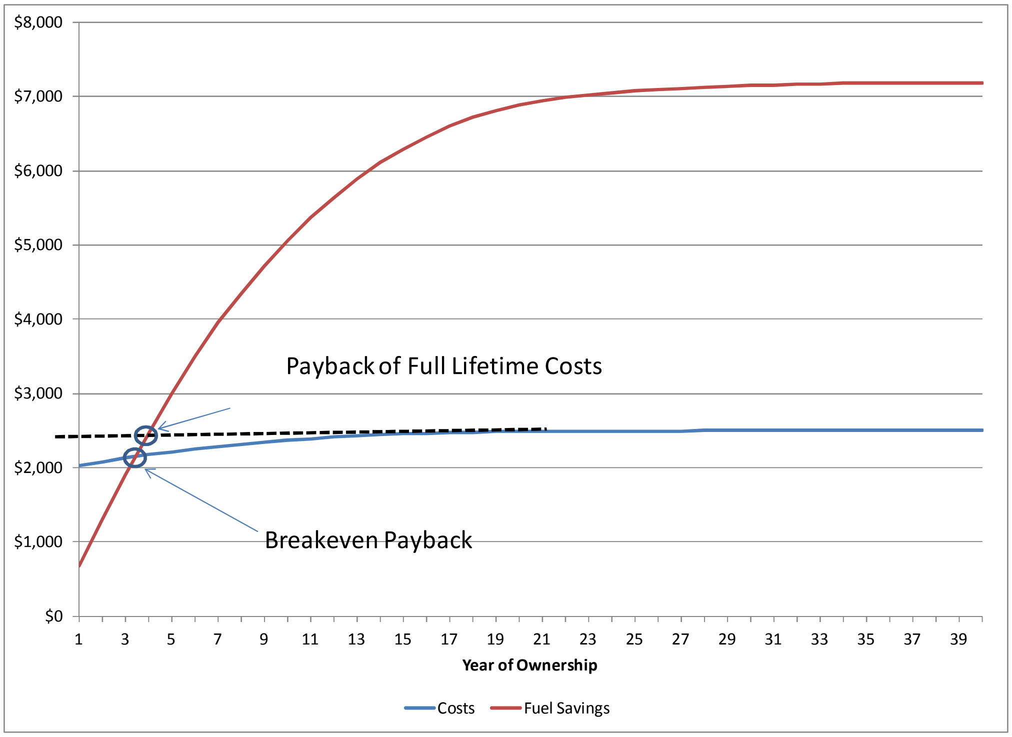

Figure 5-2 Cumulative 3% Discounted Costs & Fuel Savings for a 2025MY New Vehicle Purchase via Cash (2010 dollars)

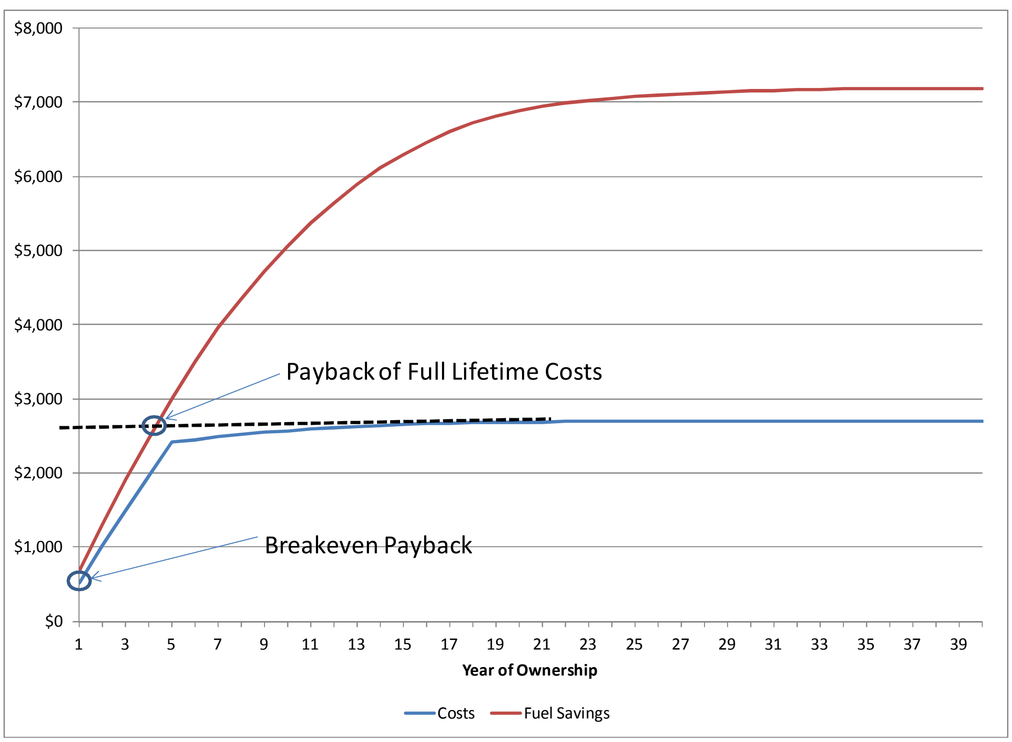

Figure 5-3 Cumulative 3% Discounted Costs & Fuel Savings for a 2025MY New Vehicle Purchase via Credit (2010 dollars)

Table 5.5-5 shows the same information using a 7 percent discount rate. Here, the fuel savings begin to outweigh the costs in just under 4 years for the cash purchase (3.4 years) and within the first year for the credit purchase. For the full lifetime owner, the payback period to recover full lifetime increased costs would be 3.9 years for the cash purchase and 4.0 years for the credit purchase. The full lifetime net savings would be $3,375 for the cash purchase and $3,330 for the credit purchase.[80]

Table 5.5-5 Payback Period for 2025MY Cash & Credit Purchases – 7% discount rate (2010 dollars)

Year of Ownership	Cumulative Discounted Increased Costs - Cash purchase[b]	Cumulative Discounted Increased Costs - Credit purchase[b]	Cumulative Discounted Fuel Savings	Cumulative Discounted Net Savings – Cash purchase	Cumulative Discounted Net Savings – Credit purchase
1	-$1,984	-$500	$682	-$1,302	$183
2	-$2,027	-$964	$1,298	-$729	$334
3	-$2,065	-$1,397	$1,859	-$206	$462
4	-$2,099	-$1,799	$2,365	$266	$565
5	-$2,129	-$2,174	$2,827	$697	$653
6	-$2,156	-$2,201	$3,248	$1,092	$1,047
7	-$2,179	-$2,224	$3,610	$1,431	$1,386
8	-$2,200	-$2,245	$3,917	$1,717	$1,672
↓	↓	↓	↓	↓	↓
NPV, 7%	-$2,300	-$2,345	$5,674	$3,375	$3,330

These payback periods are even more dramatic for the purchaser of a used 2025MY vehicle. For this analysis, we have estimated annual depreciation of 20 percent per year and have discounted all values back to the year of purchase by the purchaser of the used vehicle (so present values of a 2025MY vehicle bought 5 years into its lifetime would be discounted to 2030). We have assumed that the used car purchaser incurs the same maintenance and insurance costs as the new car purchaser, but shifted by the number equal to the age of the used car. The used car purchaser also reaps the fuel savings for the remainder of the vehicle's lifetime with appropriate discounting. Importantly, for the credit purchase case we have assumed a 3 year loan at interest rates 4 percent higher than those for the new car purchase (or 9.35%). The results for a 2025MY used car purchase 5 years into its lifetime are shown in Table 5.5-6 with 3% discounting.[81]

Table 5.5-6 Payback Period for Cash & Credit Purchases of a 5 Year Used 2025MY Vehicle – 3% discount rate (2010 dollars)

Year of Ownership	Cumulative Discounted Increased Costs - Cash purchase[b]	Cumulative Discounted Increased Costs - Credit purchase[b]	Cumulative Discounted Fuel Savings	Cumulative Discounted Net Savings – Cash purchase	Cumulative Discounted Net Savings – Credit purchase
1	-$654	-$272	$602	-$52	$330
2	-$673	-$535	$1,140	$467	$604
3	-$689	-$789	$1,613	$924	$824
4	-$704	-$804	$2,055	$1,351	$1,251
5	-$717	-$818	$2,460	$1,743	$1,643
6	-$729	-$830	$2,827	$2,098	$1,998
7	-$740	-$840	$3,156	$2,417	$2,316
8	-$749	-$849	$3,450	$2,701	$2,600
↓	↓	↓	↓	↓	↓
NPV, 3%	-$790	-$891	$5,000	$4,210	$4,109

As shown in the table, the payback period for the cash purchase case is just over 1 year (1.1 years). In the credit purchase case, the payback occurs within the first month where monthly savings are roughly $23 during the life of the 3 year loan, after which savings would be even higher.

The results for a 2025MY used car purchase 5 years into its lifetime are shown in Table 5.5-7 with 7% discounting.[82]

Table 5.5-7 Payback Period for Cash & Credit Purchases of a 5 Year Used 2025MY Vehicle – 7% discount rate (2010 dollars)

Year of Ownership	Cumulative Discounted Increased Costs - Cash purchase[b]	Cumulative Discounted Increased Costs - Credit purchase[b]	Cumulative Discounted Fuel Savings	Cumulative Discounted Net Savings – Cash purchase	Cumulative Discounted Net Savings – Credit purchase
1	-$654	-$272	$591	-$64	$319
2	-$672	-$525	$1,099	$427	$574
3	-$687	-$761	$1,529	$842	$769
4	-$700	-$774	$1,916	$1,216	$1,142
5	-$712	-$786	$2,258	$1,546	$1,473
6	-$722	-$795	$2,556	$1,834	$1,760
7	-$730	-$804	$2,813	$2,083	$2,009
8	-$737	-$811	$3,033	$2,296	$2,223
↓	↓	↓	↓	↓	↓
NPV, 3%	-$764	-$838	$3,994	$3,230	$3,157

As shown in the table, the payback period for the cash purchase case is just over 1 year (1.1 years). In the credit purchase case, the payback occurs within the first month where monthly savings are roughly $21 during the life of the 3 year loan, after which savings would be even higher.

We also looked at a 10 year old used car purchase. The results are shown in Table 5.5-8 and Table 5.5-9 using 3% and 7% discounting, respectively.[83]

Table 5.5-8 Payback Period for Cash & Credit Purchases of a 10 Year Used 2025MY Vehicle – 3% discount rate (2010 dollars)

Year of Ownership	Cumulative Discounted Increased Costs - Cash purchase[b]	Cumulative Discounted Increased Costs - Credit purchase[b]	Cumulative Discounted Fuel Savings	Cumulative Discounted Net Savings – Cash purchase	Cumulative Discounted Net Savings – Credit purchase
1	-$218	-$93	$425	$208	$333
2	-$227	-$182	$807	$580	$625
3	-$234	-$267	$1,147	$913	$880
4	-$241	-$274	$1,446	$1,205	$1,172
5	-$247	-$279	$1,708	$1,461	$1,428
6	-$251	-$284	$1,934	$1,683	$1,650
7	-$256	-$288	$2,126	$1,870	$1,837
8	-$259	-$292	$2,285	$2,026	$1,993
↓	↓	↓	↓	↓	↓
NPV, 3%	-$271	-$304	$2,944	$2,673	$2,640

As shown in Table 5.5-8, the payback period for the cash purchase case is under 1 year (0.5 years). In the credit purchase case, the payback occurs within the first month where monthly savings are roughly $24 during the life of the 3 year loan, after which savings would be even higher.[84]

Table 5.5-9 Payback Period for Cash & Credit Purchases of a 10 Year Used 2025MY Vehicle – 7% discount rate (2010 dollars)

Year of Ownership	Cumulative Discounted Increased Costs - Cash purchase[b]	Cumulative Discounted Increased Costs - Credit purchase[b]	Cumulative Discounted Fuel Savings	Cumulative Discounted Net Savings – Cash purchase	Cumulative Discounted Net Savings – Credit purchase
1	-$218	-$93	$418	$200	$325
2	-$226	-$178	$778	$552	$600
3	-$233	-$257	$1,087	$854	$830
4	-$239	-$263	$1,349	$1,110	$1,086
5	-$244	-$268	$1,570	$1,326	$1,302
6	-$248	-$272	$1,753	$1,505	$1,481
7	-$251	-$276	$1,903	$1,652	$1,627
8	-$254	-$278	$2,023	$1,769	$1,745
↓	↓	↓	↓	↓	↓
NPV, 3%	-$262	-$286	$2,435	$2,173	$2,149

As shown in the Table 5.5-9, the payback period for the cash purchase case is under 1 year (0.5 years). In the credit purchase case, the payback occurs within the first month where monthly savings are roughly $23 during the life of the 3 year loan, after which savings would be even higher.[85]

Note that throughout this consumer payback discussion, the analysis reflects the average number of vehicle miles traveled per year. Drivers who drive more miles than the average would incur fuel-related savings more quickly and, therefore, the payback would come sooner. Drivers who drive fewer miles than the average would incur fuel related savings more slowly and, therefore, the payback would come later.

Note also that the insurance costs and sales taxes included here in the cost of ownership analysis have not been included in the benefit-cost analysis because those costs are transfer payments and have no net impact on the societal costs of interest in a benefit-cost analysis. Likewise, the fuel savings presented here include taxes since those are the cost incurred by drivers. However, fuel taxes are not included in the benefit-cost analysis since, again, they are transfer payments. Lastly, in this cost of ownership analysis, we have not included rebound miles in determining maintenance costs or fuel savings, and we have not included other private benefits/costs such as the value of driving rebound miles or reduced time spent refueling, since we do not believe that consumers consider such impacts in their daily lives. In the benefit-cost analysis, we include rebound miles in estimating maintenance costs and fuel savings, and we include the other private benefits/costs listed here.

References

[75] Spreadsheet files used to generate the values presented in this chapter can be found on a compact disk placed in Docket No. EPA-HQ-OAR-2010-0799, see “LDGHG 2017-2025 Cost Development Files.”

[76] See “GHGLD_2017-2025_MaintenanceCosts.xlsx” on “LDGHG 2017-2025_Cost Development Files,” CD in Docket No. EPA-HQ-OAR-2010-0799.

[77] See “2008_OwnershipCost_Payback.xlsx” on “LDGHG 2017-2025_Cost Development Files,” CD in Docket No. EPA-HQ-OAR-2010-0799..

[78] *Ibid.*

[79] *Ibid.*

[80] *Ibid.*

[81] *Ibid.*

[82] *Ibid.*

[83] *Ibid.*

[84] *Ibid.*

[85] *Ibid.*

6 Health and Environmental Impacts

6.1 Health and Environmental Impacts of Non-GHG Pollutants

6.1.1 Health Effects Associated with Exposure to Non-GHG Pollutants

In this section we discuss the health effects associated with non-GHG pollutants, specifically: particulate matter, ozone, nitrogen oxides (NO_X), sulfur oxides (SO_X), carbon monoxide and air toxics. These pollutants will not be directly regulated by the standards, but the standards will affect emissions of these pollutants and precursors.

6.1.1.1 Background on Particulate Matter

Particulate matter (PM) is a highly complex mixture of solid particles and liquid droplets distributed among numerous atmospheric gases which interact with solid and liquid phases. Particles range in size from those smaller than 1 nanometer (10^{-9} meter) to over 100 micrometer (µm, or 10^{-6} meter) in diameter (for reference, a typical strand of human hair is 70 um in diameter and a grain of salt is about 100 µm). Atmospheric particles can be grouped into several classes according to their aerodynamic and physical sizes, including ultrafine particles (<0.1 µm), accumulation mode or 'fine' particles (< 1 to 3 µm), and coarse particles (>1 to 3 µm). For regulatory purposes, fine particles are measured as $PM_{2.5}$ and inhalable or thoracic coarse particles are measured as $PM_{10-2.5}$, corresponding to their size (diameter) range in micrometers and referring to total particle mass under 2.5 and between 2.5 and 10 micrometers, respectively. The EPA currently has standards that measure $PM_{2.5}$ and PM_{10}.[LLLLL]

Particles span many sizes and shapes and consist of hundreds of different chemicals. Particles are emitted directly from sources and are also formed through atmospheric chemical reactions; the former are often referred to as "primary" particles, and the latter as "secondary" particles. Particle pollution also varies by time of year and location and is affected by several weather-related factors, such as temperature, clouds, humidity, and wind. A further layer of complexity comes from particles' ability to shift between solid/liquid and gaseous phases, which is influenced by concentration and meteorology, especially temperature.

Fine particles are produced primarily by combustion processes and by transformations of gaseous emissions (e.g., SO_X, NO_X and volatile organic compounds (VOCs)) in the atmosphere. The chemical and physical properties of $PM_{2.5}$ may vary greatly with time, region, meteorology and source category. Thus, $PM_{2.5}$ may include a complex mixture of different components including sulfates, nitrates, organic compounds, elemental carbon and metal compounds. These particles can remain in the atmosphere for days to weeks and travel through the atmosphere hundreds to thousands of kilometers.[86]

[LLLLL] Regulatory definitions of PM size fractions, and information on reference and equivalent methods for measuring PM in ambient air, are provided in 40 CFR Parts 50, 53, and 58.

6.1.1.2 Particulate Matter Health Effects

This section provides a summary of the health effects associated with exposure to ambient concentrations of PM.[MMMMM] The information in this section is based on the information and conclusions in the Integrated Science Assessment (ISA) for Particulate Matter (December 2009) prepared by EPA's Office of Research and Development (ORD).[NNNNN]

The ISA concludes that ambient concentrations of PM are associated with a number of adverse health effects.[OOOOO] The ISA characterizes the weight of evidence for different health effects associated with three PM size ranges: $PM_{2.5}$, $PM_{10-2.5}$, and UFPs. The discussion below highlights the ISA's conclusions pertaining to these three size fractions of PM, considering variations in health effects associated with both short-term and long-term exposure periods.

6.1.1.2.1 Effects Associated with Short-term Exposure to $PM_{2.5}$

The ISA concludes that cardiovascular effects and mortality are causally associated with short-term exposure to $PM_{2.5}$.[87] It also concludes that respiratory effects are likely to be causally associated with short-term exposure to $PM_{2.5}$, including respiratory emergency department (ED) visits and hospital admissions for chronic obstructive pulmonary disease (COPD), respiratory infections, and asthma; and exacerbation of respiratory symptoms in asthmatic children.

6.1.1.2.2 Effects Associated with Long-term Exposure to $PM_{2.5}$

The ISA concludes that there are causal associations between long-term exposure to $PM_{2.5}$ and cardiovascular effects, such as the development/progression of cardiovascular disease (CVD), and premature mortality, particularly from cardiovascular causes.[88] It also concludes that long-term exposure to $PM_{2.5}$ is likely to be causally associated with respiratory effects, such as reduced lung function growth, increased respiratory symptoms, and asthma development. The ISA characterizes the evidence as suggestive of a causal relationship for associations between long-term $PM_{2.5}$ exposure and reproductive and developmental outcomes, such as low birth weight and infant mortality. It also characterizes the evidence as suggestive of a causal relationship between $PM_{2.5}$ and cancer incidence, mutagenicity, and genotoxicity.

6.1.1.2.3 Effects Associated with $PM_{10-2.5}$

The ISA summarizes evidence related to short-term exposure to $PM_{10-2.5}$. $PM_{10-2.5}$ is the fraction of PM_{10} particles that is larger than $PM_{2.5}$.[89] The ISA concludes that available evidence is suggestive of a causal relationship between short-term exposures to $PM_{10-2.5}$ and cardiovascular

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[MMMMM] Personal exposure includes contributions from many different types of particles, from many sources, and in many different environments. Total personal exposure to PM includes both ambient and nonambient components and collectively these components may contribute to adverse health effects.

[NNNNN] The ISA is available at http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546

[OOOOO] The ISA evaluates the health evidence associated with different health effects, assigning one of five "weight of evidence" determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For definitions of these levels of evidence, please refer to Section 1.5 of the ISA.

effects. It also concludes that the available evidence is suggestive of a causal relationship between short-term exposures to $PM_{10-2.5}$ and respiratory effects, including respiratory-related ED visits and hospitalizations. The ISA also concludes that the available literature suggests a causal relationship between short-term exposures to $PM_{10-2.5}$ and mortality. Data are inadequate to draw conclusions regarding health effects associated with long-term exposure to $PM_{10-2.5}$.[90]

6.1.1.2.4 Effects Associated with Ultrafine Particles

The ISA concludes that the evidence is suggestive of a causal relationship between short-term exposures to UFPs and cardiovascular effects, including changes in heart rhythm and vasomotor function (the ability of blood vessels to expand and contract).[91]

The ISA also concludes that there is suggestive evidence of a causal relationship between short-term UFP exposure and respiratory effects. The types of respiratory effects examined in epidemiologic studies include respiratory symptoms and asthma hospital admissions, the results of which are not entirely consistent. There is evidence from toxicological and controlled human exposure studies that exposure to UFPs may increase lung inflammation and produce small asymptomatic changes in lung function. Data are inadequate to draw conclusions regarding health effects associated with long-term exposure to UFPs.[92]

6.1.1.3 Background on Ozone

Ground-level ozone pollution is typically formed by the reaction of VOCs and NO_X in the lower atmosphere in the presence of sunlight. These pollutants, often referred to as ozone precursors, are emitted by many types of pollution sources such as highway and nonroad motor vehicles and engines, power plants, chemical plants, refineries, makers of consumer and commercial products, industrial facilities, and smaller area sources.

The science of ozone formation, transport, and accumulation is complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions, many of which are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and result in more ozone than typically occurs on a single high-temperature day. Ozone can be transported hundreds of miles downwind of precursor emissions, resulting in elevated ozone levels even in areas with low VOC or NO_X emissions.

The highest levels of ozone are produced when both VOC and NO_X emissions are present in significant quantities on clear summer days. Relatively small amounts of NO_X enable ozone to form rapidly when VOC levels are relatively high, but ozone production is quickly limited by removal of the NO_X. Under these conditions NO_X reductions are highly effective in reducing ozone while VOC reductions have little effect. Such conditions are called "NO_X-limited." Because the contribution of VOC emissions from biogenic (natural) sources to local ambient ozone concentrations can be significant, even some areas where man-made VOC emissions are relatively low can be NO_X-limited.

Ozone concentrations in an area also can be lowered by the reaction of nitric oxide (NO) with ozone, forming nitrogen dioxide (NO_2); as the air moves downwind and the cycle continues, the NO_2 forms additional ozone. The importance of this reaction depends, in part, on the relative concentrations of NO_X, VOC, and ozone, all of which change with time and location. When NO_X levels are relatively high and VOC levels relatively low, NO_X forms inorganic nitrates (i.e., particles) but relatively little ozone. Such conditions are called "VOC-limited." Under these conditions, VOC reductions are effective in reducing ozone, but NO_X reductions can actually increase local ozone under certain circumstances. Even in VOC-limited urban areas, NO_X reductions are not expected to increase ozone levels if the NO_X reductions are sufficiently large. Rural areas are usually NO_X-limited, due to the relatively large amounts of biogenic VOC emissions in such areas. Urban areas can be either VOC- or NO_X-limited, or a mixture of both, in which ozone levels exhibit moderate sensitivity to changes in either pollutant.

6.1.1.4 Ozone Health Effects

Exposure to ambient ozone contributes to a wide range of adverse health effects.[PPPPP] These health effects are well documented and are critically assessed in the EPA ozone air quality criteria document (ozone AQCD) and EPA staff paper.[93,94] We are relying on the data and conclusions in the ozone AQCD and staff paper, regarding the health effects associated with ozone exposure.

Ozone-related health effects include lung function decrements, respiratory symptoms, aggravation of asthma, increased hospital and emergency room visits, increased asthma medication usage, and a variety of other respiratory effects. Cellular-level effects, such as inflammation of lungs, have been documented as well. In addition, there is suggestive evidence of a contribution of ozone to cardiovascular-related morbidity and highly suggestive evidence that short-term ozone exposure directly or indirectly contributes to non-accidental and cardiopulmonary-related mortality, but additional research is needed to clarify the underlying mechanisms causing these effects. In a report on the estimation of ozone-related premature mortality published by the National Research Council (NRC), a panel of experts and reviewers concluded that short-term exposure to ambient ozone is likely to contribute to premature deaths and that ozone-related mortality should be included in estimates of the health benefits of reducing ozone exposure.[95] People who appear to be more susceptible to effects associated with exposure to ozone include children, asthmatics and the elderly. Those with greater exposures to ozone, for instance due to time spent outdoors (e.g., children and outdoor workers), are also of concern.

Based on a large number of scientific studies, EPA has identified several key health effects associated with exposure to levels of ozone found today in many areas of the country. Short-term (1 to 3 hours) and prolonged exposures (6 to 8 hours) to ambient ozone concentrations have been linked to lung function decrements, respiratory symptoms, increased hospital admissions and emergency room visits for respiratory problems.[96, 97, 98, 99, 100, 101] Repeated exposure to ozone can increase susceptibility to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma.[102, 103, 104, 105, 106] Repeated exposure to sufficient concentrations of ozone can also cause inflammation of the lung,

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[PPPPP] Human exposure to ozone varies over time due to changes in ambient ozone concentration and because people move between locations which have notable different ozone concentrations. Also, the amount of ozone delivered to the lung is not only influenced by the ambient concentrations but also by the individuals breathing route and rate.

impairment of lung defense mechanisms, and possibly irreversible changes in lung structure, which over time could affect premature aging of the lungs and/or the development of chronic respiratory illnesses, such as emphysema and chronic bronchitis.[107, 108, 109, 110]

Children and outdoor workers tend to have higher ozone exposure because they typically are active outside, working, playing and exercising, during times of day and seasons (e.g., the summer) when ozone levels are highest.[111] For example, summer camp studies have reported statistically significant reductions in lung function in children who are active outdoors.[112, 113, 114, 115, 116, 117, 118, 119] Further, children are more at risk of experiencing health effects from ozone exposure than adults because their respiratory systems are still developing. These individuals (as well as people with respiratory illnesses, such as asthma, especially asthmatic children) can experience reduced lung function and increased respiratory symptoms, such as chest pain and cough, when exposed to relatively low ozone levels during prolonged periods of moderate exertion.[120, 121, 122, 123]

6.1.1.5 Background on Nitrogen Oxides and Sulfur Oxides

Sulfur dioxide (SO_2), a member of the sulfur oxide (SO_X) family of gases, is formed from burning fuels containing sulfur (e.g., coal or oil), extracting gasoline from oil, or extracting metals from ore. Nitrogen dioxide (NO_2) is a member of the nitrogen oxide (NO_X) family of gases. Most NO_2 is formed in the air through the oxidation of nitric oxide (NO) emitted when fuel is burned at a high temperature. SO_2 and NO_2 can dissolve in water droplets and further oxidize to form sulfuric and nitric acid which react with ammonia to form sulfates and nitrates, both of which are important components of ambient PM. The health effects of ambient PM are discussed in Section 6.1.1.2. NO_X along with non-methane hydrocarbons (NMHC) are the two major precursors of ozone. The health effects of ozone are covered in Section 6.1.1.4.

6.1.1.6 Health Effects of SO_2

This section provides an overview of the health effects associated with SO_2. Additional information on the health effects of SO_2 can be found in the EPA Integrated Science Assessment for Sulfur Oxides.[124] Following an extensive evaluation of health evidence from epidemiologic and laboratory studies, the U.S. EPA has concluded that there is a causal relationship between respiratory health effects and short-term (from 5 minutes to 24 hours) exposure to SO_2. The immediate effect of SO_2 on the respiratory system in humans is bronchoconstriction. Asthmatics are more sensitive to the effects of SO_2 likely resulting from preexisting inflammation associated with this disease. In laboratory studies involving controlled human exposures to SO_2, respiratory effects have consistently been observed following 5-10 min exposures at SO_2 concentrations $\geq$ 0.4 ppm in asthmatics engaged in moderate to heavy levels of exercise, with more limited evidence of respiratory effects among exercising asthmatics exposed to concentrations as low as 0.2-0.3 ppm. A clear concentration-response relationship has been demonstrated in these studies following exposures to SO_2 at concentrations between 0.2 and 1.0 ppm, both in terms of increasing severity of respiratory symptoms and decrements in lung function, as well as the percentage of asthmatics adversely affected.

In epidemiologic studies, respiratory effects have been observed in areas where the mean 24-hour SO_2 levels range from 1 to 30 ppb, with maximum 1 to 24-hour average SO_2 values ranging from 12 to 75 ppb. Important new multicity studies and several other studies have found an association between 24-hour average ambient SO_2 concentrations and respiratory symptoms in children, particularly those with asthma. Generally consistent associations also have been observed between ambient SO_2 concentrations and emergency department visits and hospitalizations for all respiratory causes, particularly among children and older adults ($\geq$ 65 years), and for asthma. A limited subset of epidemiologic studies has examined potential confounding by copollutants using multipollutant regression models. These analyses indicate that although copollutant adjustment has varying degrees of influence on the SO_2 effect estimates, the effect of SO_2 on respiratory health outcomes appears to be generally robust and independent of the effects of gaseous and particulate copollutants, suggesting that the observed effects of SO_2 on respiratory endpoints occur independent of the effects of other ambient air pollutants. In addition, this epidemiologic evidence is plausible and coherent given the consistency of the effects observed in the epidemiologic and controlled human exposure studies along with toxicological evidence related to the mode of action of SO_2 on the human respiratory system.

Consistent associations between short-term exposure to SO_2 and mortality have been observed in epidemiologic studies, with larger effect estimates reported for respiratory mortality than for cardiovascular mortality. While this finding is consistent with the demonstrated effects of SO_2 on respiratory morbidity, uncertainty remains with respect to the interpretation of these associations due to potential confounding by various copollutants. The U.S. EPA has therefore concluded that the overall evidence is suggestive of a causal relationship between short-term exposure to SO_2 and mortality. Significant associations between short-term exposure to SO_2 and emergency department visits and hospital admissions for cardiovascular diseases have also been reported. However, these findings have been inconsistent across studies and do not provide adequate evidence to infer a causal relationship between SO_2 exposure and cardiovascular morbidity.

6.1.1.7 Health Effects of NO_2

Information on the health effects of NO_2 can be found in the EPA Integrated Science Assessment (ISA) for Nitrogen Oxides.[125] The EPA has concluded that the findings of epidemiologic, controlled human exposure, and animal toxicological studies provide evidence that is sufficient to infer a likely causal relationship between respiratory effects and short-term NO_2 exposure. The ISA concludes that the strongest evidence for such a relationship comes from epidemiologic studies of respiratory effects including symptoms, emergency department visits, and hospital admissions. Based on both short- and long-term studies, the ISA concludes that associations of NO_2 with respiratory health effects are stronger among a number of groups; these include individuals with preexisting pulmonary conditions (e.g., asthma or COPD), children and older adults. The ISA also draws two broad conclusions regarding airway responsiveness following NO_2 exposure. First, the ISA concludes that NO_2 exposure may enhance the sensitivity to allergen-induced decrements in lung function and increase the allergen-induced airway inflammatory response following 30-minute exposures of asthmatics to NO_2 concentrations as low as 0.26 ppm. Second, exposure to NO_2 has been found to enhance the inherent responsiveness of the airway to subsequent nonspecific challenges in controlled human exposure studies of asthmatic subjects. Small but significant increases in non-specific airway hyperresponsiveness were reported following 1-hour exposures of asthmatics to 0.1 ppm NO_2.

Enhanced airway responsiveness could have important clinical implications for asthmatics since transient increases in airway responsiveness following NO_2 exposure have the potential to increase symptoms and worsen asthma control. Together, the epidemiologic and experimental data sets form a plausible, consistent, and coherent description of a relationship between NO_2 exposures and an array of adverse health effects that range from the onset of respiratory symptoms to hospital admission.

Although the weight of evidence supporting a causal relationship is somewhat less certain than that associated with respiratory morbidity, NO_2 has also been linked to other health endpoints. These include all-cause (non-accidental) mortality, hospital admissions or emergency department visits for cardiovascular disease, and decrements in lung function growth associated with chronic exposure.

6.1.1.8 Health Effects of Carbon Monoxide

Information on the health effects of carbon monoxide (CO) can be found in the EPA Integrated Science Assessment (ISA) for Carbon Monoxide.[126] The ISA concludes that ambient concentrations of CO are associated with a number of adverse health effects.[QQQQQ] This section provides a summary of the health effects associated with exposure to ambient concentrations of CO.[RRRRR]

Human clinical studies of subjects with coronary artery disease show a decrease in the time to onset of exercise-induced angina (chest pain) and electrocardiogram changes following CO exposure. In addition, epidemiologic studies show associations between short-term CO exposure and cardiovascular morbidity, particularly increased emergency room visits and hospital admissions for coronary heart disease (including ischemic heart disease, myocardial infarction, and angina). Some epidemiologic evidence is also available for increased hospital admissions and emergency room visits for congestive heart failure and cardiovascular disease as a whole. The ISA concludes that a causal relationship is likely to exist between short-term exposures to CO and cardiovascular morbidity. It also concludes that available data are inadequate to conclude that a causal relationship exists between long-term exposures to CO and cardiovascular morbidity.

Animal studies show various neurological effects with in-utero CO exposure. Controlled human exposure studies report inconsistent neural and behavioral effects following low-level CO exposures. The ISA concludes the evidence is suggestive of a causal relationship with both short- and long-term exposure to CO and central nervous system effects.

[QQQQQ] The ISA evaluates the health evidence associated with different health effects, assigning one of five "weight of evidence" determinations: causal relationship, likely to be a causal relationship, suggestive of a causal relationship, inadequate to infer a causal relationship, and not likely to be a causal relationship. For definitions of these levels of evidence, please refer to Section 1.6 of the ISA.

[RRRRR] Personal exposure includes contributions from many sources, and in many different environments. Total personal exposure to CO includes both ambient and nonambient components; and both components may contribute to adverse health effects.

A number of epidemiologic and animal toxicological studies cited in the ISA have evaluated associations between CO exposure and birth outcomes such as preterm birth or cardiac birth defects. The epidemiologic studies provide limited evidence of a CO-induced effect on preterm births and birth defects, with weak evidence for a decrease in birth weight. Animal toxicological studies have found associations between perinatal CO exposure and decrements in birth weight, as well as other developmental outcomes. The ISA concludes these studies are suggestive of a causal relationship between long-term exposures to CO and developmental effects and birth outcomes.

Epidemiologic studies provide evidence of effects on respiratory morbidity such as changes in pulmonary function, respiratory symptoms, and hospital admissions associated with ambient CO concentrations. A limited number of epidemiologic studies considered co-pollutants such as ozone, SO_2, and PM in two-pollutant models and found that CO risk estimates were generally robust, although this limited evidence makes it difficult to disentangle effects attributed to CO itself from those of the larger complex air pollution mixture. Controlled human exposure studies have not extensively evaluated the effect of CO on respiratory morbidity. Animal studies at levels of 50-100 ppm CO show preliminary evidence of altered pulmonary vascular remodeling and oxidative injury. The ISA concludes that the evidence is suggestive of a causal relationship between short-term CO exposure and respiratory morbidity, and inadequate to conclude that a causal relationship exists between long-term exposure and respiratory morbidity.

Finally, the ISA concludes that the epidemiologic evidence is suggestive of a causal relationship between short-term exposures to CO and mortality. Epidemiologic studies provide evidence of an association between short-term exposure to CO and mortality, but limited evidence is available to evaluate cause-specific mortality outcomes associated with CO exposure. In addition, the attenuation of CO risk estimates which was often observed in co-pollutant models contributes to the uncertainty as to whether CO is acting alone or as an indicator for other combustion-related pollutants. The ISA also concludes that there is not likely to be a causal relationship between relevant long-term exposures to CO and mortality.

6.1.1.9 Health Effects of Air Toxics

Motor vehicle emissions contribute to ambient levels of air toxics known or suspected as human or animal carcinogens, or that have noncancer health effects. The population experiences an elevated risk of cancer and other noncancer health effects from exposure to air toxics.[127] These compounds include, but are not limited to, benzene, 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, polycyclic organic matter (POM), and naphthalene. These compounds were identified as national or regional risk drivers or contributors in the 2005 National-scale Air Toxics Assessment (NATA) and have significant inventory contributions from mobile sources. Although the 2005 NATA did not quantify cancer risks associated with exposure to diesel exhaust, EPA has concluded that diesel exhaust ranks with the other emissions that the 2005 NATA suggests pose the greatest relative risk. According to NATA for 2005, mobile sources were responsible for 43 percent of outdoor toxic emissions and over 50 percent of the cancer risk and noncancer hazard attributable to direct emissions from mobile and stationary sources.[SSSSS]

Noncancer health effects can result from chronic,[TTTTT] subchronic,[UUUUU] or acute[VVVVV] inhalation exposures to air toxics, and include neurological, cardiovascular, liver, kidney, and respiratory effects as well as effects on the immune and reproductive systems. According to the 2005 NATA, about three-fourths of the U.S. population was exposed to an average chronic concentration of air toxics that has the potential for adverse noncancer respiratory health effects. This will continue to be the case in 2030, even though toxics concentrations will be lower.[128]

The NATA modeling framework has a number of limitations which prevent its use as the sole basis for setting regulatory standards. These limitations and uncertainties are discussed on the 2005 NATA website.[129] Even so, this modeling framework is very useful in identifying air toxic pollutants and sources of greatest concern, setting regulatory priorities, and informing the decision making process.

6.1.1.9.1 Benzene

The EPA's IRIS database lists benzene as a known human carcinogen (causing leukemia) by all routes of exposure, and concludes that exposure is associated with additional health effects, including genetic changes in both humans and animals and increased proliferation of bone marrow cells in mice.[130,131,132] EPA states in its IRIS database that data indicate a causal relationship between benzene exposure and acute lymphocytic leukemia and suggest a relationship between benzene exposure and chronic non-lymphocytic leukemia and chronic lymphocytic leukemia. The International Agency for Research on Carcinogens (IARC) has determined that benzene is a human carcinogen and the U.S. Department of Health and Human Services (DHHS) has characterized benzene as a known human carcinogen.[133,134]

A number of adverse noncancer health effects including blood disorders, such as preleukemia and aplastic anemia, have also been associated with long-term exposure to benzene.[135,136] The most sensitive noncancer effect observed in humans, based on current data, is the depression of the absolute lymphocyte count in blood.[137,138] In addition, published work, including studies sponsored by the Health Effects Institute (HEI), provides evidence that biochemical responses are occurring at lower levels of benzene exposure than previously known.[139,140,141,142] EPA's IRIS program has not yet evaluated these new data.

[SSSSS] NATA also includes estimates of risk attributable to background concentrations, which includes contributions from long-range transport, persistent air toxics, and natural sources; as well as secondary concentrations, where toxics are formed via secondary formation. Mobile sources substantially contribute to long-range transport and secondarily formed air toxics.

[TTTTT] Chronic exposure is defined in the glossary of the Integrated Risk Information (IRIS) database (http://www.epa.gov/iris) as repeated exposure by the oral, dermal, or inhalation route for more than approximately 10% of the life span in humans (more than approximately 90 days to 2 years in typically used laboratory animal species).

[UUUUU] Defined in the IRIS database as exposure to a substance spanning approximately 10% of the lifetime of an organism.

[VVVVV] Defined in the IRIS database as exposure by the oral, dermal, or inhalation route for 24 hours or less.

6.1.1.9.2 1,3-Butadiene

EPA has characterized 1,3-butadiene as carcinogenic to humans by inhalation.[143,144] The IARC has determined that 1,3-butadiene is a human carcinogen and the U.S. DHHS has characterized 1,3-butadiene as a known human carcinogen.[145,146,147] There are numerous studies consistently demonstrating that 1,3-butadiene is metabolized into genotoxic metabolites by experimental animals and humans. The specific mechanisms of 1,3-butadiene-induced carcinogenesis are unknown; however, the scientific evidence strongly suggests that the carcinogenic effects are mediated by genotoxic metabolites. Animal data suggest that females may be more sensitive than males for cancer effects associated with 1,3-butadiene exposure; there are insufficient data in humans from which to draw conclusions about sensitive subpopulations. 1,3-butadiene also causes a variety of reproductive and developmental effects in mice; no human data on these effects are available. The most sensitive effect was ovarian atrophy observed in a lifetime bioassay of female mice.[148]

6.1.1.9.3 Formaldehyde

In 1991, EPA concluded that formaldehyde is a carcinogen based on nasal tumors in animal bioassays.[149] An Inhalation Unit Risk for cancer and a Reference Dose for oral noncancer effects were developed by the Agency and posted on the Integrated Risk Information System (IRIS) database. Since that time, the National Toxicology Program (NTP) and International Agency for Research on Cancer (IARC) have concluded that formaldehyde is a known human carcinogen.[150,151,152]

The conclusions by IARC and NTP reflect the results of epidemiologic research published since 1991 in combination with previous animal, human and mechanistic evidence. Research conducted by the National Cancer Institute reported an increased risk of nasopharyngeal cancer and specific lymphohematopoietic malignancies among workers exposed to formaldehyde.[153,154,155] A National Institute of Occupational Safety and Health study of garment workers also reported increased risk of death due to leukemia among workers exposed to formaldehyde.[156] Extended follow-up of a cohort of British chemical workers did not report evidence of an increase in nasopharyngeal or lymphohematopoietic cancers, but a continuing statistically significant excess in lung cancers was reported.[157] Finally, a study of embalmers reported formaldehyde exposures to be associated with an increased risk of myeloid leukemia but not brain cancer.[158]

Health effects of formaldehyde in addition to cancer were reviewed by the Agency for Toxics Substances and Disease Registry in 1999[159] and supplemented in 2010,[160] and by the World Health Organization.[161] These organizations reviewed the literature concerning effects on the eyes and respiratory system, the primary point of contact for inhaled formaldehyde, including sensory irritation of eyes and respiratory tract, pulmonary function, nasal histopathology, and immune system effects. In addition, research on reproductive and developmental effects and neurological effects were discussed.

EPA released a draft Toxicological Review of Formaldehyde – Inhalation Assessment through the IRIS program for peer review by the National Research Council (NRC) and public comment in June 2010.[162] The draft assessment reviewed more recent research from animal and human studies on cancer and other health effects. The NRC released their review report in April 2011[163] (http://www.nap.edu/catalog.php?record_id=13142). The EPA is currently revising the draft assessment in response to this review.

6.1.1.9.4 Acetaldehyde

Acetaldehyde is classified in EPA's IRIS database as a probable human carcinogen, based on nasal tumors in rats, and is considered toxic by the inhalation, oral, and intravenous routes.[164] Acetaldehyde is reasonably anticipated to be a human carcinogen by the U.S. DHHS in the 11th Report on Carcinogens and is classified as possibly carcinogenic to humans (Group 2B) by the IARC.[165,166] EPA is currently conducting a reassessment of cancer risk from inhalation exposure to acetaldehyde.

The primary noncancer effects of exposure to acetaldehyde vapors include irritation of the eyes, skin, and respiratory tract.[167] In short-term (4 week) rat studies, degeneration of olfactory epithelium was observed at various concentration levels of acetaldehyde exposure.[168,169] Data from these studies were used by EPA to develop an inhalation reference concentration. Some asthmatics have been shown to be a sensitive subpopulation to decrements in functional expiratory volume (FEV1 test) and bronchoconstriction upon acetaldehyde inhalation.[170] The agency is currently conducting a reassessment of the health hazards from inhalation exposure to acetaldehyde.

6.1.1.9.5 Acrolein

Acrolein is extremely acrid and irritating to humans when inhaled, with acute exposure resulting in upper respiratory tract irritation, mucus hypersecretion and congestion. The intense irritancy of this carbonyl has been demonstrated during controlled tests in human subjects, who suffer intolerable eye and nasal mucosal sensory reactions within minutes of exposure.[171] These data and additional studies regarding acute effects of human exposure to acrolein are summarized in EPA's 2003 IRIS Human Health Assessment for acrolein.[172] Evidence available from studies in humans indicate that levels as low as 0.09 ppm (0.21 mg/m^3) for five minutes may elicit subjective complaints of eye irritation with increasing concentrations leading to more extensive eye, nose and respiratory symptoms.[173] Lesions to the lungs and upper respiratory tract of rats, rabbits, and hamsters have been observed after subchronic exposure to acrolein.[174] Acute exposure effects in animal studies report bronchial hyperresponsiveness.[175] In one study, the acute respiratory irritant effects of exposure to 1.1 ppm acrolein were more pronounced in mice with allergic airway disease by comparison to non-diseased mice which also showed decreases in respiratory rate.[176] Based on these animal data and demonstration of similar effects in humans (e.g., reduction in respiratory rate), individuals with compromised respiratory function (e.g., emphysema, asthma) are expected to be at increased risk of developing adverse responses to strong respiratory irritants such as acrolein.

EPA determined in 2003 that the human carcinogenic potential of acrolein could not be determined because the available data were inadequate. No information was available on the carcinogenic effects of acrolein in humans and the animal data provided inadequate evidence of carcinogenicity.[177] The IARC determined in 1995 that acrolein was not classifiable as to its carcinogenicity in humans.[178]

6.1.1.9.6 Polycyclic Organic Matter (POM)

The term polycyclic organic matter (POM) defines a broad class of compounds that includes the polycyclic aromatic hydrocarbon compounds (PAHs). One of these compounds, naphthalene, is discussed separately below. POM compounds are formed primarily from combustion and are present in the atmosphere in gas and particulate form. Cancer is the major concern from exposure to POM. Epidemiologic studies have reported an increase in lung cancer in humans exposed to diesel exhaust, coke oven emissions, roofing tar emissions, and cigarette smoke; all of these mixtures contain POM compounds.[179,180] Animal studies have reported respiratory tract tumors from inhalation exposure to benzo[a]pyrene and alimentary tract and liver tumors from oral exposure to benzo[a]pyrene.[181] In 1997 EPA classified seven PAHs (benzo[a]pyrene, benz[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, dibenz[a,h]anthracene, and indeno[1,2,3-cd]pyrene) as Group B2, probable human carcinogens.[182] Since that time, studies have found that maternal exposures to PAHs in a population of pregnant women were associated with several adverse birth outcomes, including low birth weight and reduced length at birth, as well as impaired cognitive development in preschool children (3 years of age).[183,184] These and similar studies are being evaluated as a part of the ongoing IRIS assessment of health effects associated with exposure to benzo[a]pyrene.

6.1.1.9.7 Naphthalene

Naphthalene is found in small quantities in gasoline and diesel fuels. Naphthalene emissions have been measured in larger quantities in both gasoline and diesel exhaust compared with evaporative emissions from mobile sources, indicating it is primarily a product of combustion. Acute (short-term) exposure of humans to naphthalene by inhalation, ingestion, or dermal contact is associated with hemolytic anemia and damage to the liver and the nervous system.[185] Chronic (long term) exposure of workers and rodents to naphthalene has been reported to cause cataracts and retinal damage.[186] EPA released an external review draft of a reassessment of the inhalation carcinogenicity of naphthalene based on a number of recent animal carcinogenicity studies.[187] The draft reassessment completed external peer review.[188] Based on external peer review comments received, a revised draft assessment that considers all routes of exposure, as well as cancer and noncancer effects, is under development. The external review draft does not represent official agency opinion and was released solely for the purposes of external peer review and public comment. The National Toxicology Program listed naphthalene as "reasonably anticipated to be a human carcinogen" in 2004 on the basis of bioassays reporting clear evidence of carcinogenicity in rats and some evidence of carcinogenicity in mice.[189] California EPA has released a new risk assessment for naphthalene, and the IARC has reevaluated naphthalene and re-classified it as Group 2B: possibly carcinogenic to humans.[190] Naphthalene also causes a number of chronic non-cancer effects in animals, including abnormal cell changes and growth in respiratory and nasal tissues.[191]

6.1.1.9.8 Other Air Toxics

In addition to the compounds described above, other compounds in gaseous hydrocarbon and PM emissions from vehicles will be affected by the vehicle standards. Mobile source air toxic compounds that would potentially be impacted include ethylbenzene, propionaldehyde, toluene, and xylene. Information regarding the health effects of these compounds can be found in EPA's IRIS database.[wwwww]

6.1.1.10 Exposure and Health Effects Associated with Traffic-Related Air Pollution

Populations who live, work, or attend school near major roads experience elevated exposure to a wide range of air pollutants, as well as higher risks for a number of adverse health effects. While the previous sections of this RIA have focused on the health effects associated with individual criteria pollutants or air toxics, this section discusses the mixture of different exposures near major roadways, rather than the effects of any single pollutant. As such, this section emphasizes traffic-related air pollution, in general, as the relevant indicator of exposure rather than any particular pollutant.

Concentrations of many traffic-generated air pollutants are elevated for up to 300-500 meters downwind of roads with high traffic volumes.[192] Numerous sources on roads contribute to elevated roadside concentrations, including exhaust and evaporative emissions, and resuspension of road dust and tire and brake wear. Concentrations of several criteria and hazardous air pollutants are elevated near major roads. Furthermore, different semi-volatile organic compounds and chemical components of particulate matter, including elemental carbon, organic material, and trace metals, have been reported at higher concentrations near major roads.

Populations near major roads experience greater risk of certain adverse health effects. The Health Effects Institute published a report on the health effects of traffic-related air pollution.[193] It concluded that evidence is "sufficient to infer the presence of a causal association" between traffic exposure and exacerbation of childhood asthma symptoms. The HEI report also concludes that the evidence is either "sufficient" or "suggestive but not sufficient" for a causal association between traffic exposure and new childhood asthma cases. A review of asthma studies by Salam et al. (2008) reaches similar conclusions.[194] The HEI report also concludes that there is "suggestive" evidence for pulmonary function deficits associated with traffic exposure, but concluded that there is "inadequate and insufficient" evidence for causal associations with respiratory health care utilization, adult-onset asthma, COPD symptoms, and allergy. A review by Holguin (2008) notes that the effects of traffic on asthma may be modified by nutrition status, medication use, and genetic factors.[195]

The HEI report also concludes that evidence is "suggestive" of a causal association between traffic exposure and all-cause and cardiovascular mortality. There is also evidence of an association between traffic-related air pollutants and cardiovascular effects such as changes in heart rhythm, heart attack, and cardiovascular disease. The HEI report characterizes this

[wwwww] U.S. EPA Integrated Risk Information System (IRIS) database is available at: www.epa.gov/iris

evidence as "suggestive" of a causal association, and an independent epidemiological literature review by Adar and Kaufman (2007) concludes that there is "consistent evidence" linking traffic-related pollution and adverse cardiovascular health outcomes.[196]

Some studies have reported associations between traffic exposure and other health effects, such as birth outcomes (e.g., low birth weight) and childhood cancer. The HEI report concludes that there is currently "inadequate and insufficient" evidence for a causal association between these effects and traffic exposure. A review by Raaschou-Nielsen and Reynolds (2006) concluded that evidence of an association between childhood cancer and traffic-related air pollutants is weak, but noted the inability to draw firm conclusions based on limited evidence.[197]

There is a large population in the U.S. living in close proximity of major roads. According to the Census Bureau's American Housing Survey for 2007, approximately 20 million residences in the U.S., 15.6% of all homes, are located within 300 feet (91 m) of a highway with 4+ lanes, a railroad, or an airport.[198] Therefore, at current population of approximately 309 million, assuming that population and housing are similarly distributed, there are over 48 million people in the U.S. living near such sources. The HEI report also notes that in two North American cities, Los Angeles and Toronto, over 40% of each city's population live within 500 meters of a highway or 100 meters of a major road. It also notes that about 33% of each city's population resides within 50 meters of major roads. Together, the evidence suggests that a large U.S. population lives in areas with elevated traffic-related air pollution.

People living near roads are often socioeconomically disadvantaged. According to the 2007 American Housing Survey, a renter-occupied property is over twice as likely as an owner-occupied property to be located near a highway with 4+ lanes, railroad or airport. In the same survey, the median household income of rental housing occupants was less than half that of owner-occupants ($28,921/$59,886). Numerous studies in individual urban areas report higher levels of traffic-related air pollutants in areas with high minority or poor populations.[199,200,201]

Students may also be exposed in situations where schools are located near major roads. In a study of nine metropolitan areas across the U.S., Appatova et al. (2008) found that on average greater than 33% of schools were located within 400 m of an Interstate, US, or state highway, while 12% were located within 100 m.[202] The study also found that among the metropolitan areas studied, schools in the Eastern U.S. were more often sited near major roadways than schools in the Western U.S.

Demographic studies of students in schools near major roadways suggest that this population is more likely than the general student population to be of non-white race or Hispanic ethnicity, and more often live in low socioeconomic status locations.[203,204,205] There is some inconsistency in the evidence, which may be due to different local development patterns and measures of traffic and geographic scale used in the studies.[202]

6.1.2 Environmental Effects Associated with Exposure to Non-GHG Pollutants

In this section we will discuss the environmental effects associated with non-GHG pollutants, specifically: particulate matter, ozone, NO_X, SO_X and air toxics.

6.1.2.1 Visibility Degradation

Visibility can be defined as the degree to which the atmosphere is transparent to visible light.[206] Visibility impairment is caused by light scattering and absorption by suspended particles and gases. Visibility is important because it has direct significance to people's enjoyment of daily activities in all parts of the country. Individuals value good visibility for the well-being it provides them directly, where they live and work, and in places where they enjoy recreational opportunities. Visibility is also highly valued in significant natural areas, such as national parks and wilderness areas, and special emphasis is given to protecting visibility in these areas. For more information on visibility see the final 2009 PM ISA.[207]

EPA is pursuing a two-part strategy to address visibility impairment. First, EPA developed the regional haze program (64 FR 35714) which was put in place in July 1999 to protect the visibility in Mandatory Class I Federal areas. There are 156 national parks, forests and wilderness areas categorized as Mandatory Class I Federal areas (62 FR 38680-38681, July 18, 1997). These areas are defined in CAA section 162 as those national parks exceeding 6,000 acres, wilderness areas and memorial parks exceeding 5,000 acres, and all international parks which were in existence on August 7, 1977. Second, EPA has concluded that $PM_{2.5}$ causes adverse effects on visibility in other areas that are not protected by the Regional Haze Rule, depending on $PM_{2.5}$ concentrations and other factors that control their visibility impact effectiveness such as dry chemical composition and relative humidity (i.e., an indicator of the water composition of the particles), and has set secondary $PM_{2.5}$ standards to address these areas. The existing annual primary and secondary $PM_{2.5}$ standards have been remanded and are being addressed in the currently ongoing PM NAAQS review. Figure 6.1-1 shows the location of the 156 Mandatory Class I Federal areas.

Figure 6.1-1 Mandatory Class I Federal Areas in the U.S.

6.1.2.1.1 Visibility Monitoring

In conjunction with the U.S. National Park Service, the U.S. Forest Service, other Federal land managers, and State organizations in the U.S., the U.S. EPA has supported visibility monitoring in national parks and wilderness areas since 1988. The monitoring network was originally established at 20 sites, but it has now been expanded to 110 sites that represent all but one of the 156 Mandatory Federal Class I areas across the country (see Figure 6.1-1). This long-term visibility monitoring network is known as IMPROVE (Interagency Monitoring of Protected Visual Environments).

IMPROVE provides direct measurement of fine particles that contribute to visibility impairment. The IMPROVE network employs aerosol measurements at all sites, and optical and scene measurements at some of the sites. Aerosol measurements are taken for PM_{10} and $PM_{2.5}$ mass, and for key constituents of $PM_{2.5}$, such as sulfate, nitrate, organic and elemental carbon, soil dust, and several other elements. Measurements for specific aerosol constituents are used to calculate "reconstructed" aerosol light extinction by multiplying the mass for each constituent by its empirically-derived scattering and/or absorption efficiency, with adjustment for the relative humidity. Knowledge of the main constituents of a site's light extinction "budget" is critical for source apportionment and control strategy development. In addition to this indirect method of assessing light extinction, there are optical measurements which directly measure light extinction or its components. Such measurements are made principally with either a nephelometer to measure light scattering, some sites also include an aethalometer for light absorption, or at a few sites using a transmissometer, which measures total light extinction. Scene characteristics are typically recorded using digital or video photography and are used to determine the quality of visibility conditions (such as effects on color and contrast) associated with specific levels of light extinction as measured under both direct and aerosol-related methods. Directly measured light extinction is used under the IMPROVE protocol to cross check that the aerosol-derived light extinction levels are reasonable in establishing current visibility conditions. Aerosol-derived light extinction is used to document spatial and temporal trends and to determine how changes in atmospheric constituents would affect future visibility conditions.

Annual average visibility conditions (reflecting light extinction due to both anthropogenic and non-anthropogenic sources) vary regionally across the U.S. Visibility is typically worse in the summer months and the rural East generally has higher levels of impairment than remote sites in the West. Figures 9-9 through 9-11 in the PM ISA detail the percent contributions to particulate light extinction for ammonium nitrate and sulfate, EC and OC, and coarse mass and fine soil, by season.[208]

6.1.2.2 Plant and Ecosystem Effects of Ozone

There are a number of environmental or public welfare effects associated with the presence of ozone in the ambient air.[209] In this section we discuss the impact of ozone on plants, including trees, agronomic crops and urban ornamentals.

The Air Quality Criteria Document for Ozone and related Photochemical Oxidants notes that, "ozone affects vegetation throughout the United States, impairing crops, native vegetation, and ecosystems more than any other air pollutant."[210] Like carbon dioxide (CO_2) and other gaseous substances, ozone enters plant tissues primarily through apertures (stomata) in leaves in a process called "uptake."[211] Once sufficient levels of ozone (a highly reactive substance), or its reaction products, reaches the interior of plant cells, it can inhibit or damage essential cellular components and functions, including enzyme activities, lipids, and cellular membranes, disrupting the plant's osmotic (i.e., water) balance and energy utilization patterns.[212,213] If enough tissue becomes damaged from these effects, a plant's capacity to fix carbon to form carbohydrates, which are the primary form of energy used by plants, is reduced,[214] while plant respiration increases. With fewer resources available, the plant reallocates existing resources away from root growth and storage, above ground growth or yield, and reproductive processes, toward leaf repair and maintenance, leading to reduced growth and/or reproduction. Studies have shown that plants stressed in these ways may exhibit a general loss of vigor, which can lead to secondary impacts that modify plants' responses to other environmental factors. Specifically, plants may become more sensitive to other air pollutants, more susceptible to disease, insect attack, harsh weather (e.g., drought, frost) and other environmental stresses. Furthermore, there is evidence that ozone can interfere with the formation of mycorrhiza, essential symbiotic fungi associated with the roots of most terrestrial plants, by reducing the amount of carbon available for transfer from the host to the symbiont.[215,216]

This ozone damage may or may not be accompanied by visible injury on leaves, and likewise, visible foliar injury may or may not be a symptom of the other types of plant damage described above. When visible injury is present, it is commonly manifested as chlorotic or necrotic spots, and/or increased leaf senescence (accelerated leaf aging). Because ozone damage can consist of visible injury to leaves, it can also reduce the aesthetic value of ornamental vegetation and trees in urban landscapes, and negatively affects scenic vistas in protected natural areas.

Ozone can produce both acute and chronic injury in sensitive species depending on the concentration level and the duration of the exposure. Ozone effects also tend to accumulate over the growing season of the plant, so that even lower concentrations experienced for a longer duration have the potential to create chronic stress on sensitive vegetation. Not all plants, however, are equally sensitive to ozone. Much of the variation in sensitivity between individual plants or whole species is related to the plant's ability to regulate the extent of gas exchange via leaf stomata (e.g., avoidance of ozone uptake through closure of stomata)[217,218,219] Other resistance mechanisms may involve the intercellular production of detoxifying substances. Several biochemical substances capable of detoxifying ozone have been reported to occur in plants, including the antioxidants ascorbate and glutathione. After injuries have occurred, plants may be capable of repairing the damage to a limited extent.[220]

Because of the differing sensitivities among plants to ozone, ozone pollution can also exert a selective pressure that leads to changes in plant community composition. Given the range of plant sensitivities and the fact that numerous other environmental factors modify plant uptake and response to ozone, it is not possible to identify threshold values above which ozone is consistently toxic for all plants. The next few paragraphs present additional information on ozone damage to trees, ecosystems, agronomic crops and urban ornamentals.

Assessing the impact of ground-level ozone on forests in the United States involves understanding the risks to sensitive tree species from ambient ozone concentrations and accounting for the prevalence of those species within the forest. As a way to quantify the risks to particular plants from ground-level ozone, scientists have developed ozone-exposure/tree-response functions by exposing tree seedlings to different ozone levels and measuring reductions in growth as "biomass loss." Typically, seedlings are used because they are easy to manipulate and measure their growth loss from ozone pollution. The mechanisms of susceptibility to ozone within the leaves of seedlings and mature trees are identical, though the magnitude of the effect may be higher or lower depending on the tree species.[221]

Some of the common tree species in the United States that are sensitive to ozone are black cherry (*Prunus serotina*), tulip-poplar (*Liriodendron tulipifera)*, and eastern white pine (*Pinus strobus)*. Ozone-exposure/tree-response functions have been developed for each of these tree species, as well as for aspen (*Populus tremuliodes*), and ponderosa pine (*Pinus ponderosa*). Other common tree species, such as oak (*Quercus* spp.*)* and hickory (*Carya* spp.), are not nearly as sensitive to ozone. Consequently, with knowledge of the distribution of sensitive species and the level of ozone at particular locations, it is possible to estimate a "biomass loss" for each species across their range.

Ozone also has been conclusively shown to cause discernible injury to forest trees.[222,223] In terms of forest productivity and ecosystem diversity, ozone may be the pollutant with the greatest potential for regional-scale forest impacts. Studies have demonstrated repeatedly that ozone concentrations commonly observed in polluted areas can have substantial impacts on plant function.[224,225]

Because plants are at the base of the food web in many ecosystems, changes to the plant community can affect associated organisms and ecosystems (including the suitability of habitats that support threatened or endangered species and below ground organisms living in the root zone). Ozone impacts at the community and ecosystem level vary widely depending upon numerous factors, including concentration and temporal variation of tropospheric ozone, species composition, soil properties and climatic factors.[226] In most instances, responses to chronic or recurrent exposure in forested ecosystems are subtle and not observable for many years. These injuries can cause stand-level forest decline in sensitive ecosystems.[227,228,229] It is not yet possible to predict ecosystem responses to ozone with much certainty; however, considerable knowledge of potential ecosystem responses has been acquired through long-term observations in highly damaged forests in the United States.

Air pollution can have noteworthy cumulative impacts on forested ecosystems by affecting regeneration, productivity, and species composition.[230] In the U.S., ozone in the lower atmosphere is one of the pollutants of primary concern. Ozone injury to forest plants can be diagnosed by examination of plant leaves. Foliar injury is usually the first visible sign of injury to plants from ozone exposure and indicates impaired physiological processes in the leaves.[231] However, not all impaired plants will exhibit visible symptoms.

Laboratory and field experiments have also shown reductions in yields for agronomic crops exposed to ozone, including vegetables (e.g., lettuce) and field crops (e.g., cotton and wheat). The most extensive field experiments, conducted under the National Crop Loss Assessment Network (NCLAN) examined 15 species and numerous cultivars. The NCLAN results show that "several economically important crop species are sensitive to ozone levels typical of those found in the United States."[232] In addition, economic studies have shown reduced economic benefits as a result of predicted reductions in crop yields associated with observed ozone levels.[233,234,235]

Urban ornamentals represent an additional vegetation category likely to experience some degree of negative effects associated with exposure to ambient ozone levels. It is estimated that more than $20 billion (1990 dollars) are spent annually on landscaping using ornamentals, both by private property owners/tenants and by governmental units responsible for public areas.[236] This is therefore a potentially costly environmental effect. However, in the absence of adequate exposure-response functions and economic damage functions for the potential range of effects relevant to these types of vegetation, no direct quantitative analysis has been conducted.

6.1.2.2.1 Data on Visible Foliar Injury Due to Ozone in the U.S.

In the U.S. the national-level visible foliar injury indicator is based on data from the U.S. Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis (FIA) program. As part of its Phase 3 program, formerly known as Forest Health Monitoring, FIA examines ozone injury to ozone-sensitive plant species at ground monitoring sites in forest land across the country. For this indicator, forest land does not include woodlots and urban trees. Sites are selected using a systematic sampling grid, based on a global sampling design.[237,238] At each site that has at least 30 individual plants of at least three ozone-sensitive species and enough open space to ensure that sensitive plants are not protected from ozone exposure by the forest canopy, FIA looks for damage on the foliage of ozone-sensitive forest plant species. Because ozone injury is cumulative over the course of the growing season, examinations are conducted in July and August, when ozone injury is typically highest. Monitoring of ozone injury to plants by the USDA Forest Service has expanded over time from monitoring sites in 10 states in 1994 to nearly 1,000 monitoring sites in 41 states in 2002.

There is considerable regional variation in ozone-related visible foliar injury to sensitive plants in the U.S. The U.S. EPA has developed an environmental indicator based on data from the USDA FIA program which examines ozone injury to ozone-sensitive plant species at ground monitoring sites in forest land across the country. The data underlying the indicator in Figure 6.1-2 is based on averages of all observations collected in 2002, the latest year for which data are publicly available at the time the study was conducted, and is broken down by U.S. EPA Region. Ozone damage to forest plants is classified using a subjective five-category biosite index based on expert opinion, but designed to be equivalent from site to site. Ranges of biosite values translate to no injury, low or moderate foliar injury (visible foliar injury to highly sensitive or moderately sensitive plants, respectively), and high or severe foliar injury, which would be expected to result in tree-level or ecosystem-level responses, respectively.[239,240]

The highest percentages of observed high and severe foliar injury, those which are most likely to be associated with tree or ecosystem-level responses, are primarily found in the Mid-Atlantic and Southeast regions. In EPA Region 3 (which comprises the States of Pennsylvania, West Virginia, Virginia, Delaware, Maryland and Washington D.C.), 12% of ozone-sensitive plants showed signs of high or severe foliar damage, and in Regions 2 (States of New York, New Jersey), and 4 (States of North Carolina, South Carolina, Kentucky, Tennessee, Georgia, Florida, Alabama, and Mississippi) the values were 10% and 7%, respectively. The sum of high and severe ozone injury ranged from 2% to 4% in EPA Region 1 (the six New England States), Region 7 (States of Missouri, Iowa, Nebraska and Kansas), and Region 9 (States of California, Nevada, Hawaii and Arizona). The percentage of sites showing some ozone damage was about 45% in each of these EPA Regions.

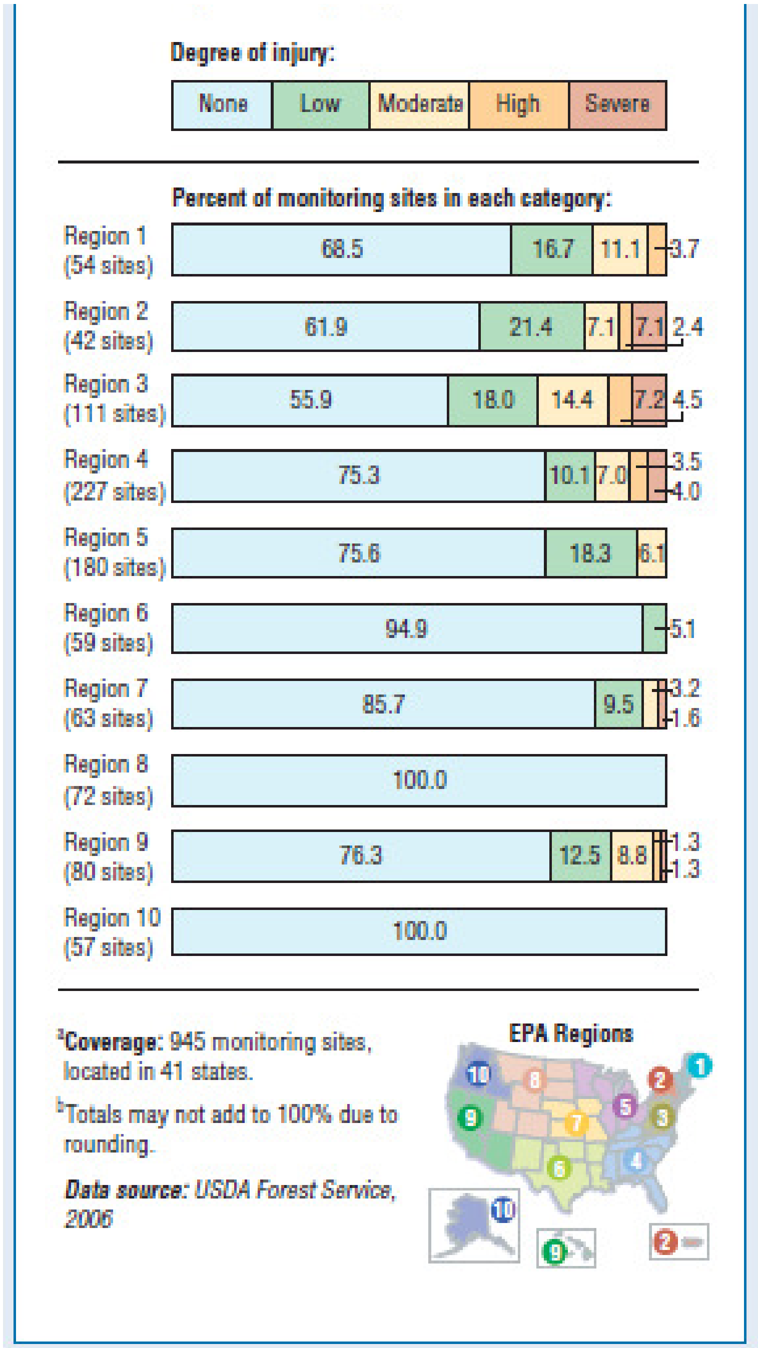

Figure 6.1-2 Ozone Injury to Forest Plants in U.S. by EPA Regions, 2002[ab]

6.1.2.2.2 Indicator Limitations

The categories for the biosite index are subjective and may not necessarily be directly related to biomass loss or physiological damage to plants in a particular area. Ozone may have other adverse impacts on plants (e.g., reduced productivity) that do not show signs of visible foliar injury.[241] The presence of diagnostic visible ozone injury on indicator plants does provide evidence that ozone is having an impact in an area. However, absence of ozone injury in an area does not necessarily mean that there is no impact from ozone exposure.

Field and laboratory studies were reviewed to identify the forest plant species in each region that are sensitive to ozone air pollution and exhibit diagnostic injury. Other forest plant species, or even genetic variants of the same species, may not show symptoms at ozone levels that cause effects on the selected ozone-sensitive species.

Because species distributions vary regionally, different ozone-sensitive plant species were examined in different parts of the country. These target species could vary with respect to ozone sensitivity, which might account for some of the apparent differences in ozone injury among regions of the U.S. Ozone damage to foliage may be reduced under conditions of low soil moisture, but most of the variability in the index (70%) was explained by ozone concentration.[242]

Though FIA has extensive spatial coverage based on a robust sample design, not all forested areas in the U.S. are monitored for ozone injury. Even though the biosite data have been collected over multiple years, most biosites were not monitored over the entire period, so these data cannot provide more than a baseline for future trends.

6.1.2.3 Particulate Matter Deposition

Particulate matter contributes to adverse effects on vegetation and ecosystems, and to soiling and materials damage. These welfare effects result predominately from exposure to excess amounts of specific chemical species, regardless of their source or predominant form (particle, gas or liquid). The following characterizations of the nature of these environmental effects are based on information contained in the 2009 PM ISA and the 2005 PM Staff Paper as well as the Integrated Science Assessment for Oxides of Nitrogen and Sulfur- Ecological Criteria.[243,244,245]

6.1.2.3.1 Deposition of Nitrogen and Sulfur

Nitrogen and sulfur interactions in the environment are highly complex. Both nitrogen and sulfur are essential, and sometimes limiting, nutrients needed for growth and productivity. Excesses of nitrogen or sulfur can lead to acidification, nutrient enrichment, and eutrophication of aquatic ecosystems.[246]

The process of acidification affects both freshwater aquatic and terrestrial ecosystems. Acid deposition causes acidification of sensitive surface waters. The effects of acid deposition on aquatic systems depend largely upon the ability of the ecosystem to neutralize the additional acid. As acidity increases, aluminum leached from soils and sediments, flows into lakes and streams and can be toxic to both terrestrial and aquatic biota. The lower pH concentrations and higher aluminum levels resulting from acidification make it difficult for some fish and other aquatic organisms to survive, grow, and reproduce. Research on effects of acid deposition on forest ecosystems has come to focus increasingly on the biogeochemical processes that affect uptake, retention, and cycling of nutrients within these ecosystems. Decreases in available base cations from soils are at least partly attributable to acid deposition. Base cation depletion is a cause for concern because of the role these ions play in acid neutralization, and because calcium, magnesium and potassium are essential nutrients for plant growth and physiology. Changes in the relative proportions of these nutrients, especially in comparison with aluminum concentrations, have been associated with declining forest health.

At current ambient levels, risks to vegetation from short-term exposures to dry deposited particulate nitrate or sulfate are low. However, when found in acid or acidifying deposition, such particles do have the potential to cause direct leaf injury. Specifically, the responses of forest trees to acid precipitation (rain, snow) include accelerated weathering of leaf cuticular surfaces, increased permeability of leaf surfaces to toxic materials, water, and disease agents; increased leaching of nutrients from foliage; and altered reproductive processes—all which serve to weaken trees so that they are more susceptible to other stresses (e.g., extreme weather, pests, pathogens). Acid deposition with levels of acidity associated with the leaf effects described above are currently found in some locations in the eastern U.S.[247] Even higher concentrations of acidity can be present in occult depositions (e.g., fog, mist or clouds) which more frequently impacts higher elevations. Thus, the risk of leaf injury occurring from acid deposition in some areas of the eastern U.S**.** is high. Nitrogen deposition has also been shown to impact ecosystems in the western U.S. A study conducted in the Columbia River Gorge National Scenic Area (CRGNSA), located along a portion of the Oregon/Washington border, indicates that lichen communities in the CRGNSA have shifted to a higher proportion of nitrophilous species and the nitrogen content of lichen tissue is elevated.[248] Lichens are sensitive indicators of nitrogen deposition effects to terrestrial ecosystems and the lichen studies in the Columbia River Gorge clearly show that ecological effects from air pollution are occurring.

Some of the most significant detrimental effects associated with excess nitrogen deposition are those associated with a condition known as nitrogen saturation. Nitrogen saturation is the condition in which nitrogen inputs from atmospheric deposition and other sources exceed the biological requirements of the ecosystem. The effects associated with nitrogen saturation include: (1) decreased productivity, increased mortality, and/or shifts in plant community composition, often leading to decreased biodiversity in many natural habitats wherever atmospheric reactive nitrogen deposition increases significantly above background and critical thresholds are exceeded; (2) leaching of excess nitrate and associated base cations from soils into streams, lakes, and rivers, and mobilization of soil aluminum; and (3) fluctuation of ecosystem processes such as nutrient and energy cycles through changes in the functioning and species composition of beneficial soil organisms.[249]

In the U.S. numerous forests now show severe symptoms of nitrogen saturation. These forests include: the northern hardwoods and mixed conifer forests in the Adirondack and Catskill Mountains of New York; the red spruce forests at Whitetop Mountain, Virginia, and Great Smoky Mountains National Park, North Carolina; mixed hardwood watersheds at Fernow Experimental Forest in West Virginia; American beech forests in Great Smoky Mountains National Park, Tennessee; mixed conifer forests and chaparral watersheds in southern California and the southwestern Sierra Nevada in Central California; the alpine tundra/subalpine conifer forests of the Colorado Front Range; and red alder forests in the Cascade Mountains in Washington.

Excess nutrient inputs into aquatic ecosystems (i.e. streams, rivers, lakes, estuaries or oceans) either from direct atmospheric deposition, surface runoff, or leaching from nitrogen saturated soils into ground or surface waters can contribute to conditions of severe water oxygen depletion; eutrophication and algae blooms; altered fish distributions, catches, and physiological states; loss of biodiversity; habitat degradation; and increases in the incidence of disease.

Atmospheric deposition of nitrogen is a significant source of total nitrogen to many estuaries in the United States. The amount of nitrogen entering estuaries that is ultimately attributable to atmospheric deposition is not well-defined. On an annual basis, atmospheric nitrogen deposition may contribute significantly to the total nitrogen load, depending on the size and location of the watershed. In addition, episodic nitrogen inputs, which may be ecologically important, may play a more important role than indicated by the annual average concentrations. Estuaries in the U.S. that suffer from nitrogen enrichment often experience a condition known as eutrophication. Symptoms of eutrophication include changes in the dominant species of phytoplankton, low levels of oxygen in the water column, fish and shellfish kills, outbreaks of toxic algae, and other population changes which can cascade throughout the food web. In addition, increased phytoplankton growth in the water column and on surfaces can attenuate light causing declines in submerged aquatic vegetation, which serves as an important habitat for many estuarine fish and shellfish species.

Severe and persistent eutrophication often directly impacts human activities. For example, losses in the nation's fishery resources may be directly caused by fish kills associated with low dissolved oxygen and toxic blooms. Declines in tourism occur when low dissolved oxygen causes noxious smells and floating mats of algal blooms create unfavorable aesthetic conditions. Risks to human health increase when the toxins from algal blooms accumulate in edible fish and shellfish, and when toxins become airborne, causing respiratory problems due to inhalation. According to a NOAA report, more than half of the nation's estuaries have moderate to high expressions of at least one of these symptoms – an indication that eutrophication is well developed in more than half of U.S. estuaries.[250]

6.1.2.3.2 Deposition of Heavy Metals

Heavy metals, including cadmium, copper, lead, chromium, mercury, nickel and zinc, have the greatest potential for impacting forest growth.[251] Investigation of trace metals near roadways and industrial facilities indicate that a substantial load of heavy metals can accumulate on vegetative surfaces. Copper, zinc, and nickel have been documented to cause direct toxicity to vegetation under field conditions. Little research has been conducted on the effects associated with mixtures of contaminants found in ambient PM. While metals typically exhibit low solubility, limiting their bioavailability and direct toxicity, chemical transformations of metal compounds occur in the environment, particularly in the presence of acidic or other oxidizing species. These chemical changes influence the mobility and toxicity of metals in the environment. Once taken up into plant tissue, a metal compound can undergo chemical changes, exert toxic effects on the plant itself, accumulate and be passed along to herbivores or can re-enter the soil and further cycle in the environment. Although there has been no direct evidence of a physiological association between tree injury and heavy metal exposures, heavy metals have been implicated because of similarities between metal deposition patterns and forest decline. This hypothesized relationship/correlation was further explored in high elevation forests in the northeastern U.S. These studies measured levels of a group of intracellular compounds found in plants that bind with metals and are produced by plants as a response to sublethal concentrations of heavy metals. These studies indicated a systematic and significant increase in concentrations of these compounds associated with the extent of tree injury. These data strongly imply that metal stress causes tree injury and contributes to forest decline in the northeastern United States.[252] Contamination of plant leaves by heavy metals can lead to elevated soil levels. Trace metals absorbed into the plant frequently bind to the leaf tissue, and then are lost when the leaf drops. As the fallen leaves decompose, the heavy metals are transferred into the soil.[253,254] Upon entering the soil environment, PM pollutants can alter ecological processes of energy flow and nutrient cycling, inhibit nutrient uptake, change ecosystem structure, and affect ecosystem biodiversity. Many of the most important effects occur in the soil. The soil environment is one of the most dynamic sites of biological interaction in nature. It is inhabited by microbial communities of bacteria, fungi, and actinomycetes. These organisms are essential participants in the nutrient cycles that make elements available for plant uptake. Changes in the soil environment that influence the role of the bacteria and fungi in nutrient cycling determine plant and ultimately ecosystem response.[255]

The environmental sources and cycling of mercury are currently of particular concern due to the bioaccumulation and biomagnification of this metal in aquatic ecosystems and the potent toxic nature of mercury in the forms in which is it ingested by people and other animals. Mercury is unusual compared with other metals in that it largely partitions into the gas phase (in elemental form), and therefore has a longer residence time in the atmosphere than a metal found predominantly in the particle phase. This property enables mercury to travel far from the primary source before being deposited and accumulating in the aquatic ecosystem. The major source of mercury in the Great Lakes is from atmospheric deposition, accounting for approximately eighty percent of the mercury in Lake Michigan.[256,257] Over fifty percent of the mercury in the Chesapeake Bay has been attributed to atmospheric deposition.[258] Overall, the National Science and Technology Council identifies atmospheric deposition as the primary source of mercury to aquatic systems.[259] Forty-four states have issued health advisories for the consumption of fish contaminated by mercury; however, most of these advisories are issued in areas without a mercury point source.

Elevated levels of zinc and lead have been identified in streambed sediments, and these elevated levels have been correlated with population density and motor vehicle use.[260,261] Zinc and nickel have also been identified in urban water and soils. In addition, platinum, palladium, and rhodium, metals found in the catalysts of modern motor vehicles, have been measured at elevated levels along roadsides.[262] Plant uptake of platinum has been observed at these locations.

6.1.2.3.3 Deposition of Polycyclic Organic Matter

Polycyclic organic matter (POM) is a byproduct of incomplete combustion and consists of organic compounds with more than one benzene ring and a boiling point greater than or equal to 100 degrees centigrade.[263] Polycyclic aromatic hydrocarbons (PAHs) are a class of POM that contains compounds which are known or suspected carcinogens.

Major sources of PAHs include mobile sources. PAHs in the environment may be present as a gas or adsorbed onto airborne particulate matter. Since the majority of PAHs are adsorbed onto particles less than 1.0 µm in diameter, long range transport is possible. However, studies have shown that PAH compounds adsorbed onto diesel exhaust particulate and exposed to ozone have half lives of 0.5 to 1.0 hours.[264]

Since PAHs are insoluble, the compounds generally are particle reactive and accumulate in sediments. Atmospheric deposition of particles is believed to be the major source of PAHs to the sediments of Lake Michigan.[265,266] Analyses of PAH deposition in Chesapeake and Galveston Bay indicate that dry deposition and gas exchange from the atmosphere to the surface water predominate.[267,268] Sediment concentrations of PAHs are high enough in some segments of Tampa Bay to pose an environmental health threat. EPA funded a study to better characterize the sources and loading rates for PAHs into Tampa Bay.[269] PAHs that enter a water body through gas exchange likely partition into organic rich particles and can be biologically recycled, while dry deposition of aerosols containing PAHs tend to be more resistant to biological recycling.[270] Thus, dry deposition is likely the main pathway for PAH concentrations in sediments while gas/water exchange at the surface may lead to PAH distribution into the food web, leading to increased health risk concerns.

Trends in PAH deposition levels are difficult to discern because of highly variable ambient air concentrations, lack of consistency in monitoring methods, and the significant influence of local sources on deposition levels.[271] Van Metre et al. noted PAH concentrations in urban reservoir sediments have increased by 200-300% over the last forty years and correlate with increases in automobile use.[272]

Cousins et al. estimate that more than ninety percent of semi-volatile organic compound (SVOC) emissions in the United Kingdom deposit on soil.[273] An analysis of PAH concentrations near a Czechoslovakian roadway indicated that concentrations were thirty times greater than background.[274]

6.1.2.3.4 Materials Damage and Soiling

The effects of the deposition of atmospheric pollution, including ambient PM, on materials are related to both physical damage and impaired aesthetic qualities. The deposition of PM (especially sulfates and nitrates) can physically affect materials, adding to the effects of natural weathering processes, by potentially promoting or accelerating the corrosion of metals, by degrading paints, and by deteriorating building materials such as concrete and limestone. Only chemically active fine particles or hygroscopic coarse particles contribute to these physical effects. In addition, the deposition of ambient PM can reduce the aesthetic appeal of buildings and culturally important articles through soiling. Particles consisting primarily of carbonaceous compounds cause soiling of commonly used building materials and culturally important items such as statues and works of art.

6.1.2.4 Environmental Effects of Air Toxics

Emissions from producing, transporting and combusting fuel contribute to ambient levels of pollutants that contribute to adverse effects on vegetation. Volatile organic compounds

(VOCs), some of which are considered air toxics, have long been suspected to play a role in vegetation damage.[275] In laboratory experiments, a wide range of tolerance to VOCs has been observed.[276] Decreases in harvested seed pod weight have been reported for the more sensitive plants, and some studies have reported effects on seed germination, flowering and fruit ripening. Effects of individual VOCs or their role in conjunction with other stressors (e.g., acidification, drought, temperature extremes) have not been well studied. In a recent study of a mixture of VOCs including ethanol and toluene on herbaceous plants, significant effects on seed production, leaf water content and photosynthetic efficiency were reported for some plant species.[277]

Research suggests an adverse impact of vehicle exhaust on plants, which has in some cases been attributed to aromatic compounds and in other cases to nitrogen oxides.[278,279,280] The impacts of VOCs on plant reproduction may have long-term implications for biodiversity and survival of native species near major roadways. Most of the studies of the impacts of VOCs on vegetation have focused on short-term exposure and few studies have focused on long-term effects of VOCs on vegetation and the potential for metabolites of these compounds to affect herbivores or insects.

6.2 Air Quality Impacts of Non-GHG Pollutants

Chapter 4 of this RIA presents the projected emissions changes due to the vehicle standards. Once the emissions changes are projected, the next step is to look at how the ambient air quality would be impacted by those emissions changes. Although the purpose of the standards is to address greenhouse gas emissions, the GHG standards will also impact emissions of criteria pollutants and air toxics. Sections 6.2.1 and 6.2.2 describe the air quality modeling methodology and results.

6.2.1 Air Quality Modeling Methodology

Air quality models use mathematical and numerical techniques to simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere. Based on inputs of meteorological data and source information, these models are designed to characterize primary pollutants that are emitted directly into the atmosphere and secondary pollutants that are formed as a result of complex chemical reactions within the atmosphere. Photochemical air quality models have become widely recognized and routinely utilized tools for regulatory analysis by assessing the effectiveness of control strategies. These models are applied at multiple spatial scales - local, regional, national, and global. This section provides detailed information on the photochemical model used for our air quality analysis (the Community Multi-scale Air Quality (CMAQ) model), atmospheric reactions and the role of chemical mechanisms in modeling, and model uncertainties and limitations. Further discussion of the modeling methodology is included in the Air Quality Modeling Technical Support Document (AQM TSD) found in the docket for this rulemaking (EPA-HQ-OAR-2010-0799). Results of the air quality modeling are presented in Section 6.2.2.

6.2.1.1 Modeling Methodology

A national-scale air quality modeling analysis was performed to estimate future year annual $PM_{2.5}$ concentrations, 24-hour $PM_{2.5}$ concentrations, 8-hour ozone concentrations, air toxics concentrations, visibility levels and nitrogen and sulfur deposition levels. The 2005-based CMAQ modeling platform was used as the basis for the air quality modeling of the future reference case and the future control scenario for this final rulemaking. This platform represents a structured system of connected modeling-related tools and data that provide a consistent and transparent basis for assessing the air quality response to projected changes in emissions. The base year of data used to construct this platform includes emissions and meteorology for 2005. The platform was developed by the U.S. EPA's Office of Air Quality Planning and Standards in collaboration with the Office of Research and Development and is intended to support a variety of regulatory and research model applications and analyses.

The CMAQ modeling system is a non-proprietary, publicly available, peer-reviewed, state-of-the-science, three-dimensional, grid-based Eulerian air quality grid model designed to estimate the formation and fate of oxidant precursors, primary and secondary PM concentrations, acid deposition, and air toxics, over regional and urban spatial scales for given input sets of meteorological conditions and emissions.[281,282,283] The CMAQ model version 4.7 was most recently peer-reviewed in February of 2009 for the U.S. EPA.[284] The CMAQ model is a well-known and well-respected tool and has been used in numerous national and international applications.[285,286,287] This 2005 multi-pollutant modeling platform used CMAQ version 4.7.1[XXXXX] with a minor internal change made by the U.S. EPA CMAQ model developers intended to speed model runtimes when only a small subset of toxics species are of interest.

CMAQ includes many science modules that simulate the emission, production, decay, deposition and transport of organic and inorganic gas-phase and particle-phase pollutants in the atmosphere. We used CMAQ v4.7.1 which reflects updates to version 4.7 to improve the underlying science. These include aqueous chemistry mass conservation improvements, improved vertical convective mixing and lowered CB05 mechanism unit yields for acrolein from 1,3-butadiene tracer reactions which were updated to be consistent with laboratory measurements. Section 6.2.1.2 of this RIA discusses the chemical mechanism and Secondary Organic Aerosol (SOA) formation.

6.2.1.1.1 Model Domain and Configuration

The CMAQ modeling domain encompasses all of the lower 48 States and portions of Canada and Mexico. The modeling domain is made up of a large continental U.S. 36 kilometer (km) grid and two 12 km grids (an Eastern US and a Western US domain), as shown in Figure 6.2-1. The modeling domain contains 14 vertical layers with the top of the modeling domain at about 16,200 meters, or 100 millibars (mb).

[XXXXX] CMAQ version 4.7.1 was released in June 2010. It is available from the Community Modeling and Analysis System (CMAS) as well as previous peer-review reports at: http://www.cmascenter.org. The air quality modeling for these final standards was initiated prior to February 2012, when CMAQ 5.0 was publically released. CMAQ 4.7.1 was used since it was the most current version of the model available at the time the air quality modeling started.

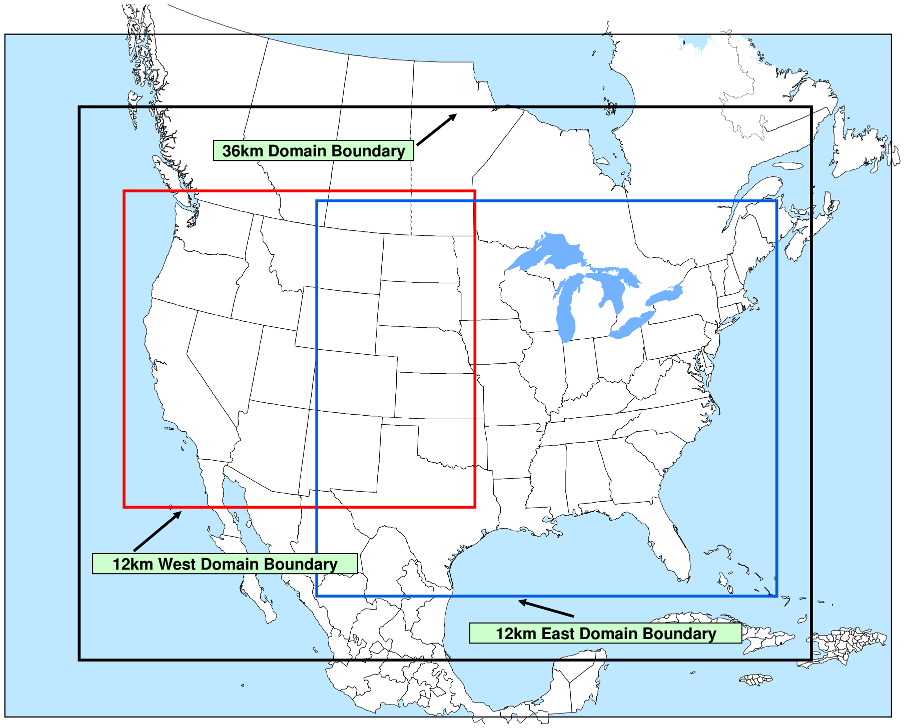

Figure 6.2-1 Map of the CMAQ Modeling Domain

6.2.1.1.2 Model Inputs

The key inputs to the CMAQ model include emissions from anthropogenic and biogenic sources, meteorological data, and initial and boundary conditions. The CMAQ meteorological input files were derived from simulations of the Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model[288] for the entire year of 2005 over model domains that are slightly larger than those shown in Figure 6.2-1. This model, commonly referred to as MM5, is a limited-area, nonhydrostatic, terrain-following system that solves for the full set of physical and thermodynamic equations which govern atmospheric motions.[289] The meteorology for the national 36 km grid and the two 12 km grids were developed by EPA and are described in more detail within the AQM TSD. The meteorological outputs from MM5 were processed to create model-ready inputs for CMAQ using the Meteorology-Chemistry Interface Processor (MCIP) version 3.4, for example: horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each grid cell in each vertical layer.[290]

The lateral boundary and initial species concentrations are provided by a three-dimensional global atmospheric chemistry model, the GEOS-CHEM model.[291] The global GEOS-CHEM model simulates atmospheric chemical and physical processes driven by assimilated meteorological observations from the NASA's Goddard Earth Observing System (GEOS). This model was run for 2005 with a grid resolution of 2 degree x 2.5 degree (latitude-longitude) and 20 vertical layers. The predictions were used to provide one-way dynamic boundary conditions at three-hour intervals and an initial concentration field for the 36 km

CMAQ simulations. The future base conditions from the 36 km coarse grid modeling were used as the initial/boundary state for all subsequent 12 km finer grid modeling.

The emissions inputs used for the 2005 base year and each of the future year base cases and control scenarios are summarized in Chapter 4 of this RIA.

6.2.1.1.3 CMAQ Evaluation

An operational model performance evaluation for ozone, $PM_{2.5}$ and its related speciated components (e.g., sulfate, nitrate, elemental carbon, organic carbon, etc.), nitrate and sulfate deposition, and specific air toxics (formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and acrolein) was conducted using 2005 state/local monitoring data in order to estimate the ability of the CMAQ modeling system to replicate base year concentrations. Model performance statistics were calculated for observed/predicted pairs of daily/monthly/seasonal/annual concentrations. Statistics were generated for the following geographic groupings: domain wide, Eastern vs. Western (divided along the 100th meridian), and each Regional Planning Organization (RPO) region.[YYYYY] The "acceptability" of model performance was judged by comparing our results to those found in recent regional $PM_{2.5}$ model applications for other, non-EPA studies.[ZZZZZ] Overall, the performance for the 2005 modeling platform is within the range or close to that of these other applications. The performance of the CMAQ modeling was evaluated over a 2005 base case. The model was able to reproduce historical concentrations of ozone and $PM_{2.5}$ over land with low bias and error results. Model predictions of annual formaldehyde, acetaldehyde and benzene showed relatively small bias and error results when compared to observations. The model yielded larger bias and error results for 1,3 butadiene and acrolein based on limited monitoring sites. A more detailed summary of the 2005 CMAQ model performance evaluation is available within the AQM TSD found in the docket for this rule.

6.2.1.1.4 Model Simulation Scenarios

As part of our analysis for this rulemaking, the CMAQ modeling system was used to calculate daily and annual $PM_{2.5}$ concentrations, 8-hour ozone concentrations, annual and seasonal (summer and winter) air toxics concentrations, visibility levels, and annual nitrogen and sulfur deposition total levels for each of the following emissions scenarios:

- 2005 base year

- 2030 reference case projection

- 2030 control case projection

[YYYYY] Regional Planning Organization regions include: Mid-Atlantic/Northeast Visibility Union (MANE-VU), Midwest Regional Planning Organization – Lake Michigan Air Directors Consortium (MWRPO-LADCO), Visibility Improvement State and Tribal Association of the Southeast (VISTAS), Central States Regional Air Partnership (CENRAP), and Western Regional Air Partnership (WRAP).

[ZZZZZ] These other modeling studies represent a wide range of modeling analyses which cover various models, model configurations, domains, years and/or episodes, chemical mechanisms, and aerosol modules.

The emission inventories used in the air quality (and benefits) modeling are different from the final rule inventories due to the considerable length of time required to conduct the modeling. However, the air quality modeling inventories are generally consistent with the final emission inventories, so the air quality modeling adequately reflects the effects of the rule. The emission inventories used for air quality modeling are discussed in Chapter 4 of this RIA. The emissions modeling TSD, found in the docket for this rule (EPA-HQ-OAR-2010-0799), contains a detailed discussion of the emissions inputs used in our air quality modeling.

We use the predictions from the model in a relative sense by combining the 2005 base-year predictions with predictions from each future-year scenario and applying these modeled ratios to ambient air quality observations to estimate daily and annual $PM_{2.5}$ concentrations, and 8-hour ozone concentrations for each of the 2030 scenarios. The ambient air quality observations are average conditions, on a site-by-site basis, for a period centered around the model base year (i.e., 2003-2007).

The projected daily and annual $PM_{2.5}$ design values were calculated using the Speciated Modeled Attainment Test (SMAT) approach. The SMAT uses a Federal Reference Method mass construction methodology that results in reduced nitrates (relative to the amount measured by routine speciation networks), higher mass associated with sulfates (reflecting water included in Federal Reference Method measurements), and a measure of organic carbonaceous mass that is derived from the difference between measured $PM_{2.5}$ and its non-carbon components. This characterization of $PM_{2.5}$ mass also reflects crustal material and other minor constituents. The resulting characterization provides a complete mass balance. It does not have any unknown mass that is sometimes presented as the difference between measured $PM_{2.5}$ mass and the characterized chemical components derived from routine speciation measurements. However, the assumption that all mass difference is organic carbon has not been validated in many areas of the U.S. The SMAT methodology uses the following $PM_{2.5}$ species components: sulfates, nitrates, ammonium, organic carbon mass, elemental carbon, crustal, water, and blank mass (a fixed value of 0.5 $\mu g/m^3$). More complete details of the SMAT procedures can be found in the report "Procedures for Estimating Future $PM_{2.5}$ Values for the CAIR Final Rule by Application of the (Revised) Speciated Modeled Attainment Test (SMAT)".[292] For this latest analysis, several datasets and techniques were updated. These changes are fully described within the technical support document for the Final Transport Rule AQM TSD.[293] The projected 8-hour ozone design values were calculated using the approach identified in EPA's guidance on air quality modeling attainment demonstrations.[294]

Additionally, we conducted an analysis to compare the absolute and percent differences between the 2030 control case and the 2030 reference cases for annual and seasonal formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and acrolein, as well as annual nitrate and sulfate deposition. These data were not compared in a relative sense due to the limited observational data available.

6.2.1.2 Chemical Mechanisms in Modeling

This rule presents inventories for NO_X, VOC, CO, $PM_{2.5}$, SO_2, NH_3 and five air toxics: benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. The air toxics are explicit model species in the CMAQv4.7 model with carbon bond 5 (CB05) mechanisms.[295] In addition to direct emissions, photochemical processes mechanisms are responsible for formation of some of these compounds in the atmosphere from precursor emissions. For some pollutants such as PM, formaldehyde, and acetaldehyde, many photochemical processes are involved. CMAQ therefore also requires inventories for a large number of other air toxics and precursor pollutants. Methods used to develop the air quality inventories can be found in Chapter 4 of the RIA.

In the CB05 mechanism, the chemistry of thousands of different VOCs in the atmosphere is represented by a much smaller number of model species which characterize the general behavior of a subset of chemical bond types; this condensation is necessary to allow the use of complex photochemistry in a fully 3-D air quality model.[296]

Complete combustion of ethanol in fuel produces carbon dioxide (CO_2) and water (H_2O). Incomplete combustion of ethanol results in the production of other air pollutants, such as acetaldehyde and other aldehydes, and the release of unburned ethanol. Ethanol is also present in evaporative emissions. In the atmosphere, ethanol from unburned fuel and evaporative emissions can undergo photodegradation to form aldehydes (acetaldehyde and formaldehyde) and peroxyacetyl nitrate (PAN), and also plays a role in ground-level ozone formation. Mechanisms for these reactions are included in CMAQ. Additionally, alkenes and other hydrocarbons are considered because any increase in acetyl peroxy radicals due to ethanol increases might be counterbalanced by a decrease in radicals resulting from decreases in other hydrocarbons.

CMAQ includes 63 inorganic reactions to account for the cycling of all relevant oxidized nitrogen species and cycling of radicals, including the termination of NO_2 and formation of nitric acid (HNO_3) without PAN formation.[AAAAAA]

$$NO_2 + \cdot OH + M \rightarrow HNO_3 + M \qquad k = 1.19 \times 10^{-11}\ cm^3 molecule^{-1} s^{-1}$$ [297]

The CB05 mechanism also includes more than 90 organic reactions that include alternate pathways for the formation of acetyl peroxy radical, such as by reaction of ethene and other alkenes, alkanes, and aromatics. Alternate reactions of acetyl peroxy radical, such as oxidation of NO to form NO_2, which again leads to ozone formation, are also included.

Atmospheric reactions and chemical mechanisms involving several key formation pathways are discussed in more detail in the following sections.

6.2.1.2.1 Acetaldehyde

Acetaldehyde is the main photodegradation product of ethanol, as well as other precursor hydrocarbons. Acetaldehyde is also a product of fuel combustion. In the atmosphere, acetaldehyde can react with the OH radical and O_2 to form the acetyl peroxy radical [$CH_3C(O)OO\cdot$].[BBBBBB] When NO_X is present in the atmosphere this radical species can then

[AAAAAA] All rate coefficients are listed at 298 K and, if applicable, 1 bar of air.

[BBBBBB] Acetaldehyde is not the only source of acetyl peroxy radicals in the atmosphere. For example, dicarbonyl compounds (methylglyoxal, biacetyl, and others) also form acetyl radicals, which can further react to form peroxyacetyl nitrate (PAN).

further react with nitric oxide (NO), to produce formaldehyde (HCHO), or with nitrogen dioxide (NO_2), to produce PAN [$CH_3C(O)OONO_2$]. An overview of these reactions and the corresponding reaction rates are provided below.[CCCCCC]

CH_3CHO + $\cdot OH \rightarrow CH_3C\cdot O + H_2O$ $k = 1.5 \times 10^{-11}\ cm^3molecule^{-1}s^{-1}$ [298]

$CH_3C\cdot O + O_2 + M \rightarrow$ **$CH_3C(O)OO\cdot$** + M

$CH_3C(O)OO\cdot$ + ***NO*** $\rightarrow CH_3C(O)O\cdot$ + ***NO_2*** $k = 2.0 \times 10^{-11}\ cm^3molecule^{-1}s^{-1}$ [299]

$CH_3C(O)O\cdot \rightarrow \cdot CH_3 + CO_2$

$\cdot CH_3 + O_2 + M \rightarrow CH_3OO\cdot + M$

$CH_3OO\cdot + NO \rightarrow CH_3O\cdot + NO_2$

$CH_3O\cdot + O_2 \rightarrow$ **HCHO** + HO_2

$CH_3C(O)OO\cdot$ + NO_2 + M $\rightarrow$ **$CH_3C(O)OONO_2$** + M $k = 1.0 \times 10^{-11}\ cm^3molecule^{-1}s^{-1}$ [300]

Acetaldehyde can react with the NO_3 radical, ground state oxygen atom (O_3P) and chlorine, although these reactions are much slower. Acetaldehyde can also photolyze (hν), which predominantly produces $\cdot CH_3$ (which reacts as shown above to form $CH_3OO\cdot$) and HCO (which rapidly forms HO_2 and CO):

CH_3CHO + hν +2 $O_2 \rightarrow CH_3OO\cdot + HO_2 + CO$ λ = 240-380 nm [301]

As mentioned above, $CH_3OO\cdot$ can react in the atmosphere to produce formaldehyde (HCHO). Formaldehyde is also a product of hydrocarbon combustion. In the atmosphere, the most important reactions of formaldehyde are photolysis and reaction with the OH, with atmospheric lifetimes of approximately 3 hours and 13 hours, respectively.[302] Formaldehyde can also react with NO_3 radical, ground state oxygen atom (O_3P) and chlorine, although these reactions are much slower. Formaldehyde is removed mainly by photolysis whereas the higher aldehydes, those with two or more carbons such as acetaldehyde, react predominantly with OH radicals. The photolysis of formaldehyde is an important source of new hydroperoxy radicals (HO_2), which can lead to ozone formation and regenerate OH radicals.

HCHO + hν + 2 $O_2 \rightarrow 2\ HO_2 + CO$ λ = 240-360 nm [303]

$HO_2 + NO \rightarrow NO_2 + OH$

Photolysis of HCHO can also proceed by a competing pathway which makes only stable products: H_2 and CO.

[CCCCCC] All rate coefficients are listed at 298 K and, if applicable, 1 bar of air.

CB05 mechanisms for acetaldehyde formation warrant a detailed discussion given the increase in vehicle and engine exhaust emissions for this pollutant and ethanol, which can form acetaldehyde in the air. Acetaldehyde is represented explicitly in the CB05 chemical mechanism[304,305] by the ALD2 model species, which can be both formed from other VOCs and can decay via reactions with oxidants and radicals. The reaction rates for acetaldehyde, as well as for the inorganic reactions that produce and cycle radicals, and the representative reactions of other VOCs have all been updated to be consistent with recommendations in the literature.[306]

The decay reactions of acetaldehyde are fewer in number and can be characterized well because they are explicit representations. In CB05, acetaldehyde can photolyze in the presence of sunlight or react with molecular oxygen ($O^3(P)$), hydroxyl radical (OH), or nitrate radicals. The reaction rates are based on expert recommendations,[307] and the photolysis rate is from IUPAC recommendations.

In CMAQ v4.7, the acetaldehyde that is formed from photochemical reactions is tracked separately from that which is due to direct emission and transport of direct emissions. In CB05, there are 25 different reactions that form acetaldehyde in molar yields ranging from 0.02 (ozone reacting with lumped products from isoprene oxidation) to 2.0 (cross reaction of acylperoxy radicals, CXO_3). The specific parent VOCs that contribute the most to acetaldehyde concentrations vary spatially and temporally depending on characteristics of the ambient air, but alkenes in particular are found to play a large role. The IOLE model species, which represents internal carbon-carbon double bonds, has high emissions and relatively high yields of acetaldehyde. The OLE model species, representing terminal carbon double bonds, also plays a role because it has high emissions although lower acetaldehyde yields. Production from peroxyproprional nitrate and other peroxyacylnitrates (PANX) and aldehydes with 3 or more carbon atoms can in some instances increase acetaldehyde but because they also are a sink of radicals, their effect is smaller. Thus, the amount of acetaldehyde (and formaldehyde as well) formed in the ambient air as well as emitted in the exhaust (the latter being accounted for in emission inventories) is affected by changes in these precursor compounds due to the addition of ethanol to fuels (e.g., decreases in alkenes would cause some decrease of acetaldehyde, and to a larger extent, formaldehyde).

The reaction of ethanol (CH_3CH_2OH) with OH is slower than some other important reactions but can be an important source of acetaldehyde if the emissions are large. Based on kinetic data for molecular reactions, the only important chemical loss process for ethanol (and other alcohols) is reaction with the hydroxyl radical (·OH).[308] This reaction produces acetaldehyde (CH_3CHO) with a 90 percent yield.[309] The lifetime of ethanol in the atmosphere can be calculated from the rate coefficient, k, and due to reaction with the OH radical, occurs on the order of a day in polluted urban areas or several days in unpolluted areas.[DDDDDD]

In CB05, reaction of one molecule of ethanol yields 0.90 molecules of acetaldehyde. It assumes the majority of the reaction occurs through H-atom abstraction of the more weakly-bonded methylene group, which reacts with oxygen to form acetaldehyde and hydroperoxy

[DDDDDD] All rate coefficients are listed at 298 K and, if applicable, 1 bar of air.

radical (HO_2), and the remainder of the reaction occurs at the –CH3 and –OH groups, creating formaldehyde (HCHO), oxidizing NO to NO_2 (represented by model species XO_2) and creating glycoaldehyde, which is represented as ALDX:

$$CH_3CHOH + OH \rightarrow HO_2 + 0.90\ CH_3CHO + 0.05\ ALDX + 0.10\ HCHO + 0.10\ XO_2$$

6.2.1.2.2 Secondary Organic Aerosols

Secondary organic aerosol (SOA) chemistry research described below has led to implementation of new pathways for SOA in CMAQ 4.7, based on recommendations of Edney et al. and the recent work of Carlton et al.[310, 311] In previous versions of CMAQ, all SOA was semivolatile and resulted from the oxidation of compounds emitted entirely in the gas-phase. In CMAQ v4.7, parameters in existing pathways were revised and new formation mechanisms were added. Some of the new pathways, such as low-NO_X oxidation of aromatics and particle-phase oligomerization, result in nonvolatile SOA.

Organic aerosol can be classified as either primary or secondary depending on whether it is emitted into the atmosphere as a particle (primary organic aerosol, POA) or formed in the atmosphere (SOA). SOA precursors include volatile organic compounds (VOCs) as well as low-volatility compounds that can react to form even lower volatility compounds. Current research suggests SOA contributes significantly to ambient organic aerosol (OA) concentrations, and in Southeast and Midwest States may make up more than 50 percent (although the contribution varies from area to area) of the organic fraction of $PM_{2.5}$ during the summer (but less in the winter).[312,313] A wide range of laboratory studies conducted over the past twenty years show that anthropogenic aromatic hydrocarbons and long-chained alkanes, along with biogenic isoprene, monoterpenes, and sesquiterpenes, contribute to SOA formation.[314,315,316,317,318] Modeling studies, as well as carbon isotope measurements, indicate that a significant fraction of SOA results from the oxidation of biogenic hydrocarbons.[319,320] Based on parameters derived from laboratory chamber experiments, SOA chemical mechanisms have been developed and integrated into air quality models such as the CMAQ model and have been used to predict OA concentrations.[321]

Over the past 10 years, ambient OA concentrations have been routinely measured in the U.S. and some of these data have been used to determine, by employing source/receptor methods, the contributions of the major OA sources, including biomass burning and vehicular gasoline and diesel exhaust. Since mobile sources are a significant source of VOC emissions, currently accounting for almost 40 percent of anthropogenic VOC,[322] mobile sources are also an important source of SOA, particularly in populated areas.

Toluene is an important contributor to anthropogenic SOA. Mobile sources are the most significant contributor to ambient toluene concentrations as shown by analyses done for the 2005 National Air Toxics Assessment (NATA)[323] and the Mobile Source Air Toxics (MSAT) Rule.[324] The 2005 NATA indicates that onroad and nonroad mobile sources accounted for almost 60 percent (1.46 $\mu g/m^3$) of the total average nationwide ambient concentration of toluene (2.48 $\mu g/m^3$), when the contribution of the estimated "background" is apportioned among source sectors.

The amount of toluene in gasoline influences the amount of toluene emitted in vehicle exhaust and evaporative emissions, although, like benzene, some toluene is formed in the combustion process. In turn, levels of toluene and other aromatics in gasoline are potentially influenced by the amount of ethanol blended into the fuel. Due to the high octane quality of ethanol, it greatly reduces the need for and levels of other high-octane components such as aromatics including toluene (which is the major aromatic compound in gasoline). Since toluene contributes to SOA and the toluene level of gasoline is decreasing, it is important to assess the effect of these reductions on ambient PM.

In addition to toluene, other mobile-source hydrocarbons such as benzene, xylene, and alkanes form SOA. Similar to toluene, the SOA produced by benzene and xylene from low-NO_X pathways is expected to be less volatile and be produced in higher yields than SOA from high-NO_X conditions. [325] Alkanes form SOA with higher yields resulting from the oxidation of longer chain as well as cyclic alkanes.[326]

It is unlikely that ethanol would form directly from SOA or affect SOA formation indirectly through changes in the radical populations from increasing ethanol exhaust. Nevertheless, scientists at the U.S. EPA's Office of Research and Development recently directed experiments to investigate ethanol's SOA forming potential.[327] The experiments were conducted under conditions where peroxy radical reactions would dominate over reaction with NO (i.e., irradiations performed in the absence of NO_X and OH produced from the photolysis of hydrogen peroxide). This was the most likely scenario under which SOA formation could occur, since a highly oxygenated C4 organic would be potentially made. As expected, no SOA was produced. From these experiments, the upper limit for the aerosol yield would have been less than 0.01 percent based on scanning mobility particle sizer (SMPS) data. Given the expected negative result based on these initial smog chamber experiments, these data were not published.

In general, measurements of organic aerosol represent the sum of POA and SOA and the fraction of aerosol that is secondary in nature can only be estimated. One of the most widely applied method of estimating total ambient SOA concentrations is the EC tracer method using ambient data which estimates the OC/EC ratio in primary source emissions.[328,329] SOA concentrations have also been estimated using OM (organic mass) to OC (organic carbon) ratios, which can indicate that SOA formation has occurred, or by subtracting the source/receptor-based total primary organic aerosol (POA) from the measured OC concentration.[330] Aerosol mass spectrometer (AMS) measurements along with positive matrix factorization (PMF) can also be used to identify surrogates for POA and SOA in ambient as well as chamber experiments. Such methods, however, may not be quantitatively accurate and provide no information on the contribution of individual biogenic and anthropogenic SOA sources, which is critical information needed to assess the impact of specific sources and the associated health risk. These methods assume that OM containing additional mass from oxidation of OC comes about largely (or solely) from SOA formation. In particular, the contributions of anthropogenic SOA sources, including those of aromatic precursors, are required to determine exposures and risks associated with replacing fossil fuels with biofuels.

Upon release into the atmosphere, numerous VOC compounds can react with free radicals in the atmosphere to form SOA. While this has been investigated in the laboratory, there is relatively little information available on the specific chemical composition of SOA compounds themselves from specific VOC precursors. This absence of compositional data from the precursors has largely prevented the identification of aromatically-derived SOA in ambient samples which, in turn, has prevented observation-based measurements of the aromatic and other SOA contributions to ambient PM levels.

As a first step in determining the ambient SOA concentrations, EPA has developed a tracer-based method to estimate such concentrations.[331,332] The method is based on using mass fractions of SOA tracer compounds, measured in smog chamber-generated SOA samples, to convert ambient concentrations of SOA tracer compounds to ambient SOA concentrations. This method consists of irradiating the SOA precursor of interest in a smog chamber in the presence of NO_X, collecting the SOA produced on filters, and then analyzing the samples for highly polar compounds using advanced analytical chemistry methods. Employing this method, candidate tracers have been identified for several VOC compounds which are emitted in significant quantities and known to produce SOA in the atmosphere. Some of these SOA-forming compounds include toluene, a variety of monoterpenes, isoprene, and β-caryophyllene, the latter three of which are emitted by vegetation and are more significant sources of SOA than toluene. Smog chamber work can also be used to investigate SOA chemical formation mechanisms.[333,334,335,336]

Although these concentrations are only estimates, due to the assumption that the mass fractions of the smog chamber SOA samples using these tracers are equal to those in the ambient atmosphere, there are presently no other means available for estimating the SOA concentrations originating from individual SOA precursors. Among the tracer compounds observed in ambient $PM_{2.5}$ samples are two tracer compounds that have been identified in smog chamber aromatic SOA samples.[337] To date, these aromatic tracer compounds have been identified, in the laboratory, for toluene and *m*-xylene SOA. Additional work is underway by the EPA to determine whether these tracers are also formed by benzene and other alkylbenzenes (including *o*-xylene, *p*-xylene, 1,2,4-trimethylbenzene, and ethylbenzene).

One caveat regarding this work is that a large number of VOCs emitted into the atmosphere, which have the potential to form SOA, have not yet been studied in this way. It is possible that these unstudied compounds produce SOA species which are being used as tracers for other VOCs. This means that the present work could overestimate the amount of SOA formed in the atmosphere by the VOCs studied to date. This approach may also estimate entire hydrocarbon classes (e.g., all methylsubstituted-monoaromatics or all monoterpenes) and not individual precursor hydrocarbons. Thus the tracers could be broadly representative and not indicative of individual precursors. This is still unknown. Also, anthropogenic precursors play a role in formation of atmospheric radicals and aerosol acidity, and these factors influence SOA formation from biogenic hydrocarbons. This anthropogenic and biogenic interaction, important to EPA and others, needs further study. The issue of SOA formation from aromatic precursors is an important one to which EPA and others are paying significant attention.

The aromatic tracer compounds and their mass fractions have also been used to estimate monthly ambient aromatic SOA concentrations from March 2004 to February 2005 in five U.S. Midwestern cities.[338] The annual tracer-based SOA concentration estimates were 0.15, 0.18, 0.13, 0.15, and 0.19 μg carbon/m^3 for Bondville, IL, East St. Louis, IL, Northbrook, IL, Cincinnati, OH and Detroit, MI, respectively, with the highest concentrations occurring in the summer. On average, the aromatic SOA concentrations made up 17 percent of the total SOA concentration. Thus, this work suggests that we are finding ambient PM levels on an annual basis of about 0.15 $\mu g/m^3$ associated with present toluene levels in the ambient air in these Midwest cities. Based on preliminary analysis of recent laboratory experiments, it appears the toluene tracer could also be formed during photooxidation of some of the xylenes.[339]

Over the past decade a variety of modeling studies have been conducted to predict ambient SOA levels. While early studies focused on the contribution of biogenic monoterpenes, additional precursors, such as sesquiterpenes, isoprene, benzene, toluene, and xylene, have been implemented in atmospheric models such as GEOS-Chem, PMCAMx, and CMAQ.[340, 341, 342, 343, 344,345,346] Studies have indicated that ambient OC levels may be underestimated by current model parameterizations.[347] While the treatment of new precursors has likely reduced the model/measurement bias, underestimates can persist.[348] In general, modeling studies focus on comparing the sum of the POA and SOA concentrations with ambient OC or estimated OA concentrations. Without a method to attribute measured OC to different sources or precursors, identifying causes of the underestimates in modeled OC via model/measurement comparisons can be challenging. Oxidation of low-volatility organic compounds as well as particle-phase reactions resulting from acidity have been explored as potential missing sources of OC in models.[349,350]

6.2.1.2.3 Ozone

As mentioned above, the addition of ethanol to fuels has been shown to contribute to PAN formation and this is one way for it to contribute therefore to ground-level ozone formation downwind of NO_X sources. PAN is a reservoir and carrier of NO_X and is the product of acetyl radicals reacting with NO_2 in the atmosphere. One source of PAN is the photooxidation of acetaldehyde (Section 6.2.1.2.1), but many VOCs have the potential for forming acetyl radicals and therefore PAN or a PAN-type compound.[EEEEEE] PAN can undergo thermal decomposition with a lifetime of approximately 1 hour at 298K or 148 days at 250K.[FFFFFF]

$$\mathbf{CH_3C(O)OONO_2} + M \rightarrow CH_3C(O)OO\cdot + \mathbf{NO_2} + M \qquad k = 3.3 \times 10^{-4}\ s^{-1}$$ [351]

The reaction above shows how NO_2 is released in the thermal decomposition of PAN, along with a peroxy radical which can oxidize NO to NO_2. NO_2 can also be formed in photodegradation reactions where NO is converted to NO_2 (see OH radical reaction of acetaldehyde in Section 6.2.1.2.1). In both cases, NO_2 further photolyzes to produce ozone (O_3).

$$\mathbf{NO_2} + h\nu \rightarrow NO + O(^3P) \qquad \lambda = 300\text{-}800\ nm$$ [352]

$$O(^3P) + O_2 + M \rightarrow \mathbf{O_3} + M$$

[EEEEEE] Many aromatic hydrocarbons, particularly those present in high percentages in gasoline (toluene, m-, o-, p-xylene, and 1,3,5-, 1,2,4-trimethylbenzene), form methylglyoxal and biacetyl, which are also strong generators of acetyl radicals (Smith, D.F., T.E. Kleindienst, C.D. McIver (1999) Primary product distribution from the reaction of OH with m-, p-xylene and 1,2,4- and 1,3,5-Trimethylbenzene. J. Atmos. Chem., 34: 339- 364.).

[FFFFFF] All rate coefficients are listed at 298 K and, if applicable, 1 bar of air.

The temperature sensitivity of PAN allows it to be stable enough at low temperatures to be transported long distances before decomposing to release NO_2. NO_2 can then participate in ozone formation in regions remote from the original NO_X source.[353] A discussion of CB05 mechanisms for ozone formation can be found in Yarwood et al. (2005).[354]

Another important way that ethanol fuels contribute to ozone formation is by increasing the formation of new radicals through increases in formaldehyde and acetaldehyde. As shown in Section 6.2.1.2.1, the photolysis of both aldehydes results in two molecules of either hydroperoxy radical or methylperoxy radical, both of which oxidize NO to NO_2 leading to ozone formation.

6.2.1.3 Modeling Uncertainties and Limitations

All the results presented below must be interpreted with the understanding that there are uncertainties in inventories, atmospheric processes in CMAQ, and other aspects of the modeling process. While it is beyond the scope of this RIA to include a comprehensive discussion of all limitations and uncertainties associated with air quality modeling, several sources of uncertainty that impact analyses for this rule are discussed.

A source of uncertainty is the photochemical mechanisms in CMAQ 4.7.1. Pollutants such as ozone, PM, acetaldehyde, formaldehyde, acrolein, and 1,3-butadiene can be formed secondarily through atmospheric chemical processes. Since secondarily formed pollutants can result from many different reaction pathways, there are uncertainties associated with each pathway. Simplifications of chemistry must be made in order to handle reactions of thousands of chemicals in the atmosphere. Mechanisms for formation of ozone, PM, acetaldehyde and peroxyacetyl nitrate (PAN) are discussed in Section 6.2.1.2.

For PM, there are a number of uncertainties associated with SOA formation. As mentioned in Section 6.2.1.2.2, a large number of VOCs emitted into the atmosphere, which have the potential to form SOA, have not yet been studied in detail. In addition, the amount of ambient SOA that comes from benzene is uncertain. Simplifications to the SOA treatment in CMAQ have also been made in order to preserve computational efficiency. These simplifications are described in release notes for CMAQ 4.7 on the Community Modeling and Analysis System (CMAS) website.[355]

6.2.2 Air Quality Modeling Results

6.2.2.1 Ozone

As described in Section 6.1.1.4, exposure to ozone causes adverse health effects, and the EPA has set national standards to provide requisite protection against those health effects. In this section, we present information on current and model-projected future ozone levels.

6.2.2.1.1 Current Levels of Ozone

Figure 6.2-2 shows a snapshot of measured ozone concentrations in 2010. The highest ozone concentrations were located in California.

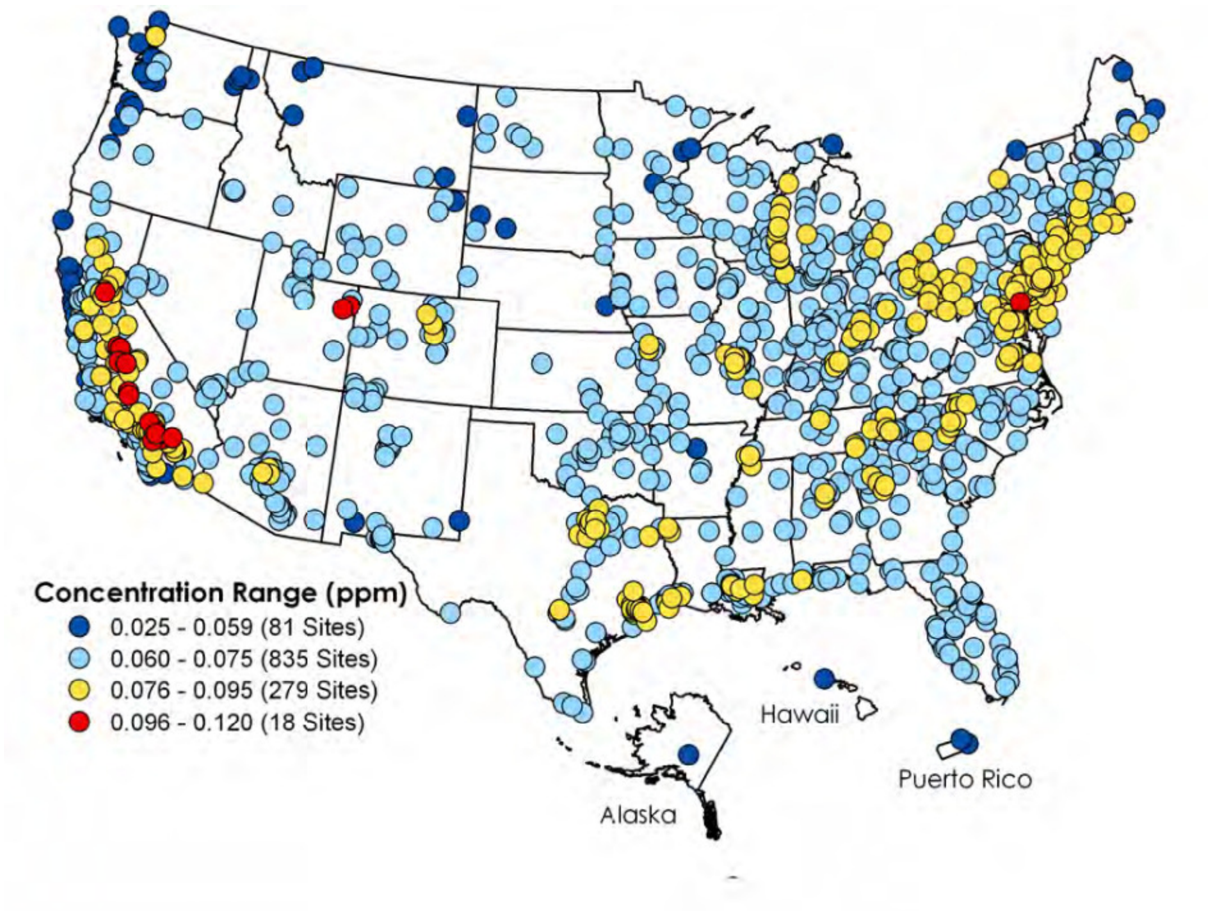

Figure 6.2-2 Ozone Concentrations (average of annual fourth highest daily maximum 8-hour concentration) in ppm for 2010[356]

The primary and secondary NAAQS for ozone are 8-hour standards set at 0.075 ppm. The most recent revision to the ozone standards was in 2008; the previous 8-hour ozone standards, set in 1997, had been set at 0.08 ppm. In 2004, the U.S. EPA designated nonattainment areas for the 1997 8-hour ozone NAAQS (69 FR 23858, April 30, 2004).[GGGGGG] As of July 20, 2012, there were 43 8-hour ozone nonattainment areas for the 1997 ozone NAAQS, composed of 237 full or partial counties, with a total population of over 129 million. Nonattainment areas for the 1997 8-hour ozone NAAQS are pictured in Figure 6.2-3. Nonattainment designations for the 2008 ozone standards were finalized on April 30, 2012 and May 31, 2012.[357] These designations include 46 areas, composed of 227 full or partial counties, with a population of over 123 million. Nonattainment areas for the 2008 ozone NAAQS are pictured in Figure 6.2-9. As of July 20, 2012, 140 million people are living in ozone nonattainment areas.

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[GGGGGG] A nonattainment area is defined in the Clean Air Act (CAA) as an area that is violating an ambient standard or is contributing to a nearby area that is violating the standard.

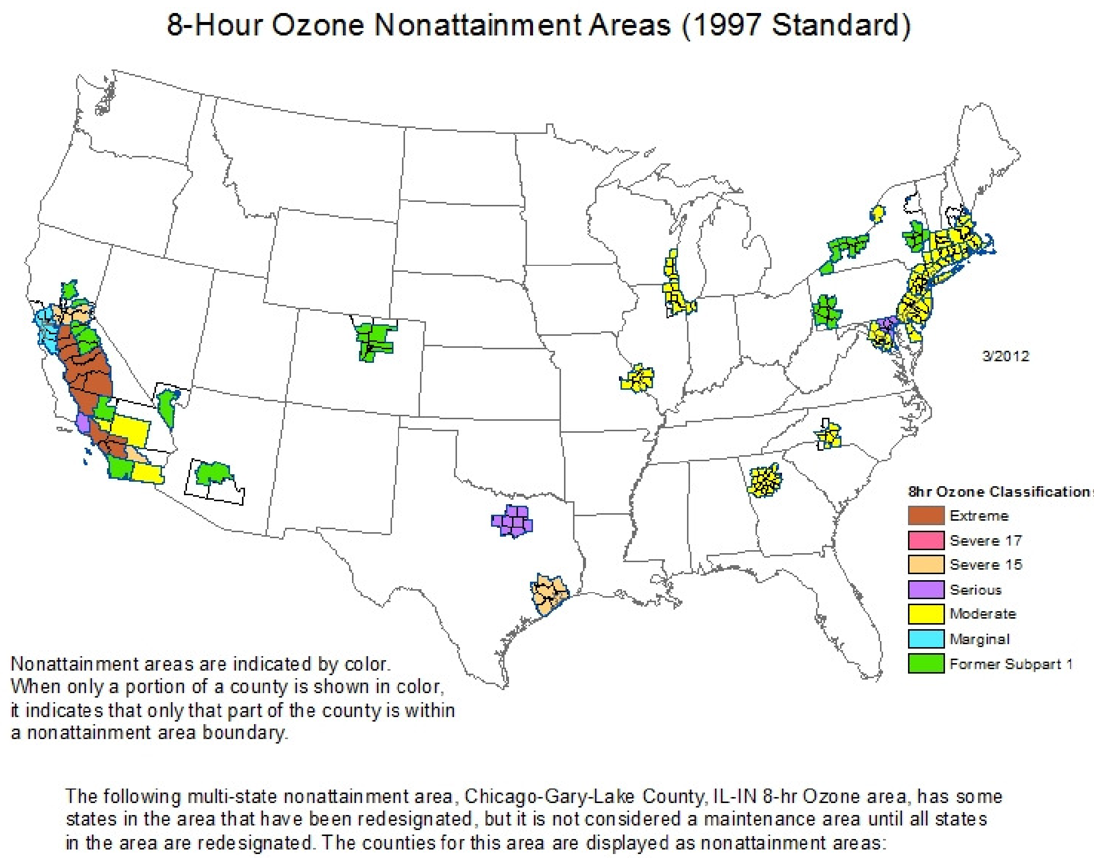

Figure 6.2-3 1997 8-hour Ozone Nonattainment Areas

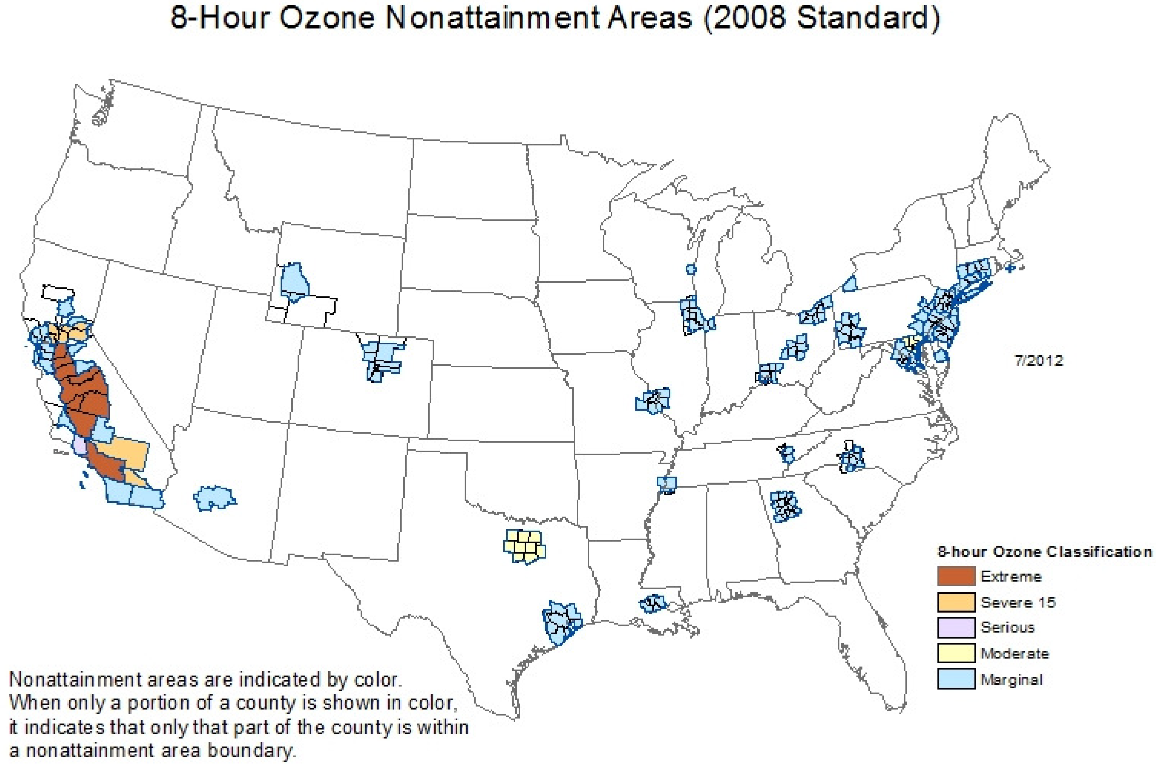

Figure 6.2-4 2008 8-hour Ozone Nonattainment Areas

States with ozone nonattainment areas are required to take action to bring those areas into attainment in the future. The attainment date assigned to an ozone nonattainment area is based on the area's classification. Most ozone nonattainment areas are required to attain the 1997 8-hour ozone NAAQS in the 2007 to 2013 time frame.[HHHHHH] Once an ozone nonattainment area has attained the NAAQS they are then required to maintain it thereafter. The attainment dates for areas designated nonattainment for the 2008 8-hour ozone NAAQS are in the 2015 to 2032 timeframe, depending on the severity of the problem in each area.

6.2.2.1.2 Projected Levels of Ozone

In the following sections, we describe projected ozone levels in the future with and without the vehicle standards. Our modeling indicates that there will be very small changes in ozone across most of the country. In addition, ozone concentrations in some areas will decrease and ozone concentrations in some other areas will increase. The impacts of the standards on ozone are a function of VMT increases from rebound, upstream reductions in petroleum

[HHHHHH] The Los Angeles South Coast Air Basin 8-hour ozone nonattainment area and the San Joaquin Valley Air Basin 8-hour ozone nonattainment area are designated as extreme and will have to attain before June 15, 2024. The Sacramento, Coachella Valley, Western Mojave, and Houston 8-hour ozone nonattainment areas are designated as severe and will have to attain by June 15, 2019.

consumption from crude oil production and transport, and gasoline production, distribution and transport, and changes in location and amount of electricity generation. Information on the air quality modeling methodology is contained in Section 6.2.1 and additional detail can be found in the air quality modeling technical support document (AQM TSD).

Projected Levels of Ozone without this Final Action

EPA has already adopted many emission control programs that are expected to reduce ambient ozone levels. These control programs include the New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder Rule (75 FR 22895, April 30, 2010), the Marine Spark-Ignition and Small Spark-Ignition Engine Rule (73 FR 59034, October 8, 2008), the Locomotive and Marine Rule (73 FR 25098, May 6, 2008), the Clean Air Interstate Rule (70 FR 25162, May 12, 2005), the Clean Air Nonroad Diesel Rule (69 FR 38957, June 29, 2004), and the Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements (66 FR 5002, January 18, 2001). As a result of these and other federal, state and local programs, 8-hour ozone levels are expected to improve in the future. However, even with the implementation of all current state and federal regulations, there are projected to be counties that would have projected design values above the level of the ozone NAAQS well into the future.

The air quality modeling projects that in 2030, with all current controls in effect but excluding the emissions changes expected to occur as a result of this final action, at least 10 counties, with a projected population of over 30 million people, would have projected design values above the level of the 2008 8-hour ozone standard of 75 ppb. Since the emission changes from this final action go into effect during the period when some areas are still working to attain the ozone NAAQS, the projected emission changes will impact state and local agencies in their effort to attain and maintain the ozone standard. In the following section we discuss the projected ozone impacts associated with the vehicle standards.

Projected Levels of Ozone with this Final Action

This section summarizes the results of our modeling of ozone air quality impacts in the future with the vehicle standards. Specifically, we compare a 2030 reference scenario, a scenario without the vehicle standards, to a 2030 control scenario which includes the vehicle standards. Our modeling indicates that there will be very small changes in ambient ozone concentrations across most of the country. However, there will be small decreases in ozone design value concentrations in some areas of the country and small increases in ozone design value concentrations in other areas. [IIIIII]

Figure 6.2-5 presents the changes in 8-hour ozone design value concentrations in 2030 between the reference case and the control case. The ozone impacts are related to downstream emissions changes from VMT rebound and upstream emissions changes in electrical power

[IIIIII] An 8-hour ozone design value is the concentration that determines whether a monitoring site meets the 8-hour ozone NAAQS. The full details involved in calculating an 8-hour ozone design value are given in appendix I of 40 CFR part 50.

generation and fuel production. In some areas the ozone impact is a result of a combination of the various emissions changes but in other areas the impact is likely mainly the result of one of the types of emissions changes. Some of the ozone increases and decreases are related mainly to upstream emissions changes in electricity generation. For example, the projected increases in Las Vegas, Dayton, and Little Rock are due mainly to increased demand for electricity from electric vehicles and the projected decrease in ozone in northeast West Virginia is due mainly to reductions in power plant emissions.[JJJJJJ] Some of the ozone decreases are mainly related to upstream emissions reductions from reduced refinery demand as fuel production decreases (e.g. the Gulf Coast) and some of the ozone increases are mainly related to increased emissions of NO_X from the VMT rebound effect (e.g., Knoxville and Atlanta).

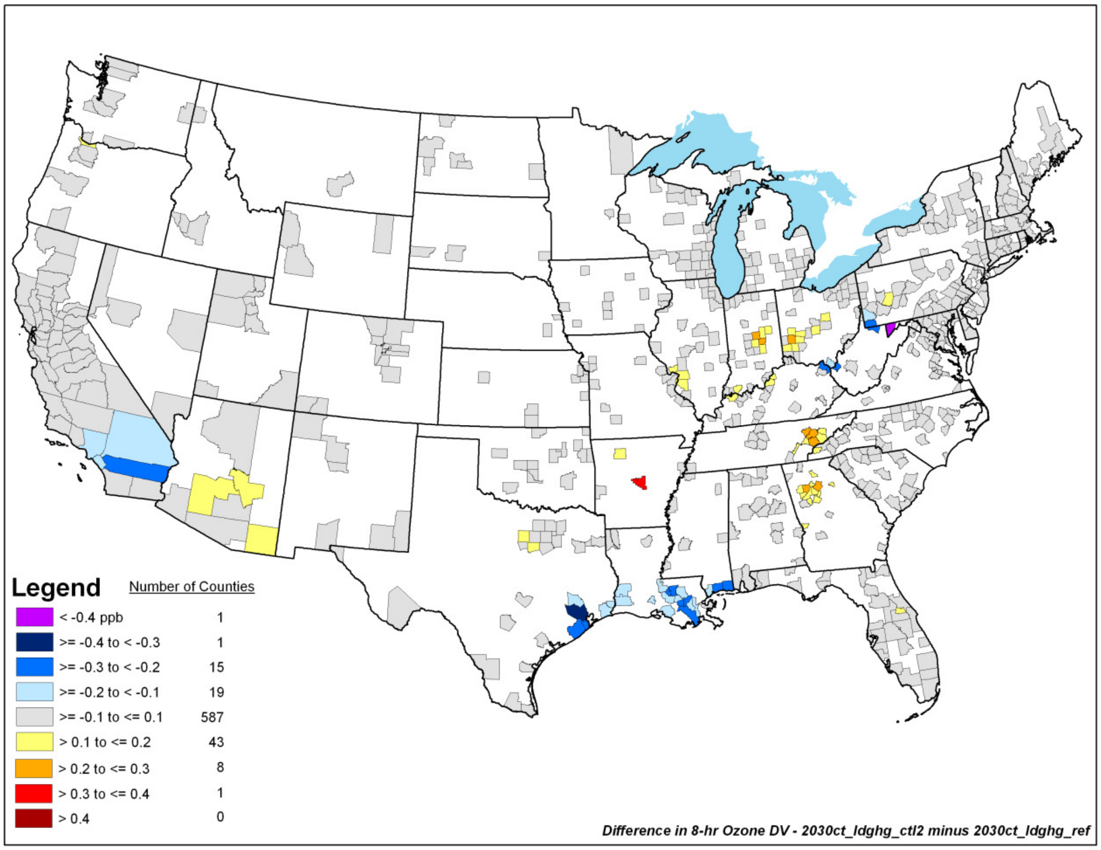

Figure 6.2-5 Projected Change in 2030 8-hour Ozone Design Values Due to the Final Standards

As can be seen in Figure 6.2-5, the majority of the ozone design value impacts are between + 0.3 ppb and -0.3 ppb. However, there are two counties that will experience 8-hour ozone design value decreases of more than 0.3 ppb: Garrett County, Maryland, and Harris County, Texas. The maximum projected decrease in an 8-hour ozone design value is 0.47 ppb in

[JJJJJJ] Section 4.7.3.1 has more information on the Integrated Planning Model (IPM) analysis which was done to project future electricity demand and plant locations.

Garrett County, Maryland and is likely related to the projected reductions in power plant emissions in northeast WV. There is also one county, Pulaski County in Arkansas, with a projected design value increase greater than 0.3 ppb. The projected increase in Pulaski County is 0.37 ppb. There are 10 counties, most of them in California, that are projected to have 8-hour ozone design values above the 2008 NAAQS in 2030 with the vehicle standards in place. Table 6.2-1 below presents the changes in design values for these counties.

Table 6.2-1 Change in Ozone Design Values (ppb) for Counties Projected to be Above the 2008 Ozone NAAQS in 2030

County Name	Change in 8-hour Ozone Design Value (ppb)	Population in 2030[a]
San Bernardino Co, California	-0.20	2,784,490
Riverside Co, California	-0.23	2,614,198
Los Angeles Co, California	-0.13	10,742,722
Kern Co, California	0.05	981,806
Harris Co, Texas	-0.31	5,268,889
Tulare Co, California	-0.02	528,663
Orange Co, California	-0.12	4,431,071
Fresno Co, California	-0.04	1,196,950
Suffolk Co, New York	-0.06	1,705,822
Brazoria Co, Texas	-0.30	364,257

Note:
[a] Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. 2001. Population by Single Year of Age CD.

Table 6.2-2 shows the average change in 2030 8-hour ozone design values for: (1) all counties with 2005 baseline design values, (2) counties with 2005 baseline design values that exceeded the 2008 ozone standard, (3) counties with 2005 baseline design values that did not exceed the 2008 standard, but were within 10% of it, (4) counties with 2030 design values that exceeded the 2008 ozone standard, and (5) counties with 2030 design values that did not exceed the standard, but were within 10% of it. Counties within 10% of the standard are intended to reflect counties that although not violating the standards, will also be impacted by changes in ozone as they work to ensure long-term maintenance of the ozone NAAQS. The average modeled future-year 8-hour ozone design values are projected to increase by 0.01 ppb in 2030. Average design values in those counties that are projected to be above the 2008 ozone standard in 2030 will decrease by 0.14 ppb due to the vehicle standards.

Table 6.2-2 Average Change in Projected 8-hour Ozone Design Value

Average[a]	Number of US Counties	2030 Population[b]	Change in 2030 design value (ppb)
All	675	261,439,344	0.01
All, population-weighted			0.00
Counties whose 2005 base year is above the 2008 8-hour ozone standard	393	194,118,748	0.02
Counties whose 2005 base year is above the 2008 8-hour ozone standard, population-weighted			0.00
Counties whose 2005 base year is within 10 percent of the 2008 8-hour ozone standard	201	44,436,103	0.02
Counties whose 2005 base year is within 10 percent of the 2008 8-hour ozone standard, population-weighted			0.01
Counties whose 2030 control case is above the 2008 8-hour ozone standard	10	30,618,868	-0.14
Counties whose 2030 control case is above the 2008 8-hour ozone standard, population-weighted			-0.16
Counties whose 2030 control case is within 10% of the 2008 8-hour ozone standard	40	29,661,201	-0.02
Counties whose 2030 control case is within 10% of the 2008 8-hour ozone standard, population-weighted			0.00

Notes:
[a] Averages are over counties with 2005 modeled design values
[b] Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. 2001. Population by Single Year of Age CD.

Ground-level ozone pollution is formed by the reaction of VOCs and NO_X in the atmosphere in the presence of heat and sunlight. The science of ozone formation, transport, and accumulation is complex.[358] The projected ozone impacts which are seen in the air quality modeling for this final action are a result of the emissions changes due to the vehicle standards combined with the photochemistry involved, the different background concentrations of VOCs and NO_X in different areas of the country, and the different meteorological conditions in different areas of the country.

When VOC levels are relatively high, relatively small amounts of NO_X enable ozone to form rapidly. Under these conditions, VOC reductions have little effect on ozone and while NO_X reductions are highly effective in reducing ozone, conversely NO_X increases lead to increases in ozone. Such conditions are called "NO_X -limited." Because the contribution of VOC emissions from biogenic (natural) sources to local ambient ozone concentrations can be significant, even some areas where man-made VOC emissions are relatively low can be NO_X -limited. Rural areas are usually NO_X -limited, due to the relatively large amounts of biogenic VOC emissions in such areas.

When NO_X levels are relatively high and VOC levels relatively low, NO_X forms inorganic nitrates (*i.e.*, particles) but relatively little ozone. Such conditions are called "NOx-saturated." Under these conditions, VOC reductions are effective in reducing ozone, but NO_X reductions can actually increase local ozone under certain circumstances.

6.2.2.2 Particulate Matter

As described in Section 6.1.1.2, exposure to $PM_{2.5}$ causes adverse health effects, and the EPA has set national standards to provide requisite protection against those health effects. In this section, we present information on current and model-projected future $PM_{2.5}$ levels.

6.2.2.2.1 Current Levels of Particulate Matter

Figure 6.2-6 and Figure 6.2-7 respectively show a snapshot of annual and 24-hour $PM_{2.5}$ concentrations in 2010. In 2010, the highest annual average $PM_{2.5}$ concentrations were in California, Indiana, Pennsylvania, and Hawaii and the highest 24-hour $PM_{2.5}$ concentrations were in California and Alaska.

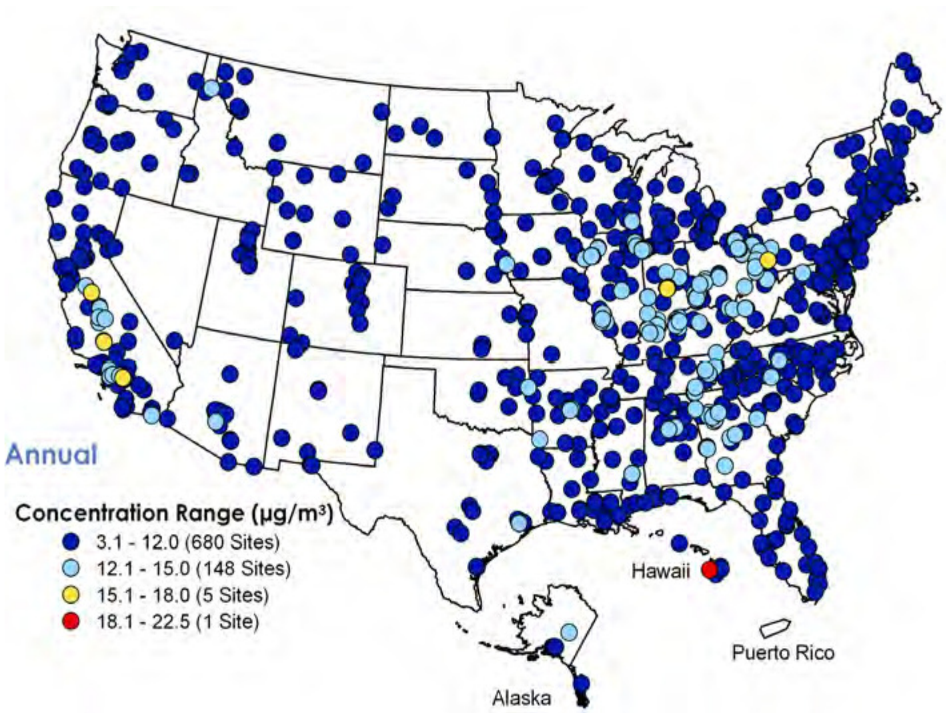

Figure 6.2-6 Annual Average $PM_{2.5}$ Concentrations in µg/m^3 for 2010[359]

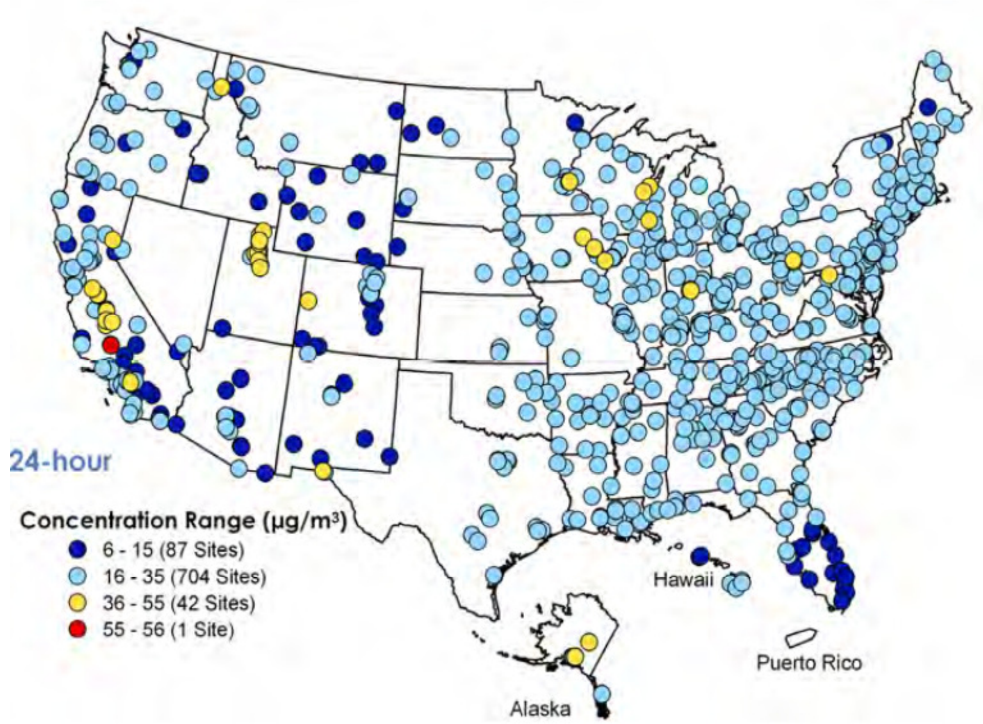

Figure 6.2-7 24-hour (98th percentile 24- hour concentrations) $PM_{2.5}$ Concentrations in µg/m³ for 2010[360]

There are two NAAQS for $PM_{2.5}$: an annual standard (15.0 µg/m³) and a 24-hour standard (35 µg/m³). The most recent revisions to these standards were in 1997 and 2006. In June 2012, EPA proposed to revise the $PM_{2.5}$ NAAQS and is scheduled to issue final revisions in December 2012 under a court-ordered schedule. The proposed changes include revising the annual $PM_{2.5}$ standard to a level between 12 and 13 µg/m³, and establishing a distinct secondary $PM_{2.5}$ standard for the protection of visibility, particularly in urban areas.

In 2005 the U.S. EPA designated nonattainment areas for the 1997 $PM_{2.5}$ NAAQS (70 FR 19844, April 14, 2005). As of July 20, 2012, over 91 million people lived in the 35 areas that are designated as nonattainment for the 1997 $PM_{2.5}$ NAAQS. These $PM_{2.5}$ nonattainment areas are comprised of 191 full or partial counties. Nonattainment areas for the 1997 $PM_{2.5}$ NAAQS are pictured in Figure 6.2-8. On October 8, 2009, the EPA issued final nonattainment area designations for the 2006 24-hour $PM_{2.5}$ NAAQS (74 FR 58688, November 13, 2009). These designations include 32 areas, composed of 121 full or partial counties, with a population of over 74 million. Nonattainment areas for the 2006 $PM_{2.5}$ NAAQS are pictured in Figure 6.2-9. In total, there are 50 $PM_{2.5}$ nonattainment areas with a population of over 105 million people.

States with $PM_{2.5}$ nonattainment areas will be required to take action to bring those areas into attainment in the future. The 1997 $PM_{2.5}$ nonattainment areas are required to attain the 1997 $PM_{2.5}$ NAAQS in the 2009 to 2015 time frame and then maintain the 1997 $PM_{2.5}$ NAAQS thereafter.[361] The 2006 24-hour $PM_{2.5}$ nonattainment areas will be required to attain the 2006 24-hour $PM_{2.5}$ NAAQS in the 2014 to 2019 time frame and then maintain the 2006 24-hour $PM_{2.5}$ NAAQS thereafter.[362]

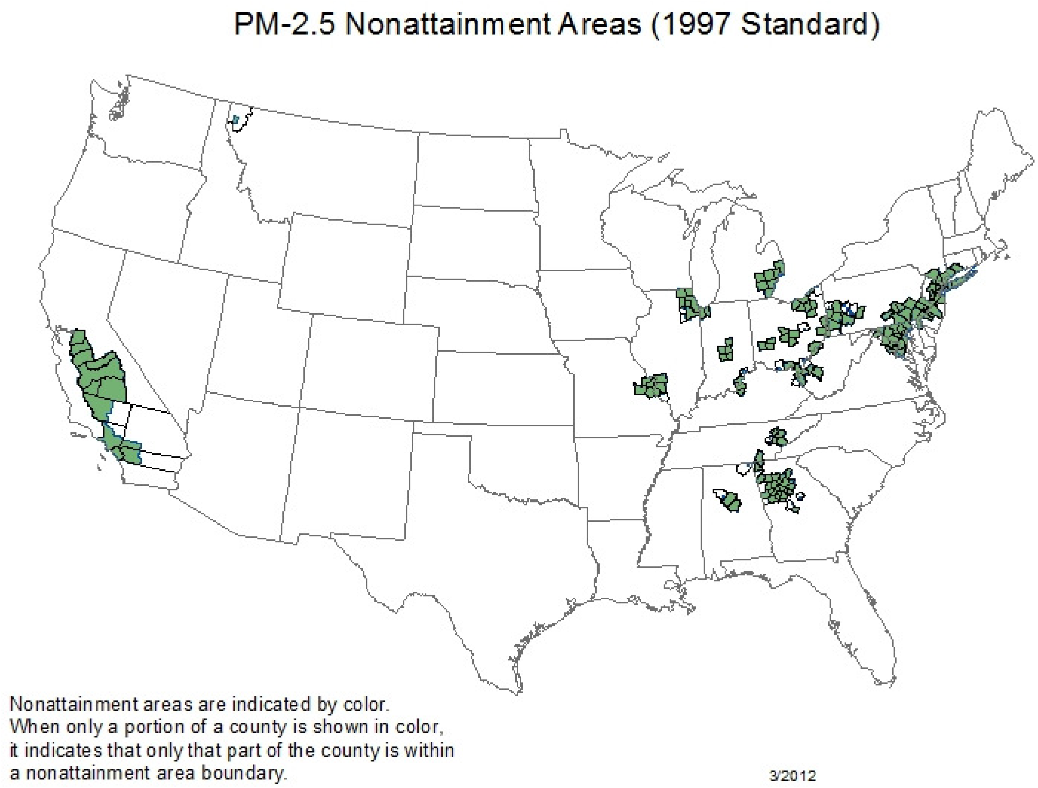

Figure 6.2-8 1997 $PM_{2.5}$ Nonattainment Areas

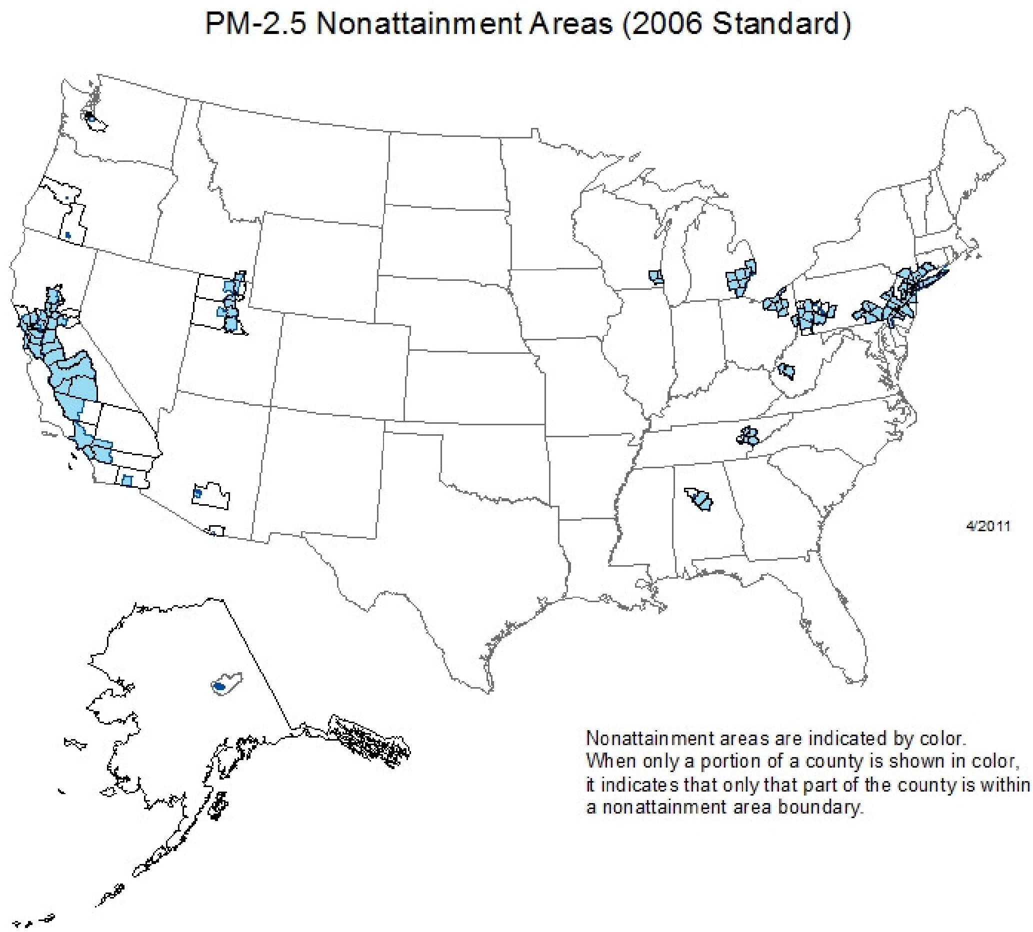

Figure 6.2-9 2006 $PM_{2.5}$ Nonattainment Areas

As of July 20, 2012, over 29 million people live in the 46 areas that are designated as nonattainment for the PM_{10} NAAQS. There are 39 full or partial counties that make up the PM_{10} nonattainment areas. Nonattainment areas for the PM_{10} NAAQS are pictured in Figure 6.2-10.

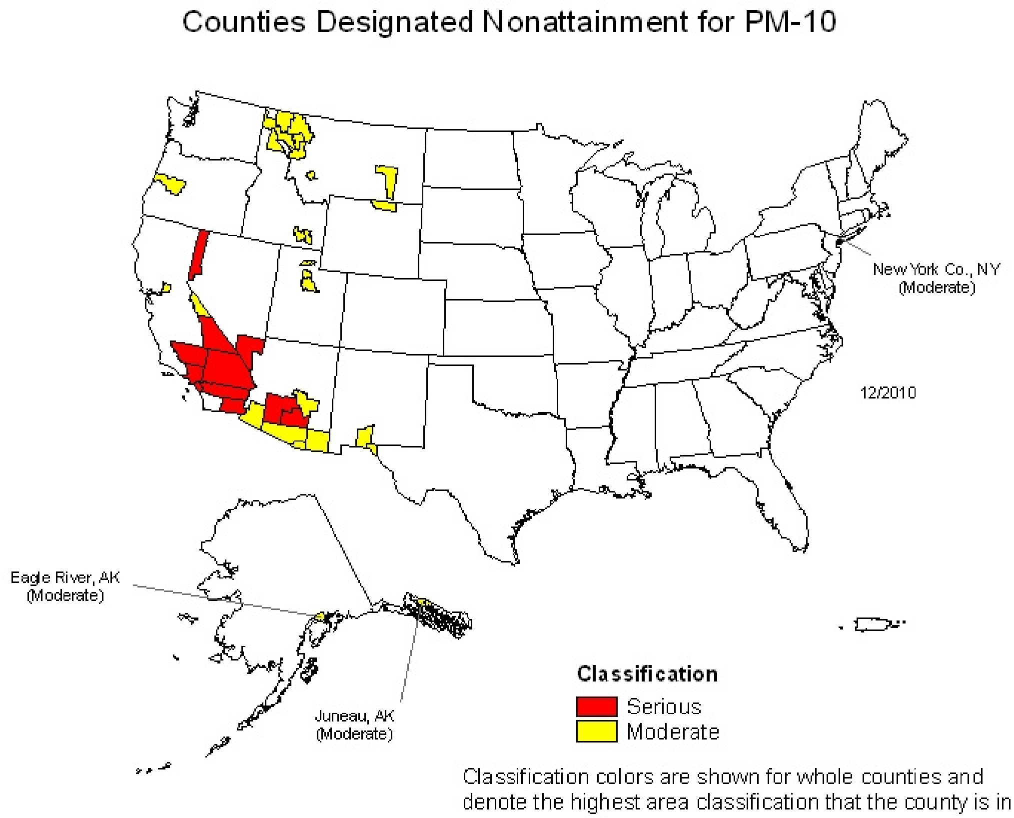

Figure 6.2-10 PM_{10} Nonattainment Areas

6.2.2.2.2 Projected Levels of $PM_{2.5}$

In the following sections we describe projected $PM_{2.5}$ levels in the future, with and without the standards. Our modeling indicates that there will be very small changes in $PM_{2.5}$ across most of the country. The impacts of the standards on $PM_{2.5}$ are a function of VMT increases from rebound, upstream reductions in petroleum consumption from crude oil production and transport, and gasoline production, distribution and transport, and changes in location and amount of electricity generation. Information on the air quality modeling methodology is contained in Section 6.2.1. Additional detail can be found in the air quality modeling technical support document (AQM TSD).

Projected Levels of PM2.5 without this Final Action

EPA has already adopted many mobile source emission control programs that are expected to reduce ambient PM levels. These control programs include the New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder Rule (75 FR 22895, April 30, 2010), the Marine Spark-Ignition and Small Spark-Ignition Engine Rule (73 FR 59034, October 8, 2008), the Locomotive and Marine Compression-Ignition Engine Rule (73 FR 25098, May 6, 2008), the Clean Air Nonroad Diesel (69 FR 38957, June 29, 2004), the Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements (66 FR 5002, January 18, 2001) and the Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements (65 FR 6698, February 10, 2000). As a result of these and other federal, state and local programs, the number of areas that fail to meet the $PM_{2.5}$ NAAQS in the future is expected to decrease. However, even with the implementation of all current state and federal regulations, there are projected to be counties that would have projected design values above the level of the $PM_{2.5}$ NAAQS well into the future.

The air quality modeling conducted projects that in 2030, with all current controls in effect but excluding the emissions changes expected to occur as a result of this final action, at least 4 counties, with a projected population of nearly 7 million people, would have projected design values above the level of the annual standard of 15 $\mu g/m^3$ and at least 21 counties, with a projected population of over 31 million people, would have projected design values above the level of the 2006 24-hour standard of 35 $\mu g/m^3$. Since the emission changes from this final action go into effect during the period when some areas are still working to attain the $PM_{2.5}$ NAAQS, the projected emission changes will impact state and local agencies in their effort to attain and maintain the $PM_{2.5}$ standard. In the following section we discuss the $PM_{2.5}$ impacts associated with the vehicle standards.

Projected Annual Average $PM_{2.5}$ Design Values with this Final Action

This section summarizes the results of our modeling of annual average $PM_{2.5}$ air quality impacts in the future due to the vehicle standards finalized in this action. Specifically, we compare a 2030 reference scenario (a scenario without the vehicle standards) to a 2030 control scenario which includes the vehicle standards. Our modeling indicates that the majority of the modeled counties will experience small changes of between 0.05 $\mu g/m^3$ and -0.05 $\mu g/m^3$ in their annual $PM_{2.5}$ design values due to the vehicle standards.

Figure 6.2-11 presents the changes in annual $PM_{2.5}$ design values in 2030.[KKKKKK]

[KKKKKK] An annual $PM_{2.5}$ design value is the concentration that determines whether a monitoring site meets the annual NAAQS for $PM_{2.5}$. The full details involved in calculating an annual $PM_{2.5}$ design value are given in appendix N of 40 CFR part 50.

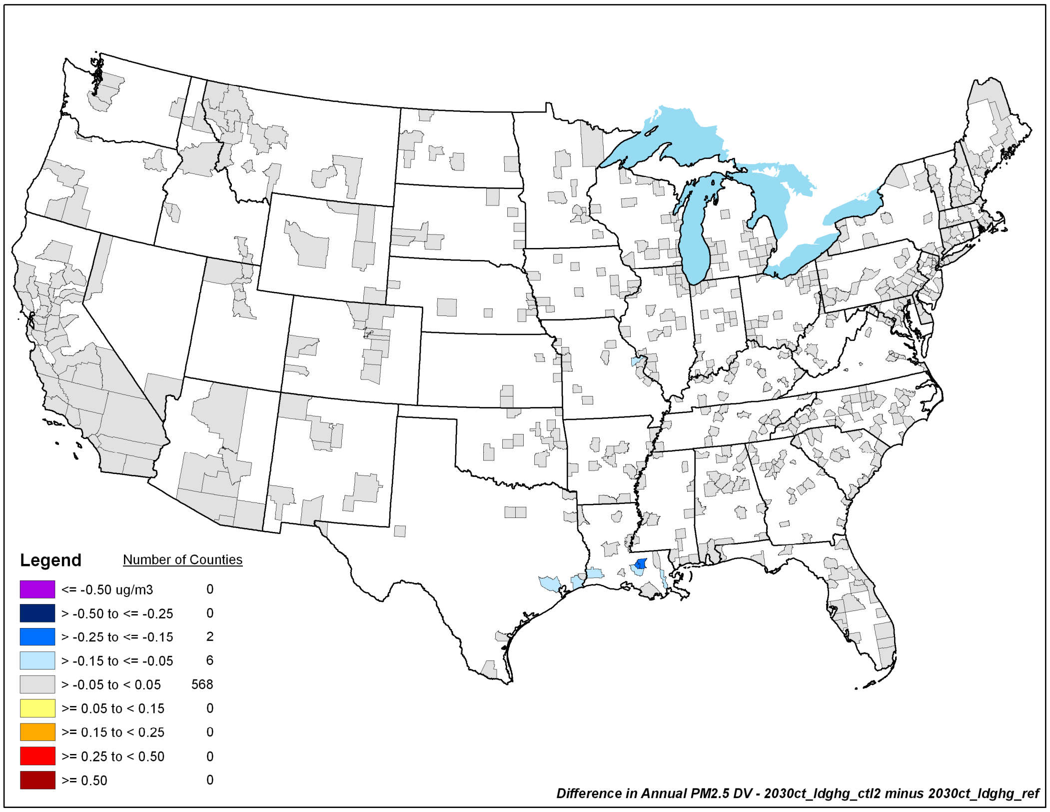

Figure 6.2-11 Projected Change in 2030 Annual $PM_{2.5}$ Design Values Due to the Final Standards

Figure 6.2-11, eight counties will experience decreases larger than 0.05 µg/m^3. These counties are in the Gulf Coast and in Missouri. The maximum projected decrease in an annual $PM_{2.5}$ design value is 0.16 µg/m^3 in West Baton Rouge County, Louisiana. The decreases in annual $PM_{2.5}$ design values in the Gulf Coast are likely due to emission reductions related to lower fuel production. Additional information on the emissions reductions that are projected with this final action is available in Section 4.7.

There are 4 counties, all in California, that are projected to have annual $PM_{2.5}$ design values above the NAAQS in 2030 with the vehicle standards in place. Table 6.2-3 below presents the changes in design values for these counties.

Table 6.2-3 Change in Annual $PM_{2.5}$ Design Values ($\mu g/m^3$) for Counties Projected to be Above the Annual $PM_{2.5}$ NAAQS in 2030

County Name	Change in Annual $PM_{2.5}$ Design Value ($\mu g/m^3$)	Population in 2030[a]
Riverside County, California	-0.01	2,614,198
San Bernardino County, California	0	2,784,489
Kern County, California	-0.02	981,806
Tulare County, California	-0.01	528,662

[a] Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. 2001. Population by Single Year of Age CD.

Average changes in 2030 annual $PM_{2.5}$ design values for a variety of metrics are all between 0.00 and -0.03 $\mu g/m^3$ illustrating the small decrease in annual $PM_{2.5}$ design values in 2030. These metrics include: (1) all counties with 2005 baseline design values, (2) counties with 2005 baseline design values that exceeded the annual $PM_{2.5}$ standard, (3) counties with 2005 baseline design values that did not exceed the standard, but were within 10% of it, (4) counties with 2030 design values that exceeded the annual $PM_{2.5}$ standard, and (5) counties with 2030 design values that did not exceed the standard, but were within 10% of it.

Projected 24-hour Average $PM_{2.5}$ Design Values with this Final Action

This section summarizes the results of our modeling of 24-hour $PM_{2.5}$ air quality impacts in the future due to the vehicle standards. Specifically, we compare a 2030 reference scenario (a scenario without the vehicle standards) to a 2030 control scenario which includes the vehicle standards. Our modeling indicates that the majority of the modeled counties will experience changes of between -0.05 $\mu g/m^3$ and 0.05 $\mu g/m^3$ in their 24-hour $PM_{2.5}$ design values. Figure 6.2-12 presents the changes in 24-hour $PM_{2.5}$ design values in 2030.[LLLLLL]

[LLLLLL] A 24-hour $PM_{2.5}$ design value is the concentration that determines whether a monitoring site meets the 24-hour NAAQS for $PM_{2.5}$. The full details involved in calculating a 24-hour $PM_{2.5}$ design value are given in appendix N of 40 CFR part 50.

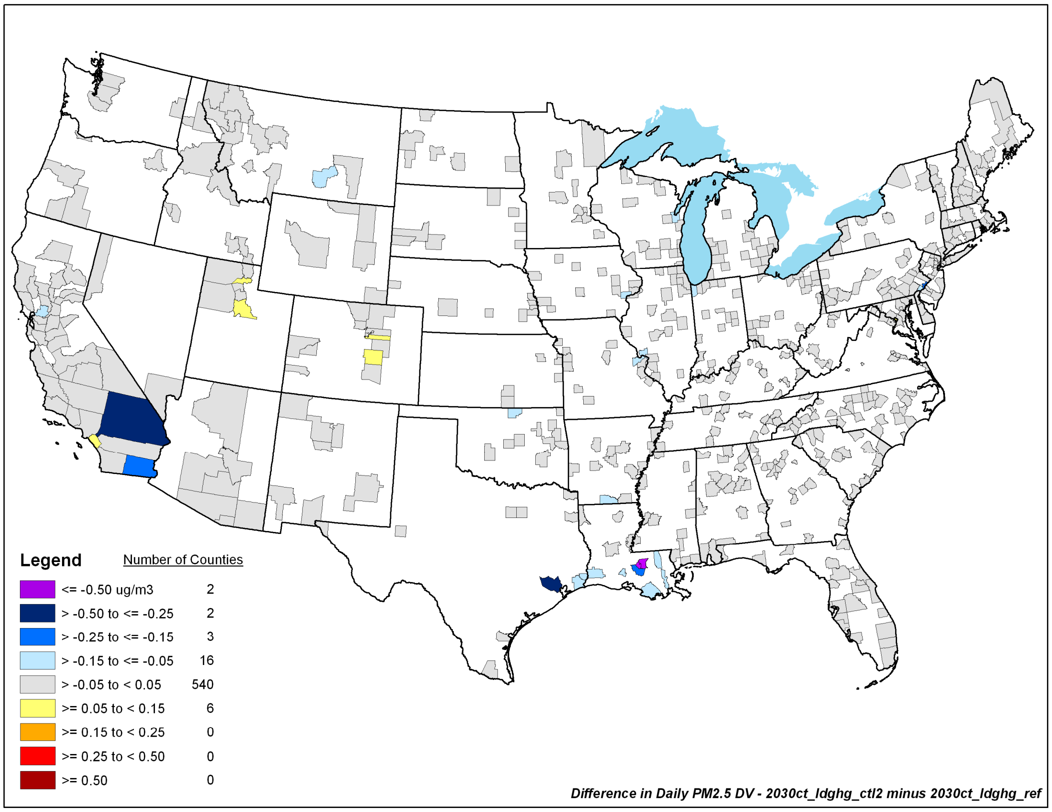

Figure 6.2-12 Projected Change in 2030 24-hour $PM_{2.5}$ Design Values Due to the Final Standards

As shown in Figure 6.2-12, design value concentrations will increase more than 0.05 $\mu g/m^3$ in six counties and design value concentrations will decrease more than 0.05 $\mu g/m^3$ in 23 counties. The decreases in 24-hour $PM_{2.5}$ design values in some counties are likely due to emission reductions related to lower fuel production. The maximum projected decrease in a 24-hour $PM_{2.5}$ design value is 0.76 $\mu g/m^3$ in East Baton Rouge County, Louisiana. The increases in 24-hour $PM_{2.5}$ design values in some counties are likely due to increased emissions from the VMT rebound effect or increased electricity generation. The maximum projected increase in a 24-hour $PM_{2.5}$ design value is 0.14 $\mu g/m^3$ in El Paso County, Colorado. Additional information on the emissions changes that are projected with this final action is available in Section 4.7.

There are 21 counties, mainly in California, that are projected to have 24-hour $PM_{2.5}$ design values above the NAAQS in 2030 with the vehicle standards in place. Table 6.2-4 below presents the changes in design values for these counties.

Table 6.2-4 Change in 24-hour $PM_{2.5}$ Design Values ($\mu g/m^3$) for Counties Projected to be Above the 24-hour $PM_{2.5}$ NAAQS in 2030

County Name	Change in 24-hour $PM_{2.5}$ Design Value ($\mu g/m^3$)	Population in 2030[a]
Kern Co, California	0.02	981,806
Riverside Co, California	-0.01	2,614,198
Fresno Co, California	-0.02	1,196,950
San Bernardino Co, California	-0.27	2,784,490
Sacramento Co, California	0	1,856,971
Kings Co, California	-0.03	195,067
Los Angeles Co, California	0.03	10,742,722
Tulare Co, California	-0.03	528,663
Lane Co, Oregon	0	460,993
Cache Co, Utah	0.04	141,446
Allegheny Co, Pennsylvania	-0.01	1,234,931
Stanislaus Co, California	-0.02	688,246
Lake Co, Montana	0	40,126
Orange Co, California	0.05	4,431,071
Klamath Co, Oregon	0	77,200
Salt Lake Co, Utah	0.02	1,431,946
Ravalli Co, Montana	0	63,914
Butte Co, California	0	287,236
Missoula Co, Montana	0.01	141,264
Pierce Co, Washington	0.03	1,082,579
Lincoln Co, Montana	0	20,454

Note:
[a] Population numbers based on Woods & Poole data. Woods & Poole Economics, Inc. 2001. Population by Single Year of Age CD.

Average changes in 2030 24-hour $PM_{2.5}$ design values for a variety of metrics are all between 0.00 and -0.01 $\mu g/m^3$ illustrating the small decrease in 24-hour $PM_{2.5}$ design values in 2030. These metrics include: (1) all counties with 2005 baseline design values, (2) counties with 2005 baseline design values that exceeded the 24-hour $PM_{2.5}$ standard, (3) counties with 2005 baseline design values that did not exceed the standard, but were within 10% of it, (4) counties with 2030 design values that exceeded the 24-hour $PM_{2.5}$ standard, and (5) counties with 2030 design values that did not exceed the standard, but were within 10% of it.

6.2.2.3 Air Toxics

According to the National Air Toxics Assessment (NATA) for 2005, mobile sources were responsible for 43 percent of outdoor toxic emissions and over 50 percent of the cancer risk and noncancer hazard attributable to direct emissions from mobile and stationary sources.[MMMMMM,NNNNNN,363] According to the 2005 NATA, about three-fourths of the U.S. population was exposed to an average chronic concentration of air toxics that has the potential for adverse noncancer respiratory health effects. In 2007 EPA finalized vehicle and fuel controls to reduce mobile source air toxics.[364] In addition, over the years, EPA has implemented a number of mobile source and fuel controls resulting in VOC reductions, which also reduce air toxic emissions. Modeling from the Mobile Source Air Toxics (MSAT) rule suggests that the mobile source contribution to ambient benzene concentrations is projected to decrease over 40% by 2015, with a decrease in ambient benzene concentration from all sources of about 25%. Although benzene is used as an example, the downward trend is projected for other air toxics as well. See the RIA for the final MSAT rule for more information on ambient air toxics projections.[365]

6.2.2.3.1 Current Levels of Air Toxics

The majority of Americans continue to be exposed to ambient concentrations of air toxics at levels which have the potential to cause adverse health effects.[366] The levels of air toxics to which people are exposed vary depending on where people live and work and the kinds of activities in which they engage, as discussed in detail in U.S. EPA's 2007 Mobile Source Air Toxics (MSAT) Rule.[367] In order to identify and prioritize air toxics, emission source types and locations which are of greatest potential concern, U. S. EPA conducts the National-Scale Air Toxics Assessment (NATA). The most recent NATA was conducted for calendar year 2005, and was released in March 2011.[368] NATA for 2005 includes four steps:

1) Compiling a national emissions inventory of air toxics emissions from outdoor sources

2) Estimating ambient concentrations of air toxics across the United States

3) Estimating population exposures across the United States

4) Characterizing potential public health risk due to inhalation of air toxics including both cancer and noncancer effects

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[MMMMMM] NATA also includes estimates of risk attributable to background concentrations, which includes contributions from long-range transport, persistent air toxics, and natural sources; as well as secondary concentrations, where toxics are formed via secondary formation. Mobile sources substantially contribute to long-range transport and secondarily formed air toxics.

[NNNNNN] NATA relies on a Guassian plume model, Assessment System for Population Exposure Nationwide (ASPEN), to estimate toxic air pollutant concentrations. Projected air toxics concentrations presented in this final action were modeled with CMAQ 4.7.1.

Figure 6.2-13 and Figure 6.2-14 depict estimated tract-level carcinogenic risk and noncancer respiratory hazard from the assessment. The respiratory hazard is dominated by a single pollutant, acrolein.

According to the NATA for 2005, mobile sources were responsible for 43 percent of outdoor toxic emissions and over 50 percent of the cancer risk and noncancer hazard attributable to direct emissions from mobile and stationary sources.[OOOOOO,PPPPPP,369] Mobile sources are also large contributors to precursor emissions which react to form secondary concentrations of air toxics. Formaldehyde is the largest contributor to cancer risk of all 80 pollutants quantitatively assessed in the 2005 NATA, and mobile sources were responsible for over 40 percent of primary emissions of this pollutant in 2005, and are major contributors to formaldehyde precursor emissions. Benzene is also a large contributor to cancer risk, and mobile sources account for over 70 percent of ambient exposure. Over the years, EPA has implemented a number of mobile source and fuel controls which have resulted in VOC reductions, which also reduced formaldehyde, benzene and other air toxic emissions.

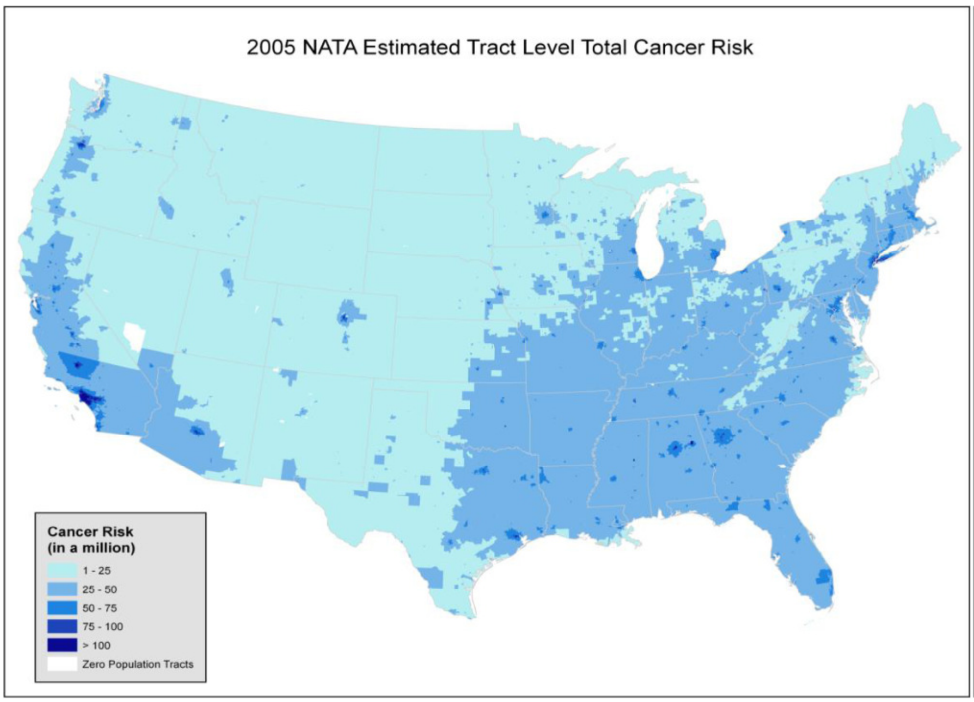


Figure 6.2-13 Tract Level Average Carcinogenic Risk, 2005 NATA

[OOOOOO] NATA also includes estimates of risk attributable to background concentrations, which includes contributions from long-range transport, persistent air toxics, and natural sources; as well as secondary concentrations, where toxics are formed via secondary formation. Mobile sources substantially contribute to long-range transport and secondarily formed air toxics

[PPPPPP] NATA relies on a Guassian plume model, Assessment System for Population Exposure Nationwide (ASPEN), to estimate toxic air pollutant concentrations. Projected air toxics concentrations presented in this final action were modeled with CMAQ 4.7.1.

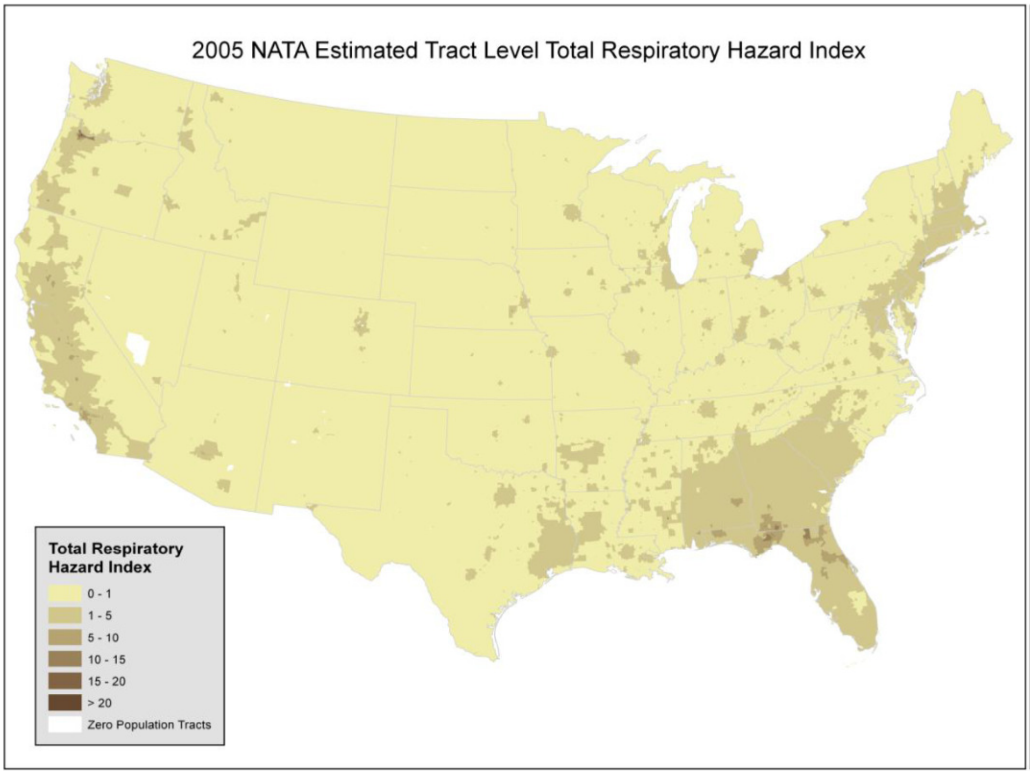


Figure 6.2-14 County Level Average Noncancer Hazard Index, 2005 NATA

6.2.2.3.2 Projected Levels of Air Toxics

In the following sections, we describe results of our modeling of air toxics levels in the future with the finalized standards. Although there are a large number of compounds which are considered air toxics, we focused on those which were identified as national and regional-scale cancer and noncancer risk drivers in past NATA assessments and were also likely to be significantly impacted by the standards. These compounds include benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. Information on the air quality modeling methodology is contained in Section 6.2.1. Additional detail, including seasonal concentration maps, can be found in the air quality modeling technical support document (AQM TSD) in the docket for this rule.

It should be noted that EPA has adopted many mobile source emission control programs that are expected to reduce ambient air toxics levels. These control programs include the Heavy-duty Onboard Diagnostic Rule (74 FR 8310, February 24, 2009), Small SI and Marine SI Engine Rule (73 FR 59034, October 8, 2008), Locomotive and Commercial Marine Rule (73 FR 25098, May 6, 2008), Mobile Source Air Toxics Rule (72 FR 8428, February 26, 2007), Clean Air Nonroad Diesel Rule (69 FR 38957, June 29, 2004), Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements (66 FR 5002, Jan. 18, 2001) and the Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements (65 FR 6698, Feb. 10, 2000). As a result of these programs, the ambient concentration of air toxics in the future is expected to decrease. The reference case and control case scenarios include these controls.

Our modeling indicates that national average ambient concentrations of the modeled air toxics change less than 1 percent across most of the country due to the final standards. Because overall impacts are relatively small in future years, we concluded that assessing exposure to ambient concentrations and conducting a quantitative risk assessment of air toxic impacts was not warranted. However, we did develop population metrics, including the population living in areas with changes in concentrations of various magnitudes.

Acetaldehyde

Our air quality modeling results show that this rule does not have substantial impacts on ambient concentrations of acetaldehyde. Figure 6.2-15 shows nationwide changes in ambient acetaldehyde in 2030 are between ± 1 percent, with decreases up to 10 percent in a few urban areas. Reductions in ambient acetaldehyde in 2030 range between 0.001 and 0.01 µg/m³ across much of the country with decreases as high as 0.1 µg/m³ in urban areas; these changes are mainly associated with reductions from upstream sources including fuel production, refining, storage and transport (Figure 6.2-15).

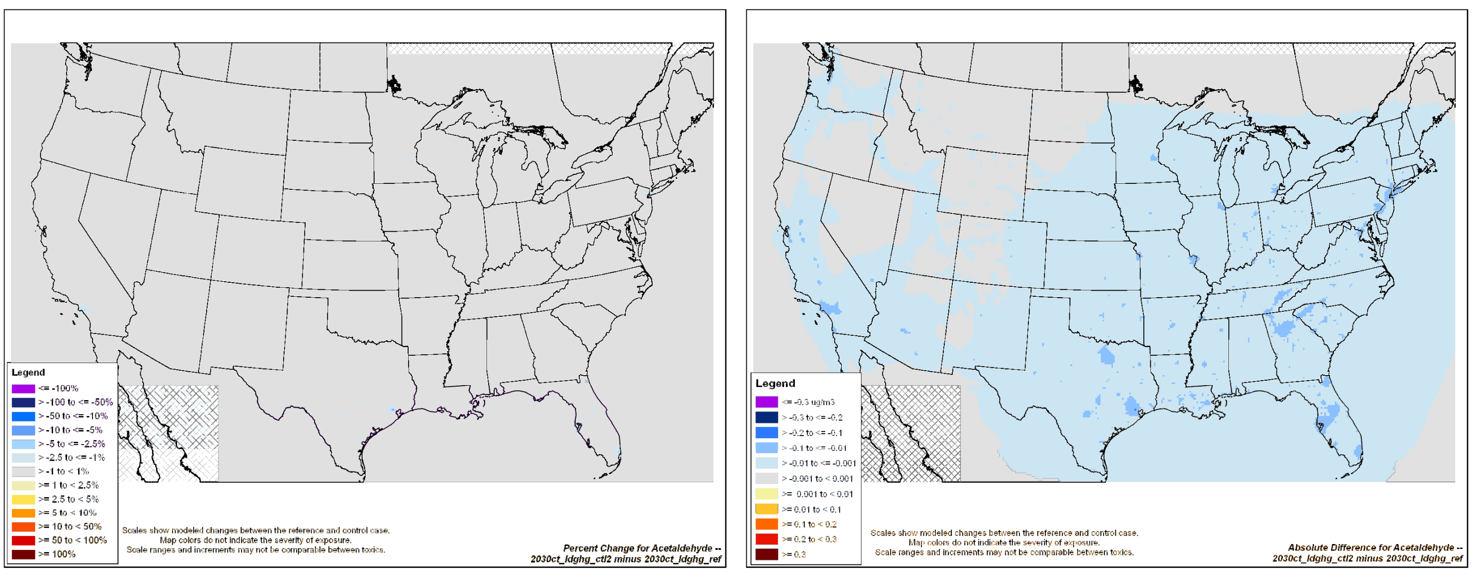


Figure 6.2-15 Changes in Acetaldehyde Ambient Concentrations in 2030 due to the Final Standards: Percent Changes (left) and Absolute Changes in µg/m³ (right)

Formaldehyde

Our air quality modeling results do not show substantial impacts on ambient concentrations of formaldehyde as a result of the final standards. In 2030, annual percent changes in ambient concentrations of formaldehyde are less than 1 percent across much of the country, with a decrease ranging from 2.5 to 10 percent in Oklahoma (Figure 6.2-16). Ambient formaldehyde reductions in 2030 generally range from 0.001 to 0.1 µg/m³ and are associated with upstream reductions in fuel production, refining, storage and transport (Figure 6.2-16). Decreases in Oklahoma are over 0.3 µg/m³ and due to reductions in emissions from refineries in that area. Increases in ambient formaldehyde concentrations range between 0.001 to 0.1 µg/m³ in areas associated with increased emissions from power plants.

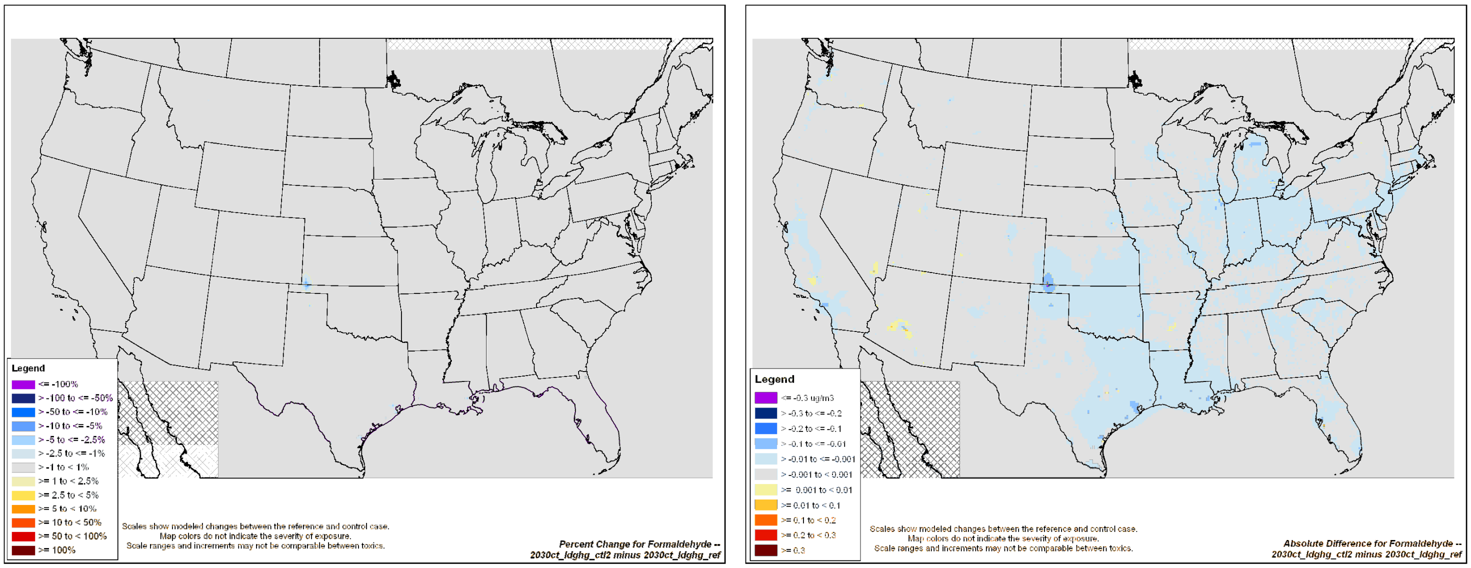
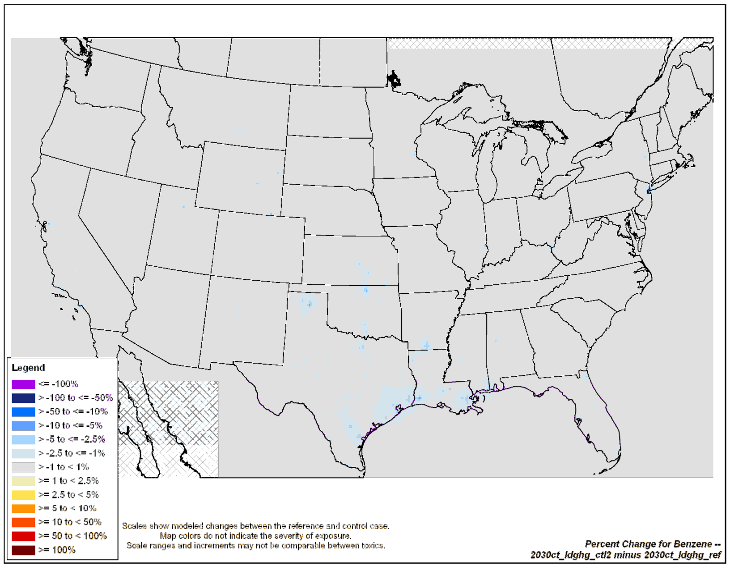


Figure 6.2-16 Changes in Formaldehyde Ambient Concentrations in 2030 due to the Final Standards: Percent Changes (left) and Absolute Changes in µg/m³ (right)

Benzene

Our air quality modeling results do not show substantial impacts on ambient concentrations of benzene as a result of this rule. In 2030, percent changes in ambient concentrations of benzene are ± 1 percent nationwide (Figure 6.2-17); a few areas, mainly in the Gulf Coast region, are projected to have benzene reductions from 1 to 10 percent, likely due to decreases in refinery emissions. Absolute changes in ambient benzene in 2030 are generally ± 0.001 µg/m³ in the western half of the U.S. with decreases up to 0.01 µg/m³ across the eastern half of the U.S due to upstream reductions in fuel production, refining, storage and transport (Figure 6.2-17).



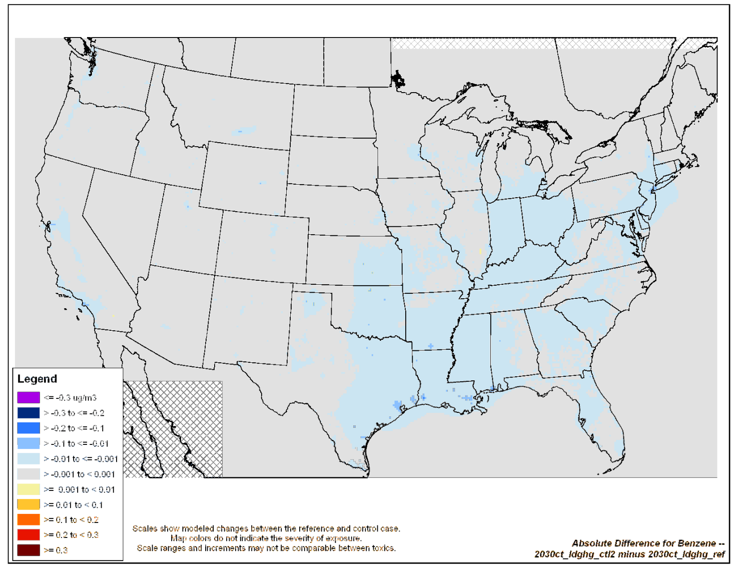


Figure 6.2-17 Changes in Benzene Ambient Concentrations in 2030 due to the Final Standards: Percent Changes (left) and Absolute Changes in µg/m³ (right)

1,3-Butadiene

Our modeling also shows that this rule does not have a significant impact on ambient 1,3-butadiene concentrations in 2030. Figure 6.2-18 shows that ambient concentrations of 1,3-butadiene generally range between ± 1 percent across the country in 2030. Some areas have 1,3-butadiene increases on the order of 1 to 2.5 percent; however, as shown in the map on the right, all changes in absolute concentrations are between ± 0.001 µg/m³ nationwide (Figure 6.2-18).

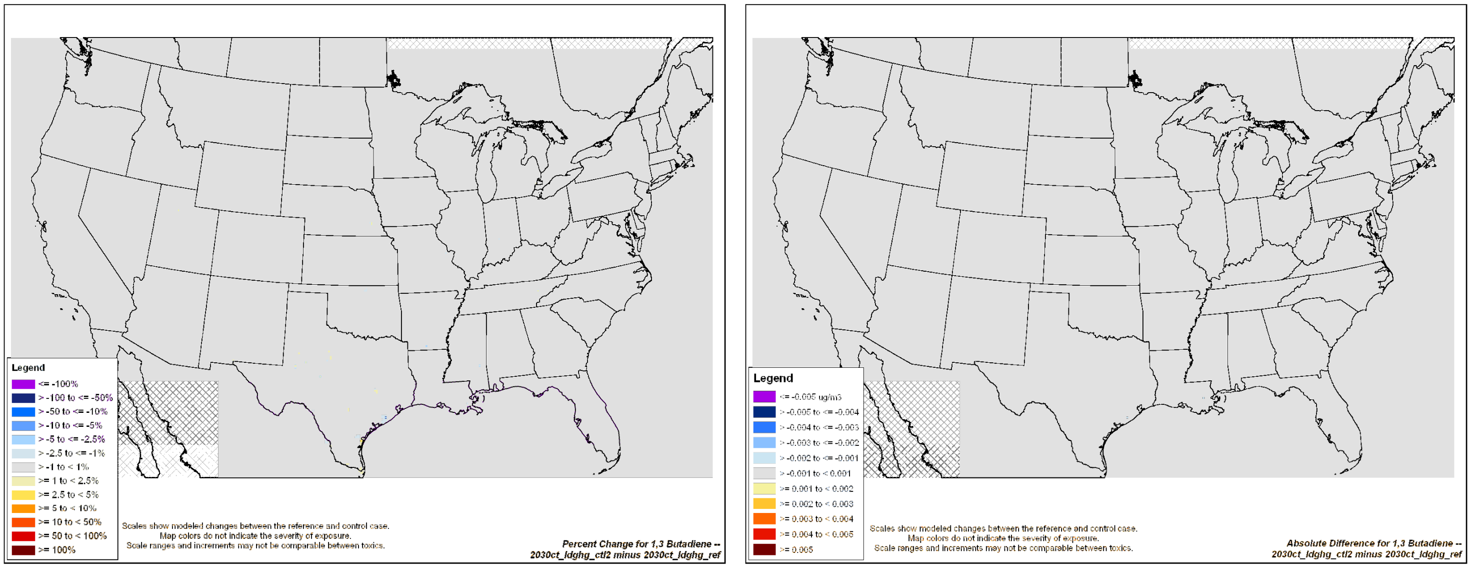


Figure 6.2-18 Changes in 1,3-Butadiene Ambient Concentrations in 2030 due to the Final Standards: Percent Changes (left) and Absolute Changes in µg/m³ (right)

Acrolein

Our air quality modeling results do not show substantial impacts on ambient concentrations of acrolein as a result of this rule. In 2030, percent changes in ambient acrolein concentrations are generally ± 1 percent nationwide (Figure 6.2-19). Parts of the Midwest and Texas have decreases in ambient acrolein concentrations generally between 1 and 10 percent and increases of similar magnitude in a few urban areas; however, all absolute changes in ambient acrolein concentrations are between ± 0.001 µg/m³ in 2030 (Figure 6.2-19).

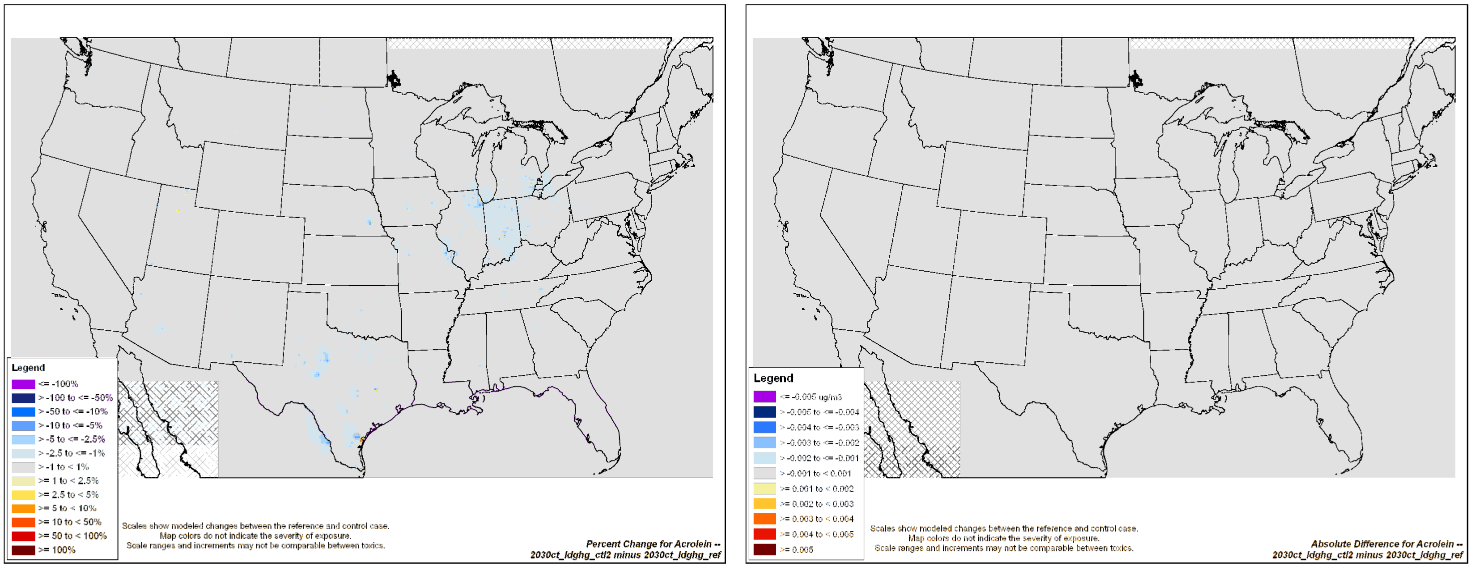


Figure 6.2-19 Changes in Acrolein Ambient Concentrations in 2030 due to the Final Standards: Percent Changes (left) and Absolute Changes in μg/m³ (right)

Population Metrics

To assess the impact of this rule's projected changes in air quality, we developed population metrics that show the population experiencing changes in annual ambient concentrations across the modeled air toxics. As shown in Table 6.2-5, over 98 percent of the U.S. population is projected to experience a less than one percent change in formaldehyde and 1,3-butadiene. Over 83 percent of the U.S. population is projected to experience a less than one percent change in acetaldehyde, benzene and acrolein, and over 12 percent are projected to experience a 1 to 5 percent decrease in these pollutants.

Table 6.2-5 Percent of Total Population Experiencing Changes in Annual Ambient Concentrations of Toxic Pollutants in 2030 as a Result of the Final Standards

Percent Change	Acetaldehyde	Formaldehyde	Benzene	1,3-Butadiene	Acrolein
≤ -100					
> -100 to ≤ -50					
> -50 to ≤ -10					
> -10 to ≤ -5	0.0%	0.0%	0.8%		0.2%
> -5 to ≤ -2.5	1.5%	0.1%	1.8%	0.0%	2.0%
> -2.5 to ≤ -1	15.3%	1.2%	13.0%	0.2%	10.3%
> -1 to < 1	83.1%	98.7%	84.4%	99.2%	86.1%
≥ 1 to < 2.5			0.0%	0.6%	0.9%
≥ 2.5 to < 5				0.0%	0.0%
≥ 5 to < 10					0.0%
≥ 10 to < 50					
≥ 50 to < 100					
≥ 100					

6.2.2.4 Deposition of Nitrogen and Sulfur

6.2.2.4.1 Current Levels of Nitrogen and Sulfur Deposition

Over the past two decades, the EPA has undertaken numerous efforts to reduce nitrogen and sulfur deposition across the U.S. Analyses of long-term monitoring data for the U.S. show that deposition of both nitrogen and sulfur compounds has decreased over the last 17 years. The data show that reductions were more substantial for sulfur compounds than for nitrogen compounds. In the eastern U.S., where data are most abundant, total sulfur deposition decreased by about 44 percent between 1990 and 2007, while total nitrogen deposition decreased by 25 percent over the same time frame.[370] These numbers are generated by the U.S. national monitoring network and they likely underestimate nitrogen deposition because neither ammonia nor organic nitrogen is measured. Although total nitrogen and sulfur deposition has decreased over time, many areas continue to be negatively impacted by deposition. Deposition of inorganic nitrogen and sulfur species routinely measured in the U.S. between 2005 and 2007 were as high as 9.6 kilograms of nitrogen per hectare (kg N/ha) averaged over three years and 20.8 kilograms of sulfur per hectare (kg S/ha) averaged over three years.[371]

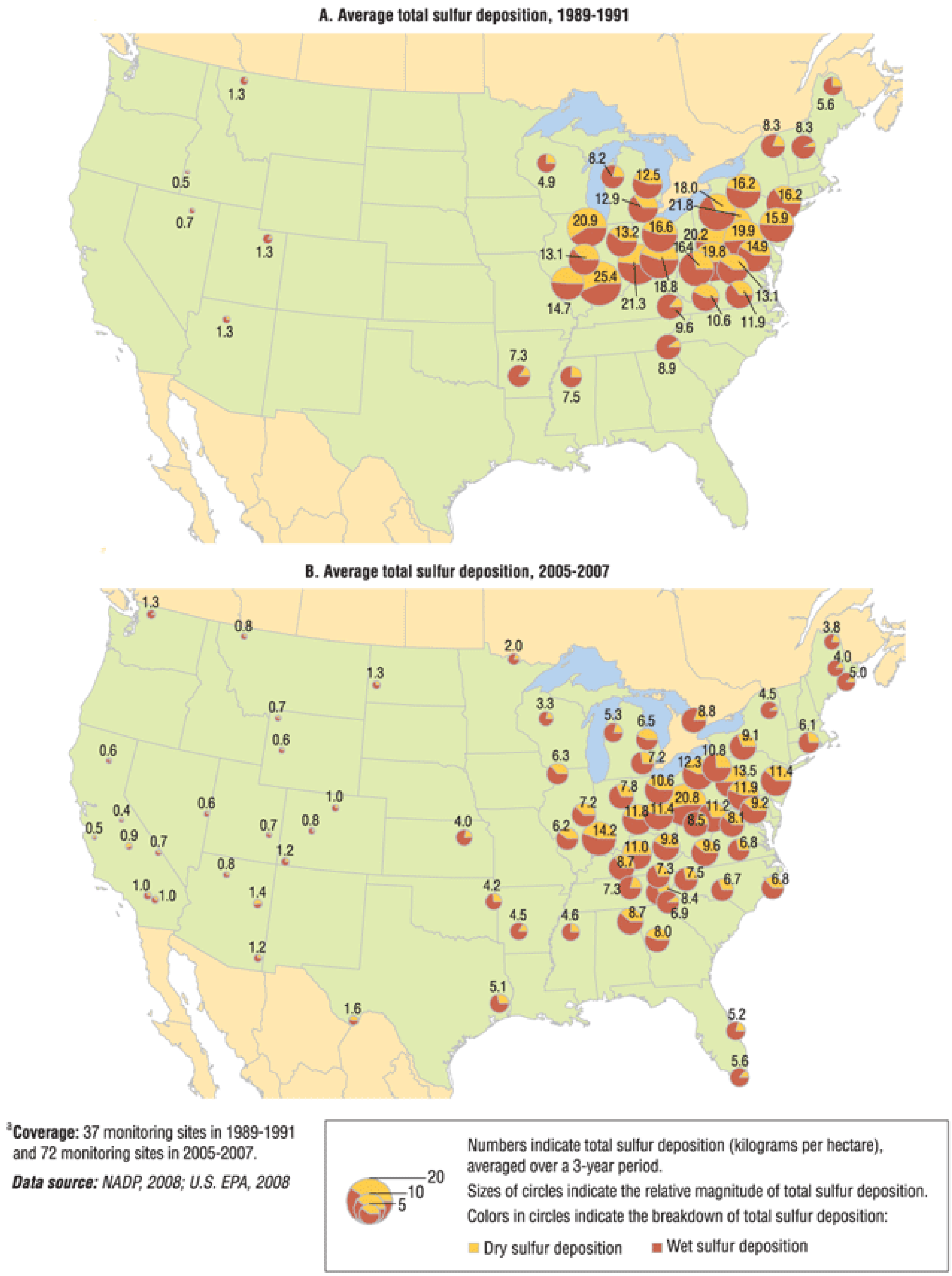


Figure 6.2-20 Total Sulfur Deposition in the Contiguous U.S., 1989-1991 and 2005 -2007

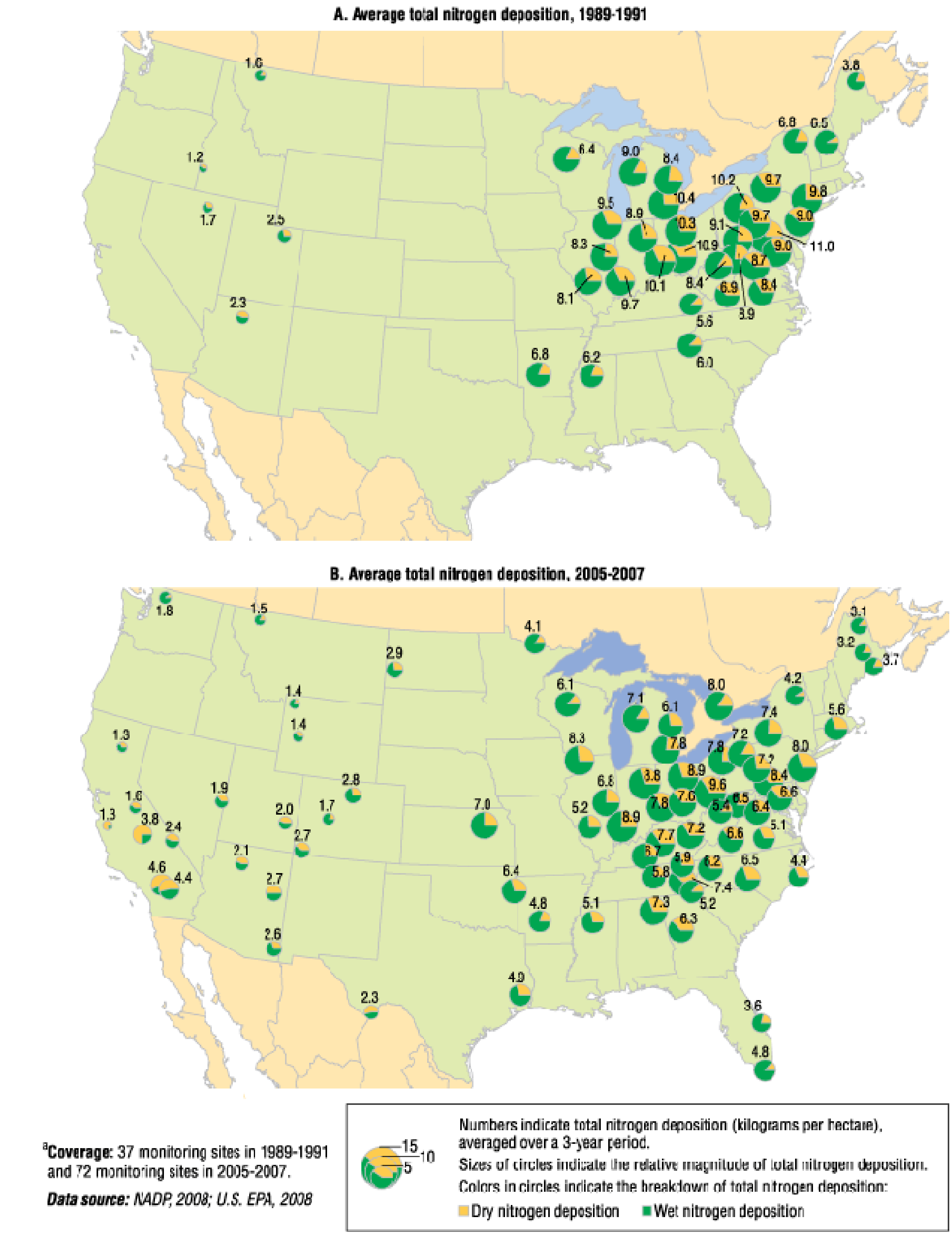


Figure 6.2-21 Total Nitrogen Deposition in the Contiguous U.S., 1989-1991 and 2005-2007

6.2.2.4.2 Projected Levels of Nitrogen and Sulfur Deposition

Our air quality modeling projects increases in nitrogen deposition in some localized areas across the U.S. along with a few areas of decreases in nitrogen deposition. Figure 6.2-22 shows that for nitrogen deposition the vehicle standards will result in annual percent increases of more than 2 percent in some areas. The increases in nitrogen deposition are likely due to projected upstream emissions increases in NO_X from increased electricity generation and increased driving due to the rebound effect. Figure 6.2-22 also shows that for nitrogen deposition the vehicle standards will result in annual percent decreases of more than 2 percent in a few areas in West Virginia and New Mexico. The decreases in nitrogen deposition are likely due to projected upstream emissions decreases in NO_X from changes in the location of electricity generation. The remainder of the country will experience only minimal changes in nitrogen deposition, ranging from decreases of less than 0.5 percent to increases of less than 0.5 percent.

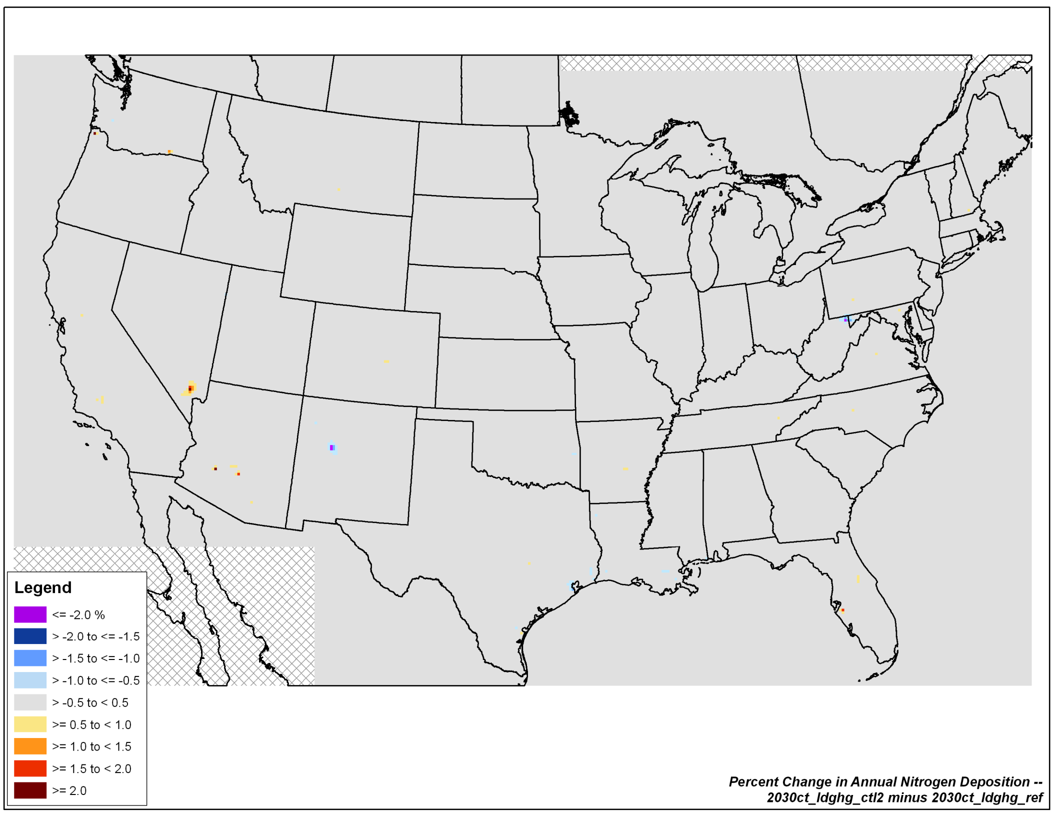


Figure 6.2-22 Percent Change in Annual Total Nitrogen Deposition as a Result of the Final Standards

Our air quality modeling projects both increases and decreases in sulfur deposition in localized areas across the U.S. Figure 6.2-23 shows that for sulfur deposition the vehicle standards will result in annual percent decreases of more than 2% in some areas. The decreases in sulfur deposition are likely due to projected upstream emissions decreases from changes in the location of electricity generation and from reduced gasoline production. Figure 6.2-23 also shows that for sulfur deposition the vehicle standards will result in annual percent increases of more than 2% in some areas. The increases in sulfur deposition are likely due to projected upstream emissions increases from increased electricity generation. The remainder of the country will experience only minimal changes in sulfur deposition, ranging from decreases of less than 0.5% to increases of less than 0.5%.

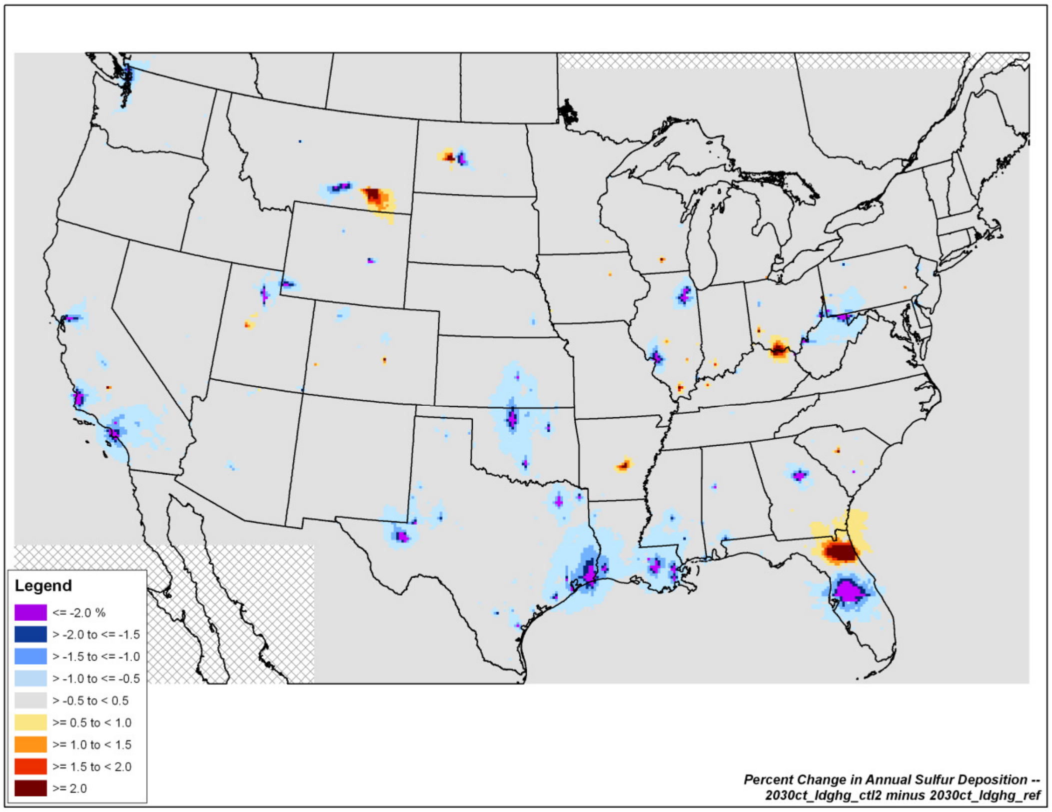


Figure 6.2-23 Percent Change in Annual Total Sulfur Deposition as a Result of the Final Standards

6.2.2.5 Visibility Degradation

6.2.2.5.1 Current Visibility Levels

As of August 30, 2011, approximately 101 million people live in nonattainment areas for the $PM_{2.5}$ NAAQS. Thus, at least these populations would likely be experiencing visibility impairment, as well as many thousands of individuals who travel to these areas. While visibility trends have improved in most Class I areas, the recent data show that these areas continue to suffer from visibility impairment.[372] Calculated from light extinction efficiencies from Trijonis et al. (1987, 1988), annual average visual range under natural conditions in the East is estimated to be 150 km ± 45 km (i.e., 65 to 120 miles) and 230 km ± 35 km (i.e., 120 to 165 miles) in the West.[373,374,375] In summary, visibility impairment is experienced throughout the U.S., in multi-state regions, urban areas, and remote Mandatory Class I Federal areas.

6.2.2.5.2 Projected Visibility Levels

Air quality modeling conducted for the final action was used to project visibility conditions in 139 mandatory class I federal areas across the U.S. in 2030. The results show that all the modeled areas will continue to have annual average deciview levels above background in 2030.[QQQQQQ] The results also indicate that the majority of the modeled mandatory class I federal areas will see very little change in their visibility. Some mandatory class I federal areas will see improvements in visibility due to the vehicle standards and a few mandatory class I federal areas will see visibility decreases. The average visibility at all modeled mandatory class I federal areas on the 20% worst days is projected to improve by 0.003 deciviews, or 0.03%, in 2030. The greatest projected improvement in visibility, 0.1% improvement (0.02 DV) in 2030 due to the vehicle standards, occurs in Sipsey Wilderness in AL, Agua Tibia Wilderness in CA, and Alpine Lake Wilderness in WA. The following seven areas will see small degradations in visibility in 2030 as a result of the heavy-duty standards: Wolf Island GA, 0.03 deciview degradation; Joshua Tree National Monument CA, 0.02 deciview degradation, San Gorgonio Wilderness CA, 0.01 deciview degradation; Upper Buffalo Wilderness AR, 0.01 deciview degradation; San Jacinto Wilderness CA, 0.01 deciview degradation; Okefenokee GA, 0.01 deciview degradation; and Hells Canyon Wilderness OR, 0.01 deciview degradation. Table 6.2-6 contains the full visibility results from 2030 for the 138 analyzed areas.

Table 6.2-6 Visibility Levels (in Deciviews) for Class I Areas on the 20% Worst Days

Class 1 Area (20% worst days)	State	2005 Base	2030 LDGHG Reference	2030 LDGHG Control	Natural Background
Sipsey Wilderness	AL	29.88	20.54	20.52	11.39
Caney Creek Wilderness	AR	26.69	19.84	19.84	11.33
Upper Buffalo Wilderness	AR	26.97	20.17	20.18	11.28
Chiricahua NM	AZ	12.89	12.08	12.07	6.92
Chiricahua Wilderness	AZ	12.89	12.08	12.07	6.91
Galiuro Wilderness	AZ	12.89	12.09	12.09	6.88
Grand Canyon NP	AZ	11.86	10.92	10.91	6.95
Mazatzal Wilderness	AZ	13.95	12.46	12.45	6.91
Mount Baldy Wilderness	AZ	11.32	10.74	10.74	6.95
Petrified Forest NP	AZ	13.56	12.65	12.65	6.97
Pine Mountain Wilderness	AZ	13.95	12.42	12.41	6.92
Saguaro NM	AZ	14.39	13.43	13.43	6.84
Sierra Ancha Wilderness	AZ	14.45	13.28	13.28	6.92
Superstition Wilderness	AZ	14.15	12.85	12.85	6.88
Sycamore Canyon Wilderness	AZ	15.45	14.67	14.67	6.96

[QQQQQQ] The level of visibility impairment in an area is based on the light-extinction coefficient and a unitless visibility index, called a "deciview", which is used in the valuation of visibility. The deciview metric provides a scale for perceived visual changes over the entire range of conditions, from clear to hazy. Under many scenic conditions, the average person can generally perceive a change of one deciview. The higher the deciview value, the worse the visibility. Thus, an improvement in visibility is a decrease in deciview value.

Agua Tibia Wilderness	CA	22.36	18.41	18.39	7.17
Ansel Adams Wilderness (Minarets)	CA	15.24	14.39	14.39	7.12
Caribou Wilderness	CA	13.65	12.68	12.67	7.29
Cucamonga Wilderness	CA	18.44	15.64	15.64	7.17
Desolation Wilderness	CA	12.87	12.10	12.09	7.13
Emigrant Wilderness	CA	16.87	15.94	15.94	7.14
Hoover Wilderness	CA	11.61	11.07	11.06	7.12
John Muir Wilderness	CA	15.24	14.34	14.34	7.14
Joshua Tree NM	CA	18.90	16.39	16.41	7.08
Kaiser Wilderness	CA	15.24	14.11	14.10	7.13
Kings Canyon NP	CA	23.73	22.19	22.19	7.13
Lassen Volcanic NP	CA	13.65	12.66	12.66	7.31
Lava Beds NM	CA	14.13	13.19	13.19	7.49
Mokelumne Wilderness	CA	12.87	12.08	12.07	7.14
Pinnacles NM	CA	17.90	15.42	15.42	7.34
Point Reyes NS	CA	22.40	21.00	21.00	7.39
Redwood NP	CA	18.55	17.66	17.66	7.81
San Gabriel Wilderness	CA	18.44	15.54	15.53	7.17
San Gorgonio Wilderness	CA	21.43	19.27	19.28	7.10
San Jacinto Wilderness	CA	21.43	18.10	18.11	7.12
San Rafael Wilderness	CA	19.43	17.40	17.39	7.28
Sequoia NP	CA	23.73	21.68	21.67	7.13
South Warner Wilderness	CA	14.13	13.31	13.31	7.32
Thousand Lakes Wilderness	CA	13.65	12.65	12.64	7.32
Ventana Wilderness	CA	17.90	16.37	16.37	7.32
Yosemite NP	CA	16.87	15.95	15.95	7.14
Black Canyon of the Gunnison NM	CO	10.00	9.21	9.21	7.06
Eagles Nest Wilderness	CO	8.82	8.05	8.05	7.08
Flat Tops Wilderness	CO	8.82	8.32	8.31	7.07
Great Sand Dunes NM	CO	11.82	11.20	11.20	7.10
La Garita Wilderness	CO	10.00	9.49	9.49	7.06
Maroon Bells-Snowmass Wilderness	CO	8.82	8.27	8.26	7.07
Mesa Verde NP	CO	12.14	11.31	11.31	7.09
Mount Zirkel Wilderness	CO	9.72	9.20	9.19	7.08
Rawah Wilderness	CO	9.72	9.15	9.14	7.08
Rocky Mountain NP	CO	12.85	12.15	12.15	7.05
Weminuche Wilderness	CO	10.00	9.46	9.46	7.06
West Elk Wilderness	CO	8.82	8.21	8.21	7.07
Everglades NP	FL	22.48	18.43	18.43	11.15
Okefenokee	GA	27.21	20.28	20.29	11.45
Wolf Island	GA	27.21	20.12	20.15	11.42
Craters of the Moon NM	ID	14.06	12.94	12.94	7.13
Sawtooth Wilderness	ID	14.97	14.70	14.70	7.15
Mammoth Cave NP	KY	32.00	22.29	22.29	11.53
Acadia NP	ME	22.75	18.34	18.33	11.45
Moosehorn	ME	21.19	17.58	17.58	11.36
Roosevelt Campobello International Park	ME	21.19	17.57	17.56	11.36
Isle Royale NP	MI	21.31	18.19	18.19	11.22

Seney	MI	25.05	20.80	20.80	11.37
Boundary Waters Canoe Area	MN	20.20	16.56	16.56	11.21
Voyageurs NP	MN	19.62	16.61	16.61	11.09
Hercules-Glades Wilderness	MO	26.95	21.00	21.00	11.27
Anaconda-Pintler Wilderness	MT	17.11	16.69	16.68	7.28
Bob Marshall Wilderness	MT	16.13	15.63	15.63	7.36
Cabinet Mountains Wilderness	MT	14.31	13.65	13.65	7.43
Gates of the Mountains Wilderness	MT	11.94	11.48	11.47	7.22
Glacier NP	MT	19.62	18.73	18.73	7.56
Medicine Lake	MT	18.21	17.17	17.17	7.30
Mission Mountains Wilderness	MT	16.13	15.50	15.49	7.39
Red Rock Lakes	MT	11.19	10.62	10.62	7.14
Scapegoat Wilderness	MT	16.13	15.59	15.59	7.29
Selway-Bitterroot Wilderness	MT	17.11	16.74	16.74	7.32
UL Bend	MT	15.49	15.00	15.00	7.18
Linville Gorge Wilderness	NC	29.66	20.08	20.07	11.43
Shining Rock Wilderness	NC	28.54	19.49	19.48	11.45
Lostwood	ND	19.61	17.64	17.64	7.33
Theodore Roosevelt NP	ND	17.88	16.02	16.02	7.31
Great Gulf Wilderness	NH	21.43	16.46	16.46	11.31
Presidential Range-Dry River Wilderness	NH	21.43	16.39	16.39	11.33
Brigantine	NJ	28.68	20.96	20.95	11.28
Bandelier NM	NM	11.97	10.51	10.51	7.02
Bosque del Apache	NM	13.81	12.40	12.40	6.97
Carlsbad Caverns NP	NM	16.51	14.48	14.47	7.02
Gila Wilderness	NM	13.12	12.41	12.40	6.95
Pecos Wilderness	NM	9.60	8.85	8.85	7.04
Salt Creek	NM	18.27	16.19	16.18	6.99
San Pedro Parks Wilderness	NM	10.42	9.63	9.62	7.03
Wheeler Peak Wilderness	NM	9.60	8.66	8.65	7.07
White Mountain Wilderness	NM	13.01	12.05	12.05	6.98
Jarbidge Wilderness	NV	12.26	11.92	11.92	7.10
Wichita Mountains	OK	23.63	18.27	18.26	11.07
Crater Lake NP	OR	13.21	12.49	12.49	7.71
Diamond Peak Wilderness	OR	13.21	12.39	12.39	7.77
Eagle Cap Wilderness	OR	17.34	16.31	16.31	7.34
Gearhart Mountain Wilderness	OR	13.21	12.61	12.61	7.46
Hells Canyon Wilderness	OR	19.00	17.57	17.58	7.32
Kalmiopsis Wilderness	OR	16.38	15.36	15.36	7.71
Mount Hood Wilderness	OR	14.68	13.03	13.03	7.77
Mount Jefferson Wilderness	OR	15.80	14.78	14.78	7.81
Mount Washington Wilderness	OR	15.80	14.78	14.77	7.89
Mountain Lakes Wilderness	OR	13.21	12.42	12.42	7.57
Strawberry Mountain Wilderness	OR	17.34	16.37	16.37	7.49
Three Sisters Wilderness	OR	15.80	14.87	14.87	7.87
Cape Romain	SC	27.43	19.70	19.70	11.36
Badlands NP	SD	16.82	14.91	14.90	7.30
Wind Cave NP	SD	15.95	14.21	14.21	7.24

Great Smoky Mountains NP	TN	30.56	21.28	21.27	11.44
Joyce-Kilmer-Slickrock Wilderness	TN	30.56	20.97	20.97	11.45
Big Bend NP	TX	17.21	15.35	15.34	6.93
Guadalupe Mountains NP	TX	16.51	14.47	14.46	7.03
Arches NP	UT	10.77	9.98	9.97	6.99
Bryce Canyon NP	UT	11.62	10.95	10.95	6.99
Canyonlands NP	UT	10.77	10.12	10.11	7.01
Capitol Reef NP	UT	10.86	10.39	10.39	7.03
James River Face Wilderness	VA	28.93	19.62	19.62	11.24
Shenandoah NP	VA	29.42	19.58	19.58	11.25
Lye Brook Wilderness	VT	24.11	16.87	16.86	11.25
Alpine Lake Wilderness	WA	16.99	15.06	15.04	7.86
Glacier Peak Wilderness	WA	13.29	12.18	12.17	7.80
Goat Rocks Wilderness	WA	12.67	11.35	11.34	7.82
Mount Adams Wilderness	WA	12.67	11.39	11.39	7.78
Mount Rainier NP	WA	17.07	15.36	15.35	7.90
North Cascades NP	WA	13.29	12.15	12.14	7.78
Olympic NP	WA	15.83	14.31	14.31	7.88
Pasayten Wilderness	WA	15.35	14.36	14.36	7.77
Dolly Sods Wilderness	WV	29.94	19.65	19.64	11.32
Otter Creek Wilderness	WV	29.94	19.73	19.72	11.33
Bridger Wilderness	WY	10.73	10.29	10.29	7.08
Fitzpatrick Wilderness	WY	10.73	10.29	10.28	7.09
Grand Teton NP	WY	11.19	10.57	10.56	7.09
North Absaroka Wilderness	WY	11.30	10.90	10.90	7.09
Teton Wilderness	WY	11.19	10.68	10.68	7.09
Washakie Wilderness	WY	11.30	10.90	10.90	7.09
Yellowstone NP	WY	11.19	10.61	10.61	7.12

6.3 Quantified and Monetized Non-GHG Health and Environmental Impacts

This section presents EPA's analysis of the non-GHG, or co-pollutant, health and environmental impacts that can be expected to occur as a result of the final light-duty vehicle GHG rule. GHG emissions are predominantly the byproduct of fossil fuel combustion processes that also produce criteria and hazardous air pollutants. The vehicles that are subject to the final standards are also significant sources of mobile source air pollution such as direct PM, NOx, VOCs and air toxics. The standards will affect exhaust emissions of these pollutants from vehicles. They will also affect emissions from upstream sources related to changes in fuel consumption and electricity generation. Changes in ambient ozone, $PM_{2.5}$, and air toxics that will result from the standards are expected to affect human health in the form of premature deaths and other serious human health effects, as well as other important public health and welfare effects.

It is important to quantify the health and environmental impacts associated with the final standards because it allows us to more accurately assess the net costs and benefits of the standards. Moreover, co-pollutant impacts tend to accrue in the near term, while effects from reduced climate change mostly accrue over a time frame of several decades or longer.

This section is split into two sub-sections: the first presents the PM- and ozone-related health and environmental impacts associated with final rule in calendar year (CY) 2030; the second presents the PM-related benefits-per-ton values used to monetize the PM-related co-benefits associated with the model year (MY) analysis (i.e., over the lifetimes of the MY 2017-2025 vehicles) of the final rule.[RRRRRR]

Though EPA is characterizing the changes in emissions associated with toxic pollutants, we were not able to quantify or monetize the human health effects associated with air toxic pollutants for this final rule analysis due to data and methodological limitations. Please refer to Chapter 4 of this RIA for more information about the air toxics emissions impacts associated with the final standards.

6.3.1 Quantified and Monetized Non-GHG Human Health Benefits of the 2030 Calendar Year (CY) Analysis

This section presents EPA's analysis of the criteria pollutant-related health and environmental impacts that will occur as a result of the final standards. Light-duty vehicles and fuels are significant sources of mobile source air pollution such as direct PM, NO_X, SO_X, VOCs and air toxics. The impact that improved fuel economy will have on rebound driving will affect exhaust and evaporative emissions of these pollutants from vehicles. In addition, increased fuel savings associated with improved fuel economy achieved under the standards will affect emissions from upstream sources (see Chapter 4 for a complete description of emission impacts associated with the final standards). Emissions of NO_X (a precursor to ozone formation and secondarily-formed $PM_{2.5}$), SO_X (a precursor to secondarily-formed $PM_{2.5}$), VOCs (a precursor to ozone formation and, to a lesser degree, secondarily-formed $PM_{2.5}$) and directly-emitted $PM_{2.5}$ contribute to ambient concentrations of $PM_{2.5}$ and ozone. Exposure to ozone and $PM_{2.5}$ is linked to adverse human health impacts such as premature deaths as well as other important public health and environmental effects.

The analysis in this section aims to characterize the benefits of the final standards by answering two key questions:

1. What are the health and welfare effects of changes in ambient particulate matter ($PM_{2.5}$) and ozone air quality resulting from reductions in precursors including NO_X and SO_2?

2. What is the economic value of these effects?

[RRRRRR] EPA typically analyzes rule impacts (emissions, air quality, costs and benefits) in the year in which they occur; for this analysis, we selected 2030 as a representative future year. We refer to this analysis as the "Calendar Year" (CY) analysis. EPA also conducted a separate analysis of the impacts over the model year lifetimes of the 2017 through 2025 model year vehicles. We refer to this analysis as the "Model Year" (MY) analysis. In contrast to the CY analysis, the MY lifetime analysis shows the lifetime impacts of the program on each MY fleet over the course of its lifetime.

For the final rule, we have quantified and monetized the health and environmental impacts in 2030, representing impacts associated with a year when the standards are fully implemented and reflects a limited degree of fleet turnover. Overall, we estimate that the final standards will lead to a net decrease in $PM_{2.5}$-related health impacts in 2030. The decrease in population-weighted national average $PM_{2.5}$ exposure results in a net decrease in adverse PM-related human health impacts (the decrease in national population-weighted annual average $PM_{2.5}$ is 0.0065 $\mu g/m^3$ in 2030).[SSSSSS] We estimate that there is a very small increase in population-weighted national average ozone exposure, which results in a very small net increase in ozone-related health impacts (population-weighted maximum 8-hour average ozone increases by 0.0009 ppb in 2030).

Using the most conservative premature mortality estimates (Pope et al., 2002 for $PM_{2.5}$ and Bell et al., 2004 for ozone),[TTTTTT,UUUUUU] we estimate that by 2030, implementation of the final standards will reduce approximately 110 premature mortalities annually and yield approximately $0.95 billion in total annual benefits. The upper end of the range of avoided premature mortality estimates associated with the standards (based on Laden et al., 2006 for $PM_{2.5}$ and Levy et al., 2005 for ozone)[VVVVVV,WWWWWW] results in approximately 280 premature mortalities avoided in 2030 and yields approximately $2.6 billion in total benefits. Thus, even taking the most conservative premature mortality assumptions, the health impacts of the standards presented in this rule are substantial.

6.3.1.1 Overview

This analysis reflects the impacts of the final MY 2017-2025 standards in 2030 compared to a future-year reference scenario without the standards in place. Overall, we estimate that the final rule will lead to a net decrease in population-weighted national average $PM_{2.5}$ exposure, which results in a net decrease in adverse PM-related human health and environmental impacts (the decrease in national population weighted annual average $PM_{2.5}$ is 0.0065 µg/m3 in 2030).

The air quality modeling also projects a very small net increase in ozone concentrations (population weighted maximum 8-hour average ozone increases by 0.0009 ppb in 2030). The

[SSSSSS] Note that the national, population-weighted $PM_{2.5}$ and ozone air quality metrics presented in this Chapter represent an average for the entire, gridded U.S. CMAQ domain. These are different than the population-weighted $PM_{2.5}$ and ozone design value metrics presented in Chapter 7, which represent the average for areas with a current air quality monitor.

[TTTTTT] Pope, C.A., III, R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G.D. Thurston. (2002). Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution. *Journal of the American Medical Association,* 287, 1132-1141.

[UUUUUU] Bell, M.L., et al. (2004). Ozone and short-term mortality in 95 US urban communities, 1987-2000.*Journal of the American Medical Association*, *292(19)*, 2372-2378.

[VVVVVV] Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery. (2006). Reduction in Fine Particulate Air Pollution and Mortality. *American Journal of Respiratory and Critical Care Medicine*. *173*, 667-672.

[WWWWWW] Levy, J.I., S.M. Chemerynski, and J.A. Sarnat. (2005). Ozone exposure and mortality: an empiric bayes metaregression analysis. *Epidemiology. 16(4)*, 458-68.

small increase in population-weighted national average ozone exposure results in a very small increase in net ozone-related health and environmental impacts.

We base our analysis of the final rule's impact on human health and the environment on peer-reviewed studies of air quality and human health effects.[376,377] Our benefits methods are also consistent with recent rulemaking analyses such as the final Transport Rule,[378] the final 2012-2016 MY Light-Duty Vehicle Rule,[379] and the final Portland Cement National Emissions Standards for Hazardous Air Pollutants (NESHAP) RIA.[380] To model the ozone and PM air quality impacts of the final standard, we used the Community Multiscale Air Quality (CMAQ) model (see Section 6.2). The modeled ambient air quality data serves as an input to the Environmental Benefits Mapping and Analysis Program version 4.0 (BenMAP).[XXXXXX] BenMAP is a computer program developed by the U.S. EPA that integrates a number of the modeling elements used in previous analyses (*e.g.*, interpolation functions, population projections, health impact functions, valuation functions, analysis and pooling methods) to translate modeled air concentration estimates into health effects incidence estimates and monetized benefits estimates.

The range of total monetized ozone- and PM-related health impacts in 2030 is presented in Table 6.3-1. We present total benefits (the sum of morbidity-related benefits and mortality-related benefits) based on the PM- and ozone-related premature mortality function used. The benefits ranges therefore reflect the addition of each estimate of ozone-related premature mortality (across six selected studies, each with its own row) to each estimate of PM-related premature mortality (based on either Pope et al., 2002 or Laden et al., 2006), along with all morbidity-related benefits. These estimates represent EPA's preferred approach to characterizing a best estimate of benefits. As is the nature of RIAs, the assumptions and methods used to estimate air quality benefits evolve to reflect the Agency's most current interpretation of the scientific and economic literature.

Table 6.3-1: Estimated 2030 Monetized PM-and Ozone-Related Health Benefits[a]

2030 Total Ozone and PM Benefits – PM Mortality Derived from American Cancer Society Analysis and Six-Cities Analysis[a]			
Premature Ozone Mortality Function	Reference	Total Benefits (Billions, 2010$, 3% Discount Rate)[b,c]	Total Benefits (Billions, 2010$, 7% Discount Rate)[b,c]
Multi-city analyses	Bell et al., 2004	Total: $1.0 – $2.6 PM: $1.1 - $2.6 Ozone: -$0.006	Total: $0.92 - $2.3 PM: $0.95 - $2.3 Ozone: -$0.006
	Huang et al., 2005	Total: $1.0 - $2.6 PM: $1.1 - $2.6 Ozone: -$0.006	Total: $0.92 - $2.3 PM: $0.95 - $2.3 Ozone: -$0.006
	Schwartz, 2005	Total: $1.0 - $2.6 PM: $1.1 - $2.6 Ozone: -$0.009	Total: $0.92 - $2.3 PM: $0.95 - $2.3 Ozone: -$0.009
Meta-analyses	Bell et al., 2005	Total: $1.0 - $2.6	Total: $0.92 - $2.3

XXXXXX Information on BenMAP, including downloads of the software, can be found at http://www.epa.gov/ttn/ecas/ benmodels.html.

		PM: \$1.1 - \$2.6 Ozone: -\$0.019	PM: \$0.95 - \$2.3 Ozone: -\$0.019
	Ito et al., 2005	Total: \$1.0 - \$2.6 PM: \$1.1 - \$2.6 Ozone: -\$0.026	Total: \$0.92 - \$2.3 PM: \$0.95 - \$2.3 Ozone: -\$0.026
	Levy et al., 2005	Total: \$1.0 - \$2.6 PM: \$1.1 - \$2.6 Ozone: -\$0.027	Total: \$0.92 - \$2.3 PM: \$0.95 - \$2.3 Ozone: -\$0.027

Notes:
[a] Total includes premature mortality-related and morbidity-related ozone and $PM_{2.5}$ benefits. Range was developed by adding the estimate from the ozone premature mortality function to the estimate of $PM_{2.5}$-related premature mortality derived from either the ACS study (Pope et al., 2002) or the Six-Cities study (Laden et al., 2006).
[b] Note that total benefits presented here do not include a number of unquantified benefits categories. A detailed listing of unquantified health and welfare effects is provided in Table 6.3-2.
[c] Results reflect the use of both a 3 and 7 percent discount rate, as recommended by EPA's Guidelines for Preparing Economic Analyses and OMB Circular A-4. Results are rounded to two significant digits for ease of presentation and computation. Totals may not sum due to rounding.

The benefits in Table 6.3-1 include all of the human health impacts we are able to quantify and monetize at this time. However, the full complement of human health and welfare effects associated with PM, ozone, and other criteria pollutants remain unquantified because of current limitations in methods or available data. We have not quantified a number of known or suspected health effects linked with ozone, PM, and other criteria pollutants for which appropriate health impact functions are not available or which do not provide easily interpretable outcomes (*e.g.*, changes in heart rate variability). Additionally, we are unable to quantify a number of known welfare effects, including reduced acid and particulate deposition damage to cultural monuments and other materials, and environmental benefits due to reductions of impacts of eutrophication in coastal areas. These are listed in Table 6.3-2. As a result, the health benefits quantified in this section are likely underestimates of the total benefits attributable to the final standards.

Table 6.3-2: Human Health and Welfare Effects of Pollutants Affected by the Final Standards

Pollutant/ Effect	*Quantified and monetized in primary estimate*	*Unquantified*
PM: health[a]	Premature mortality based on cohort study estimates[b] and expert elicitation estimates Hospital admissions: respiratory and cardiovascular Emergency room visits for asthma Nonfatal heart attacks (myocardial infarctions) Lower and upper respiratory illness Minor restricted activity days Work loss days Asthma exacerbations (among asthmatic populations Respiratory symptoms (among asthmatic populations) Infant mortality	Low birth weight, pre-term birth and other reproductive outcomes Pulmonary function Chronic respiratory diseases other than chronic bronchitis Non-asthma respiratory emergency room visits UVb exposure (+/-)[c]
PM: welfare		Visibility in Class I areas in SE, SW, and CA regions Household soiling Visibility in residential areas Visibility in non-class I areas and class 1 areas in NW, NE, and Central regions UVb exposure (+/-)[c] Global climate impacts[c]
Ozone: health	Premature mortality based on short-term study estimates Hospital admissions: respiratory Emergency room visits for asthma Minor restricted activity days School loss days	Chronic respiratory damage Premature aging of the lungs Non-asthma respiratory emergency room visits UVb exposure (+/-)[c]
Ozone: welfare	Decreased outdoor worker productivity	Yields for: --Commercial forests --Fruits and vegetables, and --Other commercial and noncommercial crops Damage to urban ornamental plants Recreational demand from damaged forest aesthetics Ecosystem functions UVb exposure (+/-)[c] Climate impacts
CO: health		Behavioral effects

Pollutant/ Effect	*Quantified and monetized in primary estimate*	*Unquantified*
Nitrate Deposition: welfare		Commercial fishing and forestry from acidic deposition effects Commercial fishing, agriculture and forestry from nutrient deposition effects Recreation in terrestrial and estuarine ecosystems from nutrient deposition effects Other ecosystem services and existence values for currently healthy ecosystems Coastal eutrophication from nitrogen deposition effects
Sulfate Deposition: welfare		Commercial fishing and forestry from acidic deposition effects Recreation in terrestrial and aquatic ecosystems from acid deposition effects Increased mercury methylation
HC/Toxics: health[d]		Cancer (benzene, 1,3-butadiene, formaldehyde, acetaldehyde) Anemia (benzene) Disruption of production of blood components (benzene) Reduction in the number of blood platelets (benzene) Excessive bone marrow formation (benzene) Depression of lymphocyte counts (benzene) Reproductive and developmental effects (1,3-butadiene) Irritation of eyes and mucus membranes (formaldehyde) Respiratory irritation (formaldehyde) Asthma attacks in asthmatics (formaldehyde) Asthma-like symptoms in non-asthmatics (formaldehyde) Irritation of the eyes, skin, and respiratory tract (acetaldehyde) Upper respiratory tract irritation and congestion (acrolein)
HC/Toxics: welfare		Direct toxic effects to animals Bioaccumulation in the food chain Damage to ecosystem function Odor

Notes:

[a] In addition to primary economic endpoints, there are a number of biological responses that have been associated with PM health effects including morphological changes and altered host defense mechanisms. The public health impact of these biological responses may be partly represented by our quantified endpoints.
[b] Cohort estimates are designed to examine the effects of long term exposures to ambient pollution, but relative risk estimates may also incorporate some effects due to shorter term exposures (see Kunzli et al., 2001 for a discussion of this issue).[381] While some of the effects of short term exposure are likely to be captured by the cohort estimates, there may be additional premature mortality from short term PM exposure not captured in the cohort estimates included in the primary analysis.
[c] May result in benefits or disbenefits.
[d] Many of the key hydrocarbons related to this action are also hazardous air pollutants listed in the CAA.

While there will be impacts associated with air toxic pollutant emission changes that result from the final standards, we do not attempt to monetize those impacts. This is primarily because currently available tools and methods to assess air toxics risk from mobile sources at the national scale are not adequate for extrapolation to incidence estimations or benefits assessment. The best suite of tools and methods currently available for assessment at the national scale are those used in the National-Scale Air Toxics Assessment (NATA). The EPA Science Advisory Board specifically commented in their review of the 1996 NATA that these tools were not yet ready for use in a national-scale benefits analysis, because they did not consider the full distribution of exposure and risk, or address sub-chronic health effects.[382] While EPA has since improved these tools, there remain critical limitations for estimating incidence and assessing benefits of reducing mobile source air toxics.

As part of the second prospective analysis of the benefits and costs of the Clean Air Act,[383] EPA conducted a case study analysis of the health effects associated with reducing exposure to benzene in Houston from implementation of the Clean Air Act. While reviewing the draft report, EPA's Advisory Council on Clean Air Compliance Analysis concluded that "the challenges for assessing progress in health improvement as a result of reductions in emissions of hazardous air pollutants (HAPs) are daunting...due to a lack of exposure-response functions, uncertainties in emissions inventories and background levels, the difficulty of extrapolating risk estimates to low doses and the challenges of tracking health progress for diseases, such as cancer, that have long latency periods."[384] EPA continues to work to address these limitations; however, we did not have the methods and tools available for national-scale application in time for the analysis of the final standards.[YYYYYY]

6.3.1.2 Human Health Impacts

Table 6.3-3 and Table 6.3-4 present the annual $PM_{2.5}$ and ozone health impacts in the 48 contiguous U.S. states associated with the final standards. For each endpoint presented in Table 6.3-3 and Table 6.3-4, we provide both the point estimate and the 90 percent confidence interval.

Using EPA's preferred estimates, based on the American Cancer Society (ACS) and Six-Cities studies and no threshold assumption in the model of mortality, we estimate that the final standards will result in between 110 and 280 cases of avoided $PM_{2.5}$-related premature deaths annually in 2030. As a sensitivity analysis, when the range of expert opinion is used, we estimate between 36 and 370 fewer premature mortalities in 2030.

The range of ozone impacts is based on changes in risk estimated using several sources of ozone-related mortality effect estimates. This analysis presents six alternative estimates for the association based upon different functions reported in the scientific literature, derived from both

[YYYYYY] In April, 2009, EPA hosted a workshop on estimating the benefits or reducing hazardous air pollutants. This workshop built upon the work accomplished in the June 2000 Science Advisory Board/EPA Workshop on the Benefits of Reductions in Exposure to Hazardous Air Pollutants, which generated thoughtful discussion on approaches to estimating human health benefits from reductions in air toxics exposure, but no consensus was reached on methods that could be implemented in the near term for a broad selection of air toxics. Please visit http://epa.gov/air/toxicair/2009workshop.html for more information about the workshop and its associated materials.

the National Morbidity, Mortality, and Air Pollution Study (NMMAPS) (Bell et al., 2004; Huang et al., 2005; Schwartz, 2005) and from a series of recent meta-analyses (Bell et al., 2005, Ito et al., 2005, and Levy et al., 2005). This approach is not inconsistent with recommendations provided by the NRC in their recent report (NRC, 2008) on the estimation of ozone-related mortality risk reductions, "The committee recommends that the greatest emphasis be placed on estimates from new systematic multicity analyses that use national databases of air pollution and mortality, such as in the NMMAPS, without excluding consideration of meta-analyses of previously published studies."[385] For ozone-related premature mortality in 2030, we estimate a range of between 1 to 3 additional premature mortalities.

Following these tables, we also provide a more comprehensive presentation of the distributions of incidence generated using the available information from empirical studies and expert elicitation.

Table 6.3-5 presents the distributions of the reduction in $PM_{2.5}$-related premature mortality based on the C-R distributions provided by each expert, as well as that from the data-derived health impact functions, based on the statistical error associated with the ACS study (Pope et al., 2002) and the Six-Cities study (Laden et al., 2006). The 90 percent confidence interval for each separate estimate of PM-related mortality is also provided.

In 2030, the effect estimates of nine of the twelve experts included in the elicitation panel fall within the empirically-derived range provided by the ACS and Six-Cities studies. Only one expert falls below this range, while two of the experts are above this range. Although the overall range across experts is summarized in these tables, the full uncertainty in the estimates is reflected by the results for the full set of 12 experts. The twelve experts' judgments as to the likely mean effect estimate are not evenly distributed across the range illustrated by arraying the highest and lowest expert means.

Table 6.3-3: Estimated $PM_{2.5}$-Related Health Impacts[a]

Health Effect	2030 Annual Reduction in Incidence (5^{th} - 95^{th} percentile)
Premature Mortality – Derived from epidemiology literature[b]	
Adult, age 30+, ACS Cohort Study (Pope et al., 2002)	110 (30 – 190)
Adult, age 25+, Six-Cities Study (Laden et al., 2006)	280 (130 – 440)
Infant, age <1 year (Woodruff et al., 1997)	0 (0 – 1)
Chronic bronchitis (adult, age 26 and over)	76 (1 – 150)
Non-fatal myocardial infarction (adult, age 18 and over)	130 (32 – 230)
Hospital admissions - respiratory (all ages)[c]	20 (8 – 32)
Hospital admissions - cardiovascular (adults, age >18)[d]	50 (33 – 60)
Emergency room visits for asthma (age 18 years and younger)	72 (34 – 110)
Acute bronchitis, (children, age 8-12)	160 (-42 – 370)

Lower respiratory symptoms (children, age 7-14)	2,100 (770 – 3,400)
Upper respiratory symptoms (asthmatic children, age 9-18)	1,600 (260 – 2,900)
Asthma exacerbation (asthmatic children, age 6-18)	3,500 (-120 – 9,700)
Work loss days	14,000 (12,000 – 16,000)
Minor restricted activity days (adults age 18-65)	81,000 (65,000 – 96,000)

Notes:
[a] Incidence is rounded to two significant digits. Estimates represent incidence within the 48 contiguous United States.
[b] PM-related adult mortality based upon the American Cancer Society (ACS) Cohort Study (Pope et al., 2002) and the Six-Cities Study (Laden et al., 2006). Note that these are two alternative estimates of adult mortality and should not be summed. PM-related infant mortality based upon a study by Woodruff, Grillo, and Schoendorf, (1997).[zzzzzz]
[c] Respiratory hospital admissions for PM include admissions for chronic obstructive pulmonary disease (COPD), pneumonia and asthma.
[d] Cardiovascular hospital admissions for PM include total cardiovascular and subcategories for ischemic heart disease, dysrhythmias, and heart failure.

Table 6.3-4: Estimated Ozone-Related Health Impacts[a]

Health Effect	2030 Annual Reduction in Incidence (5^{th} - 95^{th} percentile)
Premature Mortality, All ages[b] Multi-City Analyses	
Bell et al. (2004) – Non-accidental	-1 (-4 – 3)
Huang et al. (2005) – Cardiopulmonary	-1 (-5 – 4)
Schwartz (2005) – Non-accidental	-1 (-6 – 4)
Meta-analyses:	
Bell et al. (2005) – All cause	-2 (-10 – 6)
Ito et al. (2005) – Non-accidental	-3 (-11 – 6)
Levy et al. (2005) – All cause	-3 (-10 – 4)
Hospital admissions- respiratory causes (adult, 65 and older)c	-6 (-30 – 15)
Hospital admissions -respiratory causes (children, under 2)	-3 (-12 – 6)
Emergency room visit for asthma (all ages)	-1 (-18 – 15)
Minor restricted activity days (adults, age 18-65)	-930 (-18,000 – 16,000)

[zzzzzz] Woodruff, T.J., J. Grillo, and K.C. Schoendorf. 1997. "The Relationship Between Selected Causes of Postneonatal Infant Mortality and Particulate Air Pollution in the United States." *Environmental Health Perspectives* 105(6):608-612.

School absence days	-850 (-6,700 – 5,100)

Notes:
[a] Negatives indicate a disbenefit, or an increase in health effect incidence. Incidence is rounded to two significant digits. Estimates represent incidence within the 48 contiguous U.S.
[b] Estimates of ozone-related premature mortality are based upon incidence estimates derived from several alternative studies: Bell et al. (2004); Huang et al. (2005); Schwartz (2005) ; Bell et al. (2005); Ito et al. (2005); Levy et al. (2005). The estimates of ozone-related premature mortality should therefore not be summed.
[c] Respiratory hospital admissions for ozone include admissions for all respiratory causes and subcategories for COPD and pneumonia.

Table 6.3-5: Results of Application of Expert Elicitation: Annual Reductions in Premature Mortality in 2030 Associated with the Final Standards

Source of Mortality Estimate	2030 Incidence		
	5th Percentile	Mean	95th Percentile
Pope et al. (2002)	30	110	190
Laden et al. (2006)	130	280	440
Expert A	6	300	590
Expert B	-23	220	530
Expert C	-4	230	530
Expert D	23	160	280
Expert E	150	370	60
Expert F	120	200	290
Expert G	0	130	260
Expert H	-38	170	430
Expert I	19	220	430
Expert J	19	180	440
Expert K	0	36	190
Expert L	8	140	330

6.3.1.3 Monetized Estimates of Human Health and Environmental Impacts

Table 6.3-6 presents the estimated monetary value of changes in the incidence of ozone and $PM_{2.5}$-related health and environmental effects. Total aggregate monetized benefits are presented in Table 6.3-7. All monetized estimates are presented in 2010$. Where appropriate, estimates account for growth in real gross domestic product (GDP) per capita between 2000 and 2030.[AAAAAAA] The monetized value of $PM_{2.5}$-related mortality also accounts for a twenty-year

[AAAAAAA] Our analysis accounts for expected growth in real income over time. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real incomes increase. Benefits are therefore adjusted by multiplying the unadjusted benefits by the appropriate adjustment factor to account for income growth over time. For growth between 2000 and 2030, this factor is 1.23 for long-term mortality, 1.27 for chronic health impacts, and 1.08 for minor health impacts. For a complete discussion of how these adjustment factors were derived, we refer the reader to the PM NAAQS regulatory impact analysis.[9] Note that similar adjustments do not exist for cost-of-illness-based unit values. For these, we apply the same unit value regardless of the future year of analysis.

segmented cessation lag.[BBBBBBB] To discount the value of premature mortality that occurs at different points in the future, we apply both a 3 and 7 percent discount rate. We also use both a 3 and 7 percent discount rate to value PM-related nonfatal heart attacks (myocardial infarctions).[CCCCCCC]

In addition to omitted benefits categories such as air toxics and various welfare effects, not all known $PM_{2.5}$- and ozone-related health and welfare effects could be quantified or monetized. The estimate of total monetized health benefits of the final standards is thus equal to the subset of monetized $PM_{2.5}$- and ozone-related health impacts we are able to quantify plus the sum of the nonmonetized health and welfare benefits. Our estimate of total monetized benefits in 2030 for the final standards, using the ACS and Six-Cities PM mortality studies and the range of ozone mortality assumptions, is between $1.0 and $2.6 billion, assuming a 3 percent discount rate, or between $0.92 and $2.3 billion, assuming a 7 percent discount rate. As the results indicate, total benefits are driven primarily by the reduction in $PM_{2.5}$-related premature fatalities each year and represent the benefits of the final standards anticipated to occur annually when the program is fully implemented.

The next largest benefit is for reductions in chronic illness (chronic bronchitis and nonfatal heart attacks), although this value is more than an order of magnitude lower than for premature mortality. Hospital admissions for respiratory and cardiovascular causes, minor restricted activity days, and work loss days account for the majority of the remaining benefits. The remaining categories each account for a small percentage of total benefit; however, they represent a large number of avoided incidences affecting many individuals. A comparison of the incidence table to the monetary benefits table reveals that there is not always a close correspondence between the number of incidences avoided for a given endpoint and the monetary value associated with that endpoint. For example, there are many more work loss days than PM-related premature mortalities, yet work loss days account for only a very small fraction of total monetized benefits. This reflects the fact that many of the less severe health effects, while more common, are valued at a lower level than the more severe health effects. Also, some effects, such as hospital admissions, are valued using a proxy measure of willingness-to-pay (*e.g.*, cost-of-illness). As such, the true value of these effects may be higher than that reported here.

[BBBBBBB] Based in part on prior SAB advice, EPA has typically assumed that there is a time lag between changes in pollution exposures and the total realization of changes in health effects. Within the context of benefits analyses, this term is often referred to as "cessation lag". The existence of such a lag is important for the valuation of premature mortality incidence because economic theory suggests that benefits occurring in the future should be discounted. In this analysis, we apply a twenty-year distributed lag to PM mortality reductions. This method is consistent with the most recent recommendation by the EPA's Science Advisory Board. Refer to: EPA – Science Advisory Board, 2004. Advisory Council on Clean Air Compliance Analysis Response to Agency Request on Cessation Lag. Letter from the Health Effects Subcommittee to the U.S. Environmental Protection Agency Administrator, December.

[CCCCCCC] Nonfatal myocardial infarctions (MI) are valued using age-specific cost-of-illness values that reflect lost earnings and direct medical costs over a 5-year period following a nonfatal MI.

Table 6.3-6: Estimated Monetary Value of Changes in Incidence of Health and Welfare Effects (millions of 2010$) [a,b]

		2030
$PM_{2.5}$-Related Health Effect		(5th and 95th Percentile)
Premature Mortality – Derived from Epidemiology Studies[c,d]	Adult, age 30+ - ACS study (Pope et al., 2002)	
	3% discount rate	$980 ($110 - $2,600)
	7% discount rate	$880 ($97 - $2,400)
	Adult, age 25+ - Six-Cities study (Laden et al., 2006)	
	3% discount rate	$2,500 ($340 - $6,300)
	7% discount rate	$2,300 ($310 - $5,700)
	Infant Mortality, <1 year – (Woodruff et al. 1997)	$3.8 (-$3.9 - $15)
Chronic bronchitis (adults, 26 and over)		$42 ($0.4 - $140)
Non-fatal acute myocardial infarctions		
3% discount rate		$14 ($2.3 - $36)
7% discount rate		$12 ($1.8 - $30)
Hospital admissions for respiratory causes		$0.32 ($0.13 - $0.51)
Hospital admissions for cardiovascular causes		$0.73 ($0.07 - $1.4)
Emergency room visits for asthma		$0.03 ($0.01 - $0.05)
Acute bronchitis (children, age 8–12)		$0.08 (-$0.02 - $0.21)
Lower respiratory symptoms (children, 7–14)		$0.04 ($0.01 - $0.09)
Upper respiratory symptoms (asthma, 9–11)		$0.05 ($0.009 - $0.12)
Asthma exacerbations		$0.20 (-$0.007 - $0.58)
Work loss days		$2.2 ($1.9 - $2.6)
Minor restricted-activity days (MRADs)		$5.6 ($3.2 - $8.1)
Premature Mortality, All ages – Derived from Multi-city analyses	Bell et al., 2004	-$5.8 (-$45 - $27)
	Huang et al., 2005	-$6.2 (-$60 - $41)
	Schwartz, 2005	-$8.7 (-$71 - $44)
Premature Mortality, All ages – Derived from Meta-analyses	Bell et al., 2005	-$19 (-$120 - $38)

	Ito et al., 2005	-$26 (-$140 - $58)
	Levy et al., 2005	-$27 (-$120 - $38)
Hospital admissions- respiratory causes (adult, 65 and older)		-$0.16 (-$0.77 - $0.39)
Hospital admissions- respiratory causes (children, under 2)		-$0.03 (-$130 - $0.07)
Emergency room visit for asthma (all ages)		-$0.0003 (-$0.007 - $0.006)
Minor restricted activity days (adults, age 18-65)		-$0.06 (-$1.3 - $1.1)
School absence days		-$0.08 (-$0.65 - $0.49)

Notes:
[a] Negatives indicate a disbenefit, or an increase in health effect incidence. Monetary benefits are rounded to two significant digits for ease of presentation and computation. PM and ozone benefits are nationwide.
[b] Monetary benefits adjusted to account for growth in real GDP per capita between 1990 and the analysis year (2030).
[c] Valuation assumes discounting over the SAB recommended 20 year segmented lag structure. Results reflect the use of 3 percent and 7 percent discount rates consistent with EPA and OMB guidelines for preparing economic analyses.

Table 6.3-7: Total Monetized Ozone and PM-related Benefits Associated with the Final Standards in 2030

Total Ozone and PM Benefits (billions, 2010$) – PM Mortality Derived from the ACS and Six-Cities Studies					
3% Discount Rate			**7% Discount Rate**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
Multi-city	Bell et al., 2004	$1.0 - $2.6	Multi-city	Bell et al., 2004	$0.95 - $2.3
	Huang et al., 2005	$1.0 - $2.6		Huang et al., 2005	$0.94 - $2.3
	Schwartz, 2005	$1.0 - $2.6		Schwartz, 2005	$0.94 - $2.3
Meta-analysis	Bell et al., 2005	$1.0 - $2.6	Meta-analysis	Bell et al., 2005	$0.93 - $2.3
	Ito et al., 2005	$1.0 - $2.6		Ito et al., 2005	$0.92 - $2.3
	Levy et al., 2005	$1.0 - $2.6		Levy et al., 2005	$0.92 - $2.3
Total Ozone and PM Benefits (billions, 2010$) – PM Mortality Derived from Expert Elicitation (Lowest and Highest Estimate)					
3% Discount Rate			**7% Discount Rate**		
Ozone Mortality Function	Reference	Mean Total Benefits	Ozone Mortality Function	Reference	Mean Total Benefits
Multi-city	Bell et al., 2004	$0.39 - $3.4	Multi-city	Bell et al., 2004	$0.35 - $3.1
	Huang et al., 2005	$0.39 - $3.4		Huang et al., 2005	$0.35 - $3.1

	Schwartz, 2005	$0.39 - $3.4		Schwartz, 2005	$0.35 - $3.1
Meta-analysis	Bell et al., 2005	$0.38 - $3.4	Meta-analysis	Bell et al., 2005	$0.34 - $3.1
	Ito et al., 2005	$0.37 - $3.4		Ito et al., 2005	$0.33 - $3.0
	Levy et al., 2005	$0.37 - $3.4		Levy et al., 2005	$0.33 - $3.0

6.3.1.4 Methodology

6.3.1.4.1 Human Health Impact Functions

Health impact functions measure the change in a health endpoint of interest, such as hospital admissions, for a given change in ambient ozone or PM concentration. Health impact functions are derived from primary epidemiology studies, meta-analyses of multiple epidemiology studies, or expert elicitations. A standard health impact function has four components: (1) an effect estimate from a particular study; (2) a baseline incidence rate for the health effect (obtained from either the epidemiology study or a source of public health statistics such as the Centers for Disease Control); (3) the size of the potentially affected population; and (4) the estimated change in the relevant ozone or PM summary measures.

A typical health impact function might look like:

$$\Delta y = y_0 \cdot \left(e^{\beta \cdot \Delta x} - 1\right),$$

where y_0 is the baseline incidence (the product of the baseline incidence rate times the potentially affected population), β is the effect estimate, and Δx is the estimated change in the summary pollutant measure. There are other functional forms, but the basic elements remain the same. The following subsections describe the sources for each of the first three elements: size of the potentially affected populations; $PM_{2.5}$ and ozone effect estimates; and baseline incidence rates. We also describe the treatment of potential thresholds in PM-related health impact functions. Section 8.2 describes the ozone and PM air quality inputs to the health impact functions.

6.3.1.4.1.1 Potentially Affected Populations

The starting point for estimating the size of potentially affected populations is the 2000 U.S. Census block level dataset.[386] Benefits Modeling and Analysis Program (BenMAP) incorporates 250 age/gender/race categories to match specific populations potentially affected by ozone and other air pollutants. The software constructs specific populations matching the populations in each epidemiological study by accessing the appropriate age-specific populations from the overall population database. BenMAP projects populations to 2030 using growth factors based on economic projections.[387]

6.3.1.4.1.2 Effect Estimate Sources

The most significant quantifiable benefits of reducing ambient concentrations of ozone and PM are attributable to reductions in human health risks. EPA's Ozone and PM Criteria Documents[388,389] and the World Health Organization's 2003 and 2004[390,391] reports outline numerous human health effects known or suspected to be linked to exposure to ambient ozone and PM. EPA recently evaluated the ozone and PM literature for use in the benefits analysis for the final 2008 Ozone NAAQS and final 2006 PM NAAQS analyses. We use the same literature in this analysis; for more information on the studies that underlie the health impacts quantified in this RIA, please refer to those documents.

It is important to note that we are unable to separately quantify all of the possible PM and ozone health effects that have been reported in the literature for three reasons: (1) the possibility of double counting (such as hospital admissions for specific respiratory diseases versus hospital admissions for all or a sub-set of respiratory diseases); (2) uncertainties in applying effect relationships that are based on clinical studies to the potentially affected population; or (3) the lack of an established concentration-response (CR) relationship. Table 6.3-8 lists the health endpoints included in this analysis.

Table 6.3-8: Health Impact Functions Used in BenMAP to Estimate Impacts of $PM_{2.5}$ and Ozone Reductions

ENDPOINT	*POLLUTANT*	*STUDY*	*STUDY POPULATION*
Premature Mortality			
Premature mortality – daily time series	O_3	Multi-city Bell et al (2004) (NMMAPS study)[392] – Non-accidental Huang et al (2005)[393] - Cardiopulmonary Schwartz (2005)[394] – Non-accidental Meta-analyses: Bell et al (2005)[395] – All cause Ito et al (2005)[396] – Non-accidental Levy et al (2005)[397] – All cause	All ages
Premature mortality —cohort study, all-cause	$PM_{2.5}$	Pope et al. (2002)[398] Laden et al. (2006)[399]	>29 years >25 years
Premature mortality, total exposures	$PM_{2.5}$	Expert Elicitation (IEc, 2006)[400]	>24 years
Premature mortality — all-cause	$PM_{2.5}$	Woodruff et al. (1997)[401]	Infant (<1 year)
Chronic Illness			
Chronic bronchitis	$PM_{2.5}$	Abbey et al. (1995)[402]	>26 years
Nonfatal heart attacks	$PM_{2.5}$	Peters et al. (2001)[403]	Adults (>18 years)

ENDPOINT	POLLUTANT	STUDY	STUDY POPULATION
Hospital Admissions			
Respiratory	O_3	Pooled estimate: Schwartz (1995) - ICD 460-519 (all resp)[404] Schwartz (1994a; 1994b) - ICD 480-486 (pneumonia)[405,406] Moolgavkar et al. (1997) - ICD 480-487 (pneumonia)[407] Schwartz (1994b) - ICD 491-492, 494-496 (COPD) Moolgavkar et al. (1997) – ICD 490-496 (COPD)	>64 years
		Burnett et al. (2001)[408]	<2 years
	$PM_{2.5}$	Pooled estimate: Moolgavkar (2003)—ICD 490-496 (COPD)[409] Ito (2003)—ICD 490-496 (COPD)[410]	>64 years
	$PM_{2.5}$	Moolgavkar (2000)—ICD 490-496 (COPD)[411]	20–64 years
	$PM_{2.5}$	Ito (2003)—ICD 480-486 (pneumonia)	>64 years
	$PM_{2.5}$	Sheppard (2003)—ICD 493 (asthma)[412]	<65 years
Cardiovascular	$PM_{2.5}$	Pooled estimate: Moolgavkar (2003)—ICD 390-429 (all cardiovascular) Ito (2003)—ICD 410-414, 427-428 (ischemic heart disease, dysrhythmia, heart failure)	>64 years
	$PM_{2.5}$	Moolgavkar (2000)—ICD 390-429 (all cardiovascular)	20–64 years
Asthma-related ER visits	O_3	Pooled estimate: Peel et al (2005)[413] Wilson et al (2005)[414]	 All ages All ages
Asthma-related ER visits (cont'd)	$PM_{2.5}$	Norris et al. (1999)[415]	0–18 years
Other Health Endpoints			
Acute bronchitis	$PM_{2.5}$	Dockery et al. (1996)[416]	8–12 years
Upper respiratory symptoms	$PM_{2.5}$	Pope et al. (1991)[417]	Asthmatics, 9–11 years
Lower respiratory symptoms	$PM_{2.5}$	Schwartz and Neas (2000)[418]	7–14 years
Asthma exacerbations	$PM_{2.5}$	Pooled estimate: Ostro et al. (2001)[419] (cough, wheeze and shortness of breath) Vedal et al. (1998)[420] (cough)	6–18 years[a]
Work loss days	$PM_{2.5}$	Ostro (1987)[421]	18–65 years
School absence days	O_3	Pooled estimate: Gilliland et al. (2001)[422] Chen et al. (2000)[423]	5–17 years[b]
Minor Restricted Activity Days (MRADs)	O_3	Ostro and Rothschild (1989)[424]	18–65 years
	$PM_{2.5}$	Ostro and Rothschild (1989)	18–65 years

Notes:

[a] The original study populations were 8 to 13 for the Ostro et al. (2001) study and 6 to 13 for the Vedal et al. (1998) study. Based on advice from the Science Advisory Board Health Effects Subcommittee (SAB-HES), we extended the applied population to 6 to 18, reflecting the common biological basis for the effect in children in the broader age group. See: U.S. Science Advisory Board. 2004. Advisory Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis –Benefits and Costs of the Clean Air Act, 1990—2020. EPA-SAB-COUNCIL-ADV-04-004. See also National Research Council (NRC). 2002. *Estimating the Public Health Benefits of Proposed Air Pollution Regulations*. Washington, DC: The National Academies Press.
[b] Gilliland et al. (2001) studied children aged 9 and 10. Chen et al. (2000) studied children 6 to 11. Based on recent advice from the National Research Council and the EPA SAB-HES, we have calculated reductions in school absences for all school-aged children based on the biological similarity between children aged 5 to 17.

In selecting epidemiological studies as sources of effect estimates, we applied several criteria to develop a set of studies that is likely to provide the best estimates of impacts in the U.S. To account for the potential impacts of different health care systems or underlying health status of populations, we give preference to U.S. studies over non-U.S. studies. In addition, due to the potential for confounding by co-pollutants, we give preference to effect estimates from models including both ozone and PM over effect estimates from single-pollutant models.[425,426]

6.3.1.4.1.3 Baseline Incidence Rates

Epidemiological studies of the association between pollution levels and adverse health effects generally provide a direct estimate of the relationship of air quality changes to the *relative risk* of a health effect, rather than estimating the absolute number of avoided cases. For example, a typical result might be that a 100 ppb decrease in daily ozone levels might, in turn, decrease hospital admissions by 3 percent. The baseline incidence of the health effect is necessary to convert this relative change into a number of cases. A baseline incidence rate is the estimate of the number of cases of the health effect per year in the assessment location, as it corresponds to baseline pollutant levels in that location. To derive the total baseline incidence per year, this rate must be multiplied by the corresponding population number. For example, if the baseline incidence rate is the number of cases per year per 100,000 people, that number must be multiplied by the number of 100,000s in the population.

Table 6.3-9 summarizes the sources of baseline incidence rates and provides average incidence rates for the endpoints included in the analysis. Table 6.3-10 presents the asthma prevalence rates used in this analysis. For both baseline incidence and prevalence data, we used age-specific rates where available. We applied concentration-response functions to individual age groups and then summed over the relevant age range to provide an estimate of total population benefits. In most cases, we used a single national incidence rate, due to a lack of more spatially disaggregated data. Whenever possible, the national rates used are national averages, because these data are most applicable to a national assessment of benefits. For some studies, however, the only available incidence information comes from the studies themselves; in these cases, incidence in the study population is assumed to represent typical incidence at the national level. Regional incidence rates are available for hospital admissions, and county-level data are available for premature mortality. We have projected mortality rates such that future mortality rates are consistent with our projections of population growth.[427]

Table 6.3-9: Baseline Incidence Rates and Population Prevalence Rates for Use in Impact Functions, General Population

Endpoint	*Parameter*	*Rates*	
		Value	*Source*
Mortality	Daily or annual mortality rate projected to 2020	Age-, cause-, and county-specific rate	CDC Wonder (2006–2008)[428] U.S. Census bureau
Hospitalizations	Daily hospitalization rate	Age-, region-, state-, county- and cause-specific rate	2007 HCUP data files[a,429]
Asthma ER Visits	Daily asthma ER visit rate	Age-, region-, state-, county- and cause-specific rate	2007 HCUP data files[a]
Chronic Bronchitis	Annual prevalence rate per person Aged 18–44 Aged 45–64 Aged 65 and older	 0.0367 0.0505 0.0587	1999 NHIS (American Lung Association, 2002, Table 4)[430]
	Annual incidence rate per person	0.00378	Abbey et al. (1993, Table 3)
Nonfatal Myocardial Infarction (heart attacks)	Daily nonfatal myocardial infarction incidence rate per person, 18+	Age-, region-, state-, and county- specific rate	2007 HCUP data files[a]; adjusted by 0.93 for probability of surviving after 28 days (Rosamond et al., 1999)
Asthma Exacerbations	Incidence among asthmatic African-American children daily wheeze daily cough daily dyspnea	0.076 0.067 0.037	Ostro et al. (2001)
Acute Bronchitis	Annual bronchitis incidence rate, children	0.043	American Lung Association (2002, Table 11)[431]
Lower Respiratory Symptoms	Daily lower respiratory symptom incidence among children[b]	0.0012	Schwartz et al. (1994, Table 2)
Upper Respiratory Symptoms	Daily upper respiratory symptom incidence among asthmatic children	0.3419	Pope et al. (1991, Table 2)
Work Loss Days	Daily WLD incidence rate per person (18–65) Aged 18–24 Aged 25–44 Aged 45–64	 0.00540 0.00678 0.00492	1996 HIS (Adams, Hendershot, and Marano, 1999, Table 41);[432] U.S. Bureau of the Census (2000)[433]
School Loss Days	Rate per person per year, assuming 180 school days per year	9.9	National Center for Education Statistics (1996)[434] and 1996 HIS (Adams et al., 1999, Table 47);
Minor Restricted-Activity Days	Daily MRAD incidence rate per person	0.02137	Ostro and Rothschild (1989, p. 243)

Notes:

[a] Healthcare Cost and Utilization Program (HCUP) database contains individual level, state and regional-level hospital and emergency department discharges for a variety of ICD codes.

[b] Lower respiratory symptoms are defined as two or more of the following: cough, chest pain, phlegm, and wheeze.

Table 6.3-10: Asthma Prevalence Rates Used for this Analysis

Population Group	*Asthma Prevalence Rates*	
	Value	*Source*
All Ages	0.0780	American Lung Association (2010, Table 7)
< 18	0.0941	
5–17	0.1070	
18–44	0.0719	
45–64	0.0745	
65+	0.0716	
African American, 5 to 17	0.1776	American Lung Association (2010, Table 9)
African American, <18	0.1553	American Lung Association[b]

Notes:
[a] See ftp://ftp.cdc.gov/pub/Health_Statistics/NCHS/Datasets/NHIS/2000/.
[b] Calculated by ALA for U.S. EPA, based on NHIS data (CDC, 2008).[435]

6.3.1.4.2 Economic Values for Health Outcomes

Reductions in ambient concentrations of air pollution generally lower the risk of future adverse health effects for a large population. Therefore, the appropriate economic measure is willingness-to-pay (WTP) for changes in risk of a health effect rather than WTP for a health effect that would occur with certainty (Freeman, 1993).[436] Epidemiological studies generally provide estimates of the relative risks of a particular health effect that is avoided because of a reduction in air pollution. We converted those to units of avoided statistical incidence for ease of presentation. We calculated the value of avoided statistical incidences by dividing individual WTP for a risk reduction by the related observed change in risk. For example, suppose a pollution-reduction regulation is able to reduce the risk of premature mortality from 2 in 10,000 to 1 in 10,000 (a reduction of 1 in 10,000). If individual WTP for this risk reduction is $100, then the WTP for an avoided statistical premature death is $1 million ($100/0.0001 change in risk).

WTP estimates generally are not available for some health effects, such as hospital admissions. In these cases, we used the cost of treating or mitigating the effect as a primary estimate. These cost-of-illness (COI) estimates generally understate the true value of reducing the risk of a health effect, because they reflect the direct expenditures related to treatment, but not the value of avoided pain and suffering (Harrington and Portney, 1987; Berger, 1987).[437,438] We provide unit values for health endpoints (along with information on the distribution of the unit value) in Table 6.3-11. All values are in constant year 2010 dollars, adjusted for growth in real income out to 2030 using projections provided by Standard and Poor's. Economic theory argues that WTP for most goods (such as environmental protection) will increase if real income increases. Many of the valuation studies used in this analysis were conducted in the late 1980s and early 1990s. Because real income has grown since the studies were conducted, people's willingness to pay for reductions in the risk of premature death and disease likely has grown as well. We did not adjust cost of illness-based values because they are based on current costs. Similarly, we did not adjust the value of school absences, because that value is based on current wage rates. For details on valuation estimates for PM-related endpoints, see the 2006 PM NAAQS RIA.[439] For details on valuation estimates for ozone-related endpoints, see the 2008 Ozone NAAQS RIA.[440]

Table 6.3-11: Unit Values for Economic Valuation of Health Endpoints (2010$)

Health Endpoint	Central Estimate of Value Per Statistical Incidence		
	2000 Income Level	2030 Income Level	Derivation of Distributions of Estimates
Premature Mortality (Value of a Statistical Life)	$8,000,000	$9,900,000	EPA currently recommends a central VSL of $6.3m (2000$) based on a Weibull distribution fitted to 26 published VSL estimates (5 contingent valuation and 21 labor market studies). The underlying studies, the distribution parameters, and other useful information are available in Appendix B of EPA's current Guidelines for Preparing Economic Analyses (U.S. EPA, 2000).
Chronic Bronchitis (CB)	$450,000	$550,000	The WTP to avoid a case of pollution-related CB is calculated as where x is the severity of an average CB case, WTP_{13} is the WTP for a severe case of CB, and $ is the parameter relating WTP to severity, based on the regression results reported in Krupnick and Cropper (1992). The distribution of WTP for an average severity-level case of CB was generated by Monte Carlo methods, drawing from each of three distributions: (1) WTP to avoid a severe case of CB is assigned a 1/9 probability of being each of the first nine deciles of the distribution of WTP responses in Viscusi et al. (1991); (2) the severity of a pollution-related case of CB (relative to the case described in the Viscusi study) is assumed to have a triangular distribution, with the most likely value at severity level 6.5 and endpoints at 1.0 and 12.0; and (3) the constant in the elasticity of WTP with respect to severity is normally distributed with mean = 0.18 and standard deviation = 0.0669 (from Krupnick and Cropper [1992]). This process and the rationale for choosing it is described in detail in the Costs and Benefits of the Clean Air Act, 1990 to 2010 (U.S. EPA, 1999).
Nonfatal Myocardial Infarction (heart attack) 3% discount rate Age 0–24 Age 25–44 Age 45–54 Age 55–65 Age 66 and over 7% discount rate Age 0–24 Age 25–44 Age 45–54 Age 55–65 Age 66 and over	 $89,373 $100,690$1 06,053 $185,785 $89,373 $88,547 $98,680 $103,481 $174,866 $88,548	 $89,373 $100,690 $106,053 $185,785 $89,373 $88,547 $98,680 $103,481 $174,866 $88,548	No distributional information available. Age-specific cost-of-illness values reflect lost earnings and direct medical costs over a 5-year period following a nonfatal MI. Lost earnings estimates are based on Cropper and Krupnick (1990). Direct medical costs are based on simple average of estimates from Russell et al. (1998) and Wittels et al. (1990). Lost earnings: Cropper and Krupnick (1990). Present discounted value of 5 years of lost earnings: age of onset: at 3% at 7% 25–44 $8,774 $7,855 45–54 $12,932 $11,578 55–65 $74,746 $66,920 Direct medical expenses: An average of: 1. Wittels et al. (1990) ($102,658—no discounting) 2. Russell et al. (1998), 5-year period ($22,331 at 3% discount rate; $21,113 at 7% discount rate)

Hospital Admissions			
Chronic Obstructive Pulmonary Disease (COPD)	$17,996	$17,996	No distributional information available. The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (*e.g.*, average hospital care costs, average length of hospital stay, and weighted share of total COPD category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
Asthma Admissions	$11,957	$11,957	No distributional information available. The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (*e.g.*, average hospital care costs, average length of hospital stay, and weighted share of total asthma category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
All Cardiovascular	$30,256	$30,256	No distributional information available. The COI estimates (lost earnings plus direct medical costs) are based on ICD-9 code-level information (*e.g.*, average hospital care costs, average length of hospital stay, and weighted share of total cardiovascular category illnesses) reported in Agency for Healthcare Research and Quality (2000) (www.ahrq.gov).
All respiratory (ages 65+)	$25,413	$25,413	No distributions available. The COI point estimates (lost earnings plus direct medical costs) are based on ICD-9 code level information (*e.g.*, average hospital care costs, average length of hospital stay, and weighted share of total COPD category illnesses) reported in Agency for Healthcare Research and Quality, 2000 (www.ahrq.gov).
All respiratory (ages 0–2)	$10,943	$10,943	No distributions available. The COI point estimates (lost earnings plus direct medical costs) are based on ICD-9 code level information (*e.g.*, average hospital care costs, average length of hospital stay, and weighted share of total COPD category illnesses) reported in Agency for Healthcare Research and Quality, 2000 (www.ahrq.gov).
Emergency Room Visits for Asthma	$405	$405	No distributional information available. Simple average of two unit COI values: (1) $311.55, from Smith et al. (1997) and (2) $260.67, from Stanford et al. (1999).
Respiratory Ailments Not Requiring Hospitalization			
Upper Respiratory Symptoms (URS)	$32	$34	Combinations of the three symptoms for which WTP estimates are available that closely match those listed by Pope et al. result in seven different “symptom clusters,” each describing a “type” of URS. A dollar value was derived for each type of URS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. In the absence of information surrounding the frequency with which each of the seven types of URS occurs within the URS symptom complex, we assumed a uniform distribution between $9.2 and $43.1.
Lower Respiratory Symptoms (LRS)	$20	$21	Combinations of the four symptoms for which WTP estimates are available that closely match those listed by Schwartz et al. result in 11 different “symptom clusters,” each describing a “type” of LRS. A dollar value was derived for each type of LRS, using mid-range estimates of WTP (IEc, 1994) to avoid each symptom in the cluster and assuming additivity of WTPs. The dollar value for LRS is the average of the dollar values for the 11 different types of LRS. In the absence of information surrounding the frequency with which each of the 11 types of LRS occurs within the LRS symptom complex, we assumed a uniform distribution between $6.9 and $24.46.
Asthma Exacerbations	$55	$57	Asthma exacerbations are valued at $45 per incidence, based on the mean of average WTP estimates for the four severity definitions of a “bad asthma day,” described in Rowe and Chestnut (1986). This study

			surveyed asthmatics to estimate WTP for avoidance of a "bad asthma day," as defined by the subjects. For purposes of valuation, an asthma exacerbation is assumed to be equivalent to a day in which asthma is moderate or worse as reported in the Rowe and Chestnut (1986) study. The value is assumed have a uniform distribution between \$15.6 and \$70.8.
Acute Bronchitis	\$452	\$494	Assumes a 6-day episode, with the distribution of the daily value specified as uniform with the low and high values based on those recommended for related respiratory symptoms in Neumann et al. (1994). The low daily estimate of \$10 is the sum of the mid-range values recommended by IEc 1994 for two symptoms believed to be associated with acute bronchitis: coughing and chest tightness. The high daily estimate was taken to be twice the value of a minor respiratory restricted-activity day, or \$110.
Work Loss Days (WLDs)	Variable (U.S. median = \$137)	Variable (U.S. median = \$137)	No distribution available. Point estimate is based on county-specific median annual wages divided by 50 (assuming 2 weeks of vacation) and then by 5—to get median daily wage. U.S. Year 2000 Census, compiled by Geolytics, Inc.
Minor Restricted Activity Days (MRADs)	\$64	\$69	Median WTP estimate to avoid one MRAD from Tolley et al. (1986). Distribution is assumed to be triangular with a minimum of \$22 and a maximum of \$83, with a most likely value of \$52. Range is based on assumption that value should exceed WTP for a single mild symptom (the highest estimate for a single symptom—for eye irritation—is \$16.00) and be less than that for a WLD. The triangular distribution acknowledges that the actual value is likely to be closer to the point estimate than either extreme.
School Absence Days	\$95	\$95	No distribution available

6.3.1.4.3 Processing Air Quality Modeling Data for Health Impacts Analysis

In Section 6.2, we summarized the methods for and results of estimating air quality for the standards. These air quality results are in turn associated with human populations to estimate changes in health effects. For the purposes of this analysis, we focus on the health effects that have been linked to ambient changes in ozone and $PM_{2.5}$ related to emission reductions estimated to occur due to the implementation of the standards. We estimate ambient $PM_{2.5}$ and ozone concentrations using the Community Multiscale Air Quality model (CMAQ). This section describes how we converted the CMAQ modeling output into full-season profiles suitable for the health impacts analysis.

6.3.1.4.3.1 General Methodology

First, we extracted hourly, surface-layer PM and ozone concentrations for each grid cell from the standard CMAQ output files. For ozone, these model predictions are used in conjunction with the observed concentrations obtained from the Aerometric Information Retrieval System (AIRS) to generate ozone concentrations for the entire ozone season.[DDDDDDD,EEEEEEE] The predicted changes in ozone concentrations from the future-year base

[DDDDDDD] The ozone season for this analysis is defined as the 5-month period from May to September.

[EEEEEEE] Based on AIRS, there were 961 ozone monitors with sufficient data (*i.e.*, 50 percent or more days reporting at case to future-year control scenario serve as inputs to the health and welfare impact functions of the benefits analysis (*i.e.*, BenMAP).

To estimate ozone-related health effects for the contiguous United States, full-season ozone data are required for every BenMAP grid-cell. Given available ozone monitoring data, we generated full-season ozone profiles for each location in two steps: (1) we combined monitored observations and modeled ozone predictions to interpolate hourly ozone concentrations to a grid of 12-km by 12-km population grid cells for the contiguous 48 states, and (2) we converted these full-season hourly ozone profiles to an ozone measure of interest, such as the daily 8-hour maximum.[FFFFFFF,GGGGGGG]

For $PM_{2.5}$, we also use the model predictions in conjunction with observed monitor data. CMAQ generates predictions of hourly PM species concentrations for every grid. The species include a primary coarse fraction (corresponding to PM in the 2.5 to 10 micron size range), a primary fine fraction (corresponding to PM less than 2.5 microns in diameter), and several secondary particles (*e.g.*, sulfates, nitrates, and organics). $PM_{2.5}$ is calculated as the sum of the primary fine fraction and all of the secondarily formed particles. Future-year estimates of $PM_{2.5}$ were calculated using relative reduction factors (RRFs) applied to 2005 ambient $PM_{2.5}$ and $PM_{2.5}$ species concentrations. A gridded field of $PM_{2.5}$ concentrations was created by interpolating Federal Reference Monitor ambient data and IMPROVE ambient data. Gridded fields of $PM_{2.5}$ species concentrations were created by interpolating EPA speciation network (ESPN) ambient data and IMPROVE data. The ambient data were interpolated to the CMAQ 12 km grid.

The procedures for determining the RRFs are similar to those in EPA's draft guidance for modeling the $PM_{2.5}$ standard (EPA, 2001).[441] The guidance recommends that model predictions be used in a relative sense to estimate changes expected to occur in each major $PM_{2.5}$ species. The procedure for calculating future-year $PM_{2.5}$ design values is called the "Speciated Modeled Attainment Test (SMAT)." EPA used this procedure to estimate the ambient impacts of the final standards.

Table 6.3-12 provides those ozone and $PM_{2.5}$ metrics for grid cells in the modeled domain that enter the health impact functions for health benefits endpoints. The population-weighted average reflects the baseline levels and predicted changes for more populated areas of the nation. This measure better reflects the potential benefits through exposure changes to these populations.

least nine hourly observations per day [8 am to 8 pm] during the ozone season).

[FFFFFFF] The 12-km grid squares contain the population data used in the health benefits analysis model, BenMAP.

[GGGGGGG] This approach is a generalization of planar interpolation that is technically referred to as enhanced Voronoi Neighbor Averaging (EVNA) spatial interpolation. See the BenMAP manual for technical details, available for download at http://www.epa.gov/air/benmap.

Table 6.3-12: Summary of CMAQ-Derived Population-Weighted Ozone and $PM_{2.5}$ Air Quality Metrics for Health Benefits Endpoints Associated with the Final Standards

	2030	
Statistic[a]	Baseline	Change[b]
Ozone Metric: National Population-Weighted Average (ppb)[c]		
Daily Maximum 8-Hour Average Concentration	42.3735	0.0009
$PM_{2.5}$ Metric: National Population-Weighted Average ($\mu g/m^3$)		
Annual Average Concentration	8.1135	-0.0065

Notes:

[a] Ozone and $PM_{2.5}$ metrics are calculated at the CMAQ grid-cell level for use in health effects estimates. Ozone metrics are calculated over relevant time periods during the daylight hours of the "ozone season" (*i.e.*, May through September). Note that the national, population-weighted $PM_{2.5}$ and ozone air quality metrics presented in this chapter represent an average for the entire, gridded U.S. CMAQ domain. These are different than the population-weighted $PM_{2.5}$ and ozone design value metrics presented in Chapter 7, which represent the average for areas with a current air quality monitor.
[b] The change is defined as the control-case value minus the base-case value; a negative value therefore indicates a reduction and a positive value an increase.
[c] Calculated by summing the product of the projected CMAQ grid-cell population and the estimated CMAQ grid cell seasonal ozone concentration and then dividing by the total population.

Emissions and air quality modeling decisions are made early in the analytical process. For this reason, the emission control scenarios used in the air quality and benefits modeling are slightly different than the final emission inventories estimated for the final standards. Please refer to Section 6.2.1 for more information about the inventories used in the air quality modeling that supports the health impacts analysis.

6.3.1.4.4 Methods for Describing Uncertainty

In any complex analysis using estimated parameters and inputs from numerous models, there are likely to be many sources of uncertainty and this analysis is no exception. As outlined both in this and preceding chapters, many inputs were used to derive the estimate of benefits for the final standards, including emission inventories, air quality models (with their associated parameters and inputs), epidemiological health effect estimates, estimates of values (both from WTP and COI studies), population estimates, income estimates, and estimates of the future state of the world (*i.e.*, regulations, technology, and human behavior). Each of these inputs may be uncertain and, depending on its role in the benefits analysis, may have a disproportionately large impact on estimates of total benefits. For example, emissions estimates are used in the first stage of the analysis. As such, any uncertainty in emissions estimates will be propagated through the entire analysis. When compounded with uncertainty in later stages, small uncertainties in emission levels can lead to large impacts on total benefits.

The National Research Council (NRC) (2002, 2008)[442,443] highlighted the need for EPA to conduct rigorous quantitative analysis of uncertainty in its benefits estimates and to present these estimates to decision makers in ways that foster an appropriate appreciation of their inherent uncertainty. In general, the NRC concluded that EPA's general methodology for calculating the benefits of reducing air pollution is reasonable and informative in spite of inherent uncertainties.

Since the publication of these reports, EPA's Office of Air and Radiation (OAR) continues to make progress toward the goal of characterizing the aggregate impact of uncertainty in key modeling elements on both health incidence and benefits estimates in two key ways: Monte Carlo analysis and expert-derived concentration-response functions. In this analysis, we use both of these two methods to assess uncertainty quantitatively, as well as provide a qualitative assessment for those aspects that we are unable to address quantitatively.

First, we used Monte Carlo methods for characterizing random sampling error associated with the concentration response functions from epidemiological studies and random effects modeling to characterize both sampling error and variability across the economic valuation functions. Monte Carlo simulation uses random sampling from distributions of parameters to characterize the effects of uncertainty on output variables, such as incidence of premature mortality. Specifically, we used Monte Carlo methods to generate confidence intervals around the estimated health impact and dollar benefits. The reported standard errors in the epidemiological studies determined the distributions for individual effect estimates.

Second, because characterization of random statistical error omits important sources of uncertainty (*e.g.*, in the functional form of the model—*e.g.*, whether or not a threshold may exist), we also incorporate the results of an expert elicitation on the relationship between premature mortality and ambient $PM_{2.5}$ concentration (Roman et al., 2008).[444] Use of the expert elicitation and incorporation of the standard errors approaches provide insights into the likelihood of different outcomes and about the state of knowledge regarding the benefits estimates. However, there are significant unquantified uncertainties present in upstream inputs including emission and air quality. Both approaches have different strengths and weaknesses, which are fully described in Chapter 5 of the PM NAAQS RIA (U.S. EPA, 2006).

In benefit analyses of air pollution regulations conducted to date, the estimated impact of reductions in premature mortality has accounted for 85 to 95 percent of total monetized benefits. Therefore, it is particularly important to attempt to characterize the uncertainties associated with reductions in premature mortality. The health impact functions used to estimate avoided premature deaths associated with reductions in ozone have associated standard errors that represent the statistical errors around the effect estimates in the underlying epidemiological studies. In our results, we report credible intervals based on these standard errors, reflecting the uncertainty in the estimated change in incidence of avoided premature deaths. We also provide multiple estimates, to reflect model uncertainty between alternative study designs.

For premature mortality associated with exposure to PM, we follow the same approach used in the RIA for 2006 PM NAAQS (U.S. EPA, 2006), presenting two empirical estimates of premature deaths avoided, and a set of twelve estimates based on results of the expert elicitation study. Even these multiple characterizations, including confidence intervals, omit the contribution to overall uncertainty of uncertainty in air quality changes, baseline incidence rates, populations exposed and transferability of the effect estimate to diverse locations. Furthermore, the approach presented here does not yet include methods for addressing correlation between input parameters and the identification of reasonable upper and lower bounds for input distributions characterizing uncertainty in additional model elements. As a result, the reported confidence intervals and range of estimates give an incomplete picture about the overall uncertainty in the estimates. This information should be interpreted within the context of the larger uncertainty surrounding the entire analysis.

In 2006 the EPA requested an NAS study to evaluate the extent to which the epidemiological literature to that point improved the understanding of ozone-related mortality. The NAS found that short-term ozone exposure was likely to contribute to ozone-related mortality (NRC, 2008) and issued a series of recommendations to EPA, including that the Agency should:

1. Present multiple short-term ozone mortality estimates, including those based on multi-city analyses such as the National Morbidity, Mortality and Air Pollution Study (NMMAPS) as well as meta-analytic studies.

2. Report additional risk metrics, including the percentage of baseline mortality attributable to short-term exposure.

3. Remove reference to a no-causal relationship between ozone exposure and premature mortality.

The quantification and presentation of ozone-related premature mortality in this chapter is responsive to these NRC recommendations.

Some key sources of uncertainty in each stage of both the PM and ozone health impact assessment are the following:

- gaps in scientific data and inquiry;

- variability in estimated relationships, such as epidemiological effect estimates, introduced through differences in study design and statistical modeling;

- errors in measurement and projection for variables such as population growth rates;

- errors due to misspecification of model structures, including the use of surrogate variables, such as using PM_{10} when $PM_{2.5}$ is not available, excluded variables, and simplification of complex functions; and

- biases due to omissions or other research limitations.

In Table 6.3-13 we summarize some of the key uncertainties in the benefits analysis.

Table 6.3-13: Primary Sources of Uncertainty in the Benefits Analysis

1. Uncertainties Associated with Impact Functions
- The value of the ozone or PM effect estimate in each impact function. - Application of a single impact function to pollutant changes and populations in all locations. - Similarity of future-year impact functions to current impact functions. - Correct functional form of each impact function. - Extrapolation of effect estimates beyond the range of ozone or PM concentrations observed in the source epidemiological study. - Application of impact functions only to those subpopulations matching the original study population.
2. Uncertainties Associated with CMAQ-Modeled Ozone and PM Concentrations
- Responsiveness of the models to changes in precursor emissions from the control policy. - Projections of future levels of precursor emissions, especially ammonia and crustal materials. - Lack of ozone and $PM_{2.5}$ monitors in all rural areas requires extrapolation of observed ozone data from urban to rural areas.
3. Uncertainties Associated with PM Mortality Risk
- Limited scientific literature supporting a direct biological mechanism for observed epidemiological evidence. - Direct causal agents within the complex mixture of PM have not been identified. - The extent to which adverse health effects are associated with low-level exposures that occur many times in the year versus peak exposures. - The extent to which effects reported in the long-term exposure studies are associated with historically higher levels of PM rather than the levels occurring during the period of study. - Reliability of the $PM_{2.5}$ monitoring data in reflecting actual $PM_{2.5}$ exposures.
4. Uncertainties Associated with Possible Lagged Effects
- The portion of the PM-related long-term exposure mortality effects associated with changes in annual PM levels that would occur in a single year is uncertain as well as the portion that might occur in subsequent years.
5. Uncertainties Associated with Baseline Incidence Rates
- Some baseline incidence rates are not location specific (*e.g.*, those taken from studies) and therefore may not accurately represent the actual location-specific rates. - Current baseline incidence rates may not approximate well baseline incidence rates in 2030. - Projected population and demographics may not represent well future-year population and demographics.
6. Uncertainties Associated with Economic Valuation
- Unit dollar values associated with health and welfare endpoints are only estimates of mean WTP and therefore have uncertainty surrounding them. - Mean WTP (in constant dollars) for each type of risk reduction may differ from current estimates because of differences in income or other factors.
7. Uncertainties Associated with Aggregation of Monetized Benefits
- Health and welfare benefits estimates are limited to the available impact functions. Thus, unquantified or unmonetized benefits are not included.

6.3.2 PM-related Monetized Benefits of the Model Year (MY) Analysis

As described in Chapter 4, the final standards will reduce emissions of several criteria and toxic pollutants and precursors. In the MY analysis, EPA estimates the economic value of the human health benefits associated with reducing $PM_{2.5}$ exposure. Due to analytical limitations, this analysis does not estimate benefits related to other criteria pollutants (such as ozone, NO_2 or SO_2) or toxics pollutants, nor does it monetize all of the potential health and welfare effects associated with $PM_{2.5}$.

The MY analysis uses a "benefit-per-ton" method to estimate a selected suite of $PM_{2.5}$-related health benefits described below. These $PM_{2.5}$-related benefit-per-ton estimates provide the total monetized human health benefits (the sum of premature mortality and premature morbidity) of reducing one ton of directly emitted $PM_{2.5}$, or one ton of a pollutant that contributes to secondarily-formed $PM_{2.5}$ (such as NOx and SOx) from a specified source. Ideally, the human health benefits would be estimated based on changes in ambient $PM_{2.5}$ concentrations and population exposure, as determined by complete air quality and exposure modeling. However, conducting such detailed modeling for the model year analysis was not possible within the timeframe for the final rule. Note that EPA conducted full-scale photochemical air quality modeling for the calendar year analysis. Please refer to Chapter 6.2 for a description of EPA's air quality modeling results and to Chapter 6.3.1 for a description of the quantified and monetized PM- and ozone-related health impacts of the FRM.

Due to analytical limitations, the estimated benefit-per-ton values do not include comparable benefits related to reductions in other ambient concentrations of criteria pollutants (such as ozone, NO_2 or SO_2) or toxic air pollutants, nor do they monetize all of the potential health and welfare effects associated with $PM_{2.5}$ or the other criteria pollutants. As a result, monetizing PM-related health impacts alone underestimates the benefits associated with reductions of the suite of non-GHG pollutants that would be reduced by the final standards.

The dollar-per-ton estimates used to monetize reductions in emissions that contribute to ambient concentrations of $PM_{2.5}$ are provided in Table 6.3-14.

Table 6.3-14 $PM_{2.5}$-related Benefits-per-ton Values (2010$)[a]

Year	All Sources[d]	Upstream (Non-EGU) Sources[d]		Mobile Sources	
	SO_2	NO_X	Direct $PM_{2.5}$	NO_X	Direct $PM_{2.5}$
Dollar-per-ton Derived from American Cancer Society Analysis (Pope et al., 2002) Estimated Using a 3 Percent Discount Rate[c]					
2015	$30,000	$4,900	$230,000	$5,100	$280,000
2020	$33,000	$5,400	$250,000	$5,600	$310,000
2030	$38,000	$6,400	$290,000	$6,700	$370,000
2040	$45,000	$7,600	$340,000	$8,000	$440,000
Dollar-per-ton Derived from American Cancer Society Analysis (Pope et al., 2002) Estimated Using a 7 Percent Discount Rate[c]					
2015	$27,000	$4,500	$210,000	$4,600	$250,000
2020	$30,000	$4,900	$230,000	$5,100	$280,000
2030	$35,000	$5,800	$270,000	$6,100	$330,000
2040	$41,000	$6,900	$310,000	$7,300	$400,000
Dollar-per-ton Derived from Six Cities Analysis (Laden et al., 2006) Estimated Using a 3 Percent Discount Rate[c]					
2015	$73,000	$12,000	$560,000	$12,000	$680,000
2020	$80,000	$13,000	$620,000	$14,000	$750,000
2030	$94,000	$16,000	$720,000	$16,000	$900,000
2040	$110,000	$19,000	$840,000	$20,000	$1,100,000
Dollar-per-ton Derived from Six Cities Analysis (Laden et al., 2006) Estimated Using a 7 Percent Discount Rate[c]					
2015	$66,000	$11,000	$510,000	$11,000	$620,000
2020	$72,000	$12,000	$560,000	$12,000	$680,000
2030	$84,000	$14,000	$650,000	$15,000	$810,000
2040	$99,000	$17,000	$760,000	$18,000	$960,000

[a] Total dollar-per-ton estimates include monetized $PM_{2.5}$-related premature mortality and morbidity endpoints. Range of estimates are a function of the estimate of $PM_{2.5}$-related premature mortality derived from either the ACS study (Pope et al., 2002) or the Six-Cities study (Laden et al., 2006).
[b] Dollar-per-ton values were estimated for the years 2015, 2020, and 2030. For 2040, EPA extrapolated exponentially based on the growth between 2020 and 2030.
[c] The dollar-per-ton estimates presented in this table assume either a 3 percent or 7 percent discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag.
[d] Note that the dollar-per-ton value for SO2 is based on the value for Stationary (Non-EGU) sources; no SO2 value was estimated for mobile sources.

As Table 6.3-14 indicates, EPA projects that the per-ton values for reducing emissions of criteria pollutants from both vehicle use and stationary sources such as fuel refineries and storage facilities will increase over time.[HHHHHHH] These projected increases reflect rising income levels, which are assumed to increase affected individuals' willingness to pay for reduced exposure to health threats from air pollution. They also reflect future population growth and increased life expectancy, which expands the size of the population exposed to air pollution in both urban and rural areas, especially in older age groups with the highest mortality risk.[445,IIIIIII]

For certain $PM_{2.5}$-related pollutants (such as direct $PM_{2.5}$ and NOx), EPA estimates different per-ton values for reducing mobile source emissions than for reductions in emissions of the same pollutant from stationary sources such as fuel refineries and storage facilities. These reflect differences in the typical geographic distributions of emissions of each pollutant by different sources, their contributions to ambient levels of $PM_{2.5}$, and resulting changes in population exposure. EPA applies these separate values to its estimates of changes in emissions from vehicle use and from fuel production and distribution to determine the net change in total economic damages from emissions of those pollutants.

The benefit per-ton technique has been used in previous analyses, including the 2012-2016 Light-Duty Greenhouse Gas Rule,[446] the Ozone National Ambient Air Quality Standards (NAAQS) RIA,[447] the Portland Cement National Emissions Standards for Hazardous Air Pollutants (NESHAP) RIA,[448] and the final NO_2 NAAQS.[449] Table 6.3-15 shows the quantified and monetized $PM_{2.5}$-related co-benefits that are captured in these benefit-per-ton estimates, and also lists other effects that remain un-quantified and are thus excluded from the estimates.

[HHHHHHH] As we discuss in the emissions chapter of EPA's DRIA (Chapter 4), the rule would yield emission reductions from upstream refining and fuel distribution due to decreased petroleum consumption.
[IIIIIII] For more information about EPA's population projections, please refer to the following: http://www.epa.gov/air/benmap/models/BenMAPManualAppendicesAugust2010.pdf (See Appendix K)

Table 6.3-15 Human Health and Welfare Effects of $PM_{2.5}$

Quantified and Monetized in Primary Estimates	Un-quantified Effects Changes in:
Adult premature mortality Bronchitis: chronic and acute Hospital admissions: respiratory and cardiovascular Emergency room visits for asthma Nonfatal heart attacks (myocardial infarction) Lower and upper respiratory illness Minor restricted-activity days Work loss days Asthma exacerbations (asthmatic population) Infant mortality	Subchronic bronchitis cases Low birth weight Pulmonary function Chronic respiratory diseases other than chronic bronchitis Non-asthma respiratory emergency room visits Visibility Household soiling

Consistent with the NO_2 NAAQS,[JJJJJJJ] the benefits estimates utilize concentration-response functions as reported in the epidemiology literature. Readers interested in reviewing the complete methodology for creating the benefit-per-ton estimates used in this analysis can consult the Technical Support Document (TSD)[450] accompanying the final ozone NAAQS RIA. Readers can also refer to Fann et al. (2009)[451] for a detailed description of the benefit-per-ton methodology.[KKKKKKK]

As described above, national per-ton estimates were developed for selected pollutant/source category combinations. The per-ton values calculated therefore apply only to tons reduced from those specific pollutant/source combinations (*e.g.*, NO_2 emitted from mobile sources; direct PM emitted from stationary sources). Our estimate of total $PM_{2.5}$ benefits is therefore based on the total direct $PM_{2.5}$ and $PM_{2.5}$–related precursor emissions (NOx, SOx, and VOCs) controlled from each source and multiplied by the respective per-ton values of reducing emissions from that source.

The benefit-per-ton coefficients in this analysis were derived using modified versions of the health impact functions used in the PM NAAQS Regulatory Impact Analysis. Specifically, this analysis uses the benefit-per-ton estimates first applied in the Portland Cement NESHAP RIA, which incorporated concentration-response functions directly from the epidemiology

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[JJJJJJJ] Although we summarize the main issues in this chapter, we encourage interested readers to see benefits chapter of the NO2 NAAQS for a more detailed description of recent changes to the PM benefits presentation and preference for the no-threshold model.

[KKKKKKK] The values included in this report are different from those presented in the article cited above. Benefits methods change to reflect new information and evaluation of the science. Since publication of the June 2009 article, EPA has made two significant changes to its benefits methods: (1) We no longer assume that a threshold exists in PM-related models of health impacts, which is consistent with the findings reported in published research; and (2) We have revised the Value of a Statistical Life to equal $6.3 million (year 2000$), up from an estimate of $5.5 million (year 2000$) used in the June 2009 report. Please refer to the following website for updates to the dollar-per-ton estimates: http://www.epa.gov/air/benmap/bpt.html studies, without any adjustment for an assumed threshold. Removing the threshold assumption is a key difference between the method used in this analysis to estimate PM co-benefits and the methods used in analyses prior to EPA's Portland Cement NESHAP.[LLLLLLL] As a consequence, the benefit-per-ton estimates used in this analysis include incremental benefits of reductions in $PM_{2.5}$ concentrations down to their lowest modeled levels. This approach is also consistent with EPA's analysis of the 2012-2016 Light-Duty Vehicle Greenhouse Gas rule.

Reductions in PM-related mortality provide the majority of the monetized value in each benefit-per-ton estimate. Typically, the premature mortality-related effect coefficients that underlie the benefits-per-ton estimates are drawn from epidemiology studies that examine two large population cohorts: the American Cancer Society cohort (Pope et al., 2002)[452] and the Harvard Six Cities cohort (Laden et al., 2006).[453] The concentration-response (C-R) function developed from the extended analysis of American Cancer Society (ACS) cohort, as reported in Pope et al. (2002), has previously been used by EPA to generate its primary benefits estimate. The extended analysis of the Harvard Six Cities cohort, as reported by Laden et al (2006), was published after the completion of the Staff Paper for the 2006 $PM_{2.5}$ NAAQS and has been used as an alternative estimate in the $PM_{2.5}$ NAAQS RIA and $PM_{2.5}$ co-benefits estimates in analyses completed since the $PM_{2.5}$ NAAQS.

These studies provide logical choices for co-equal anchor points when presenting PM-related benefits because, while both studies are well designed and peer-reviewed, there are strengths and weaknesses inherent in each. Although EPA's primary method of characterizing PM-related premature mortality is to use both studies to generate a co-equal range of benefits estimates, EPA has chosen to present only the benefit-per-ton value derived from the ACS study in its summary tables of total Model Year costs and benefits (See RIA Chapter 7). This decision was made to provide the reader with summary tables that are easier to understand and interpret and does not convey any preference for one study over the other. We note that this is also the more conservative of the two estimates - PM-related benefits would be approximately 245 percent (or nearly two-and-a-half times) larger had we used the per-ton benefit values based on the Harvard Six Cities study instead. See RIA Chapter 7.3 for the monetized PM-related health impacts of the Model Year analysis.

As is the nature of benefits analyses, assumptions and methods evolve over time to reflect the most current interpretation of the scientific and economic literature. For a period of time

[LLLLLLL] Based on a review of the current body of scientific literature, EPA estimates PM-related mortality without applying an assumed concentration threshold. EPA's Integrated Science Assessment for Particulate Matter (U.S. Environmental Protection Agency. 2009. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment – RTP Division. December), which was reviewed by EPA's Clean Air Scientific Advisory Committee (U.S. Environmental Protection Agency - Science Advisory Board. 2009. Review of EPA's Integrated Science Assessment for Particulate Matter (First External Review Draft, December 2008). EPA-COUNCIL-09-008. May.; U.S. Environmental Protection Agency Science Advisory Board . 2009. Consultation on EPA's Particulate Matter National Ambient Air Quality Standards: Scope and Methods Plan for Health Risk and Exposure Assessment. EPA-COUNCIL-09-009. May), concluded that the scientific literature consistently finds that a no-threshold log-linear model most adequately portrays the PM-mortality concentration-response relationship while recognizing potential uncertainty about the exact shape of the concentration-response function. This assumption is incorporated into the calculation of the PM-related benefits-per-ton values.

(2004-2008), EPA's Office of Air and Radiation (OAR) valued mortality risk reductions using a value of statistical life (VSL) estimate derived from a limited analysis of some of the available studies. OAR arrived at a VSL using a range of $1 million to $10 million (2000$) consistent with two meta-analyses of the wage-risk literature.

The $1 million value represented the lower end of the interquartile range from the Mrozek and Taylor (2002)[454] meta-analysis of 33 studies. The $10 million value represented the upper end of the interquartile range from the Viscusi and Aldy (2003)[455] meta-analysis of 43 studies. The mean estimate of $5.5 million (2000$) was also consistent with the mean VSL of $5.4 million estimated in the Kochi et al. (2006)[456] meta-analysis. However, the Agency neither changed its official guidance on the use of VSL in rulemakings nor subjected the interim estimate to a scientific peer-review process through the Science Advisory Board (SAB) or other peer-review group.

Until updated guidance is available, EPA determined that a single, peer-reviewed estimate applied consistently best reflects the Science Advisory Board Environmental Economics Advisory Committee (SAB-EEAC) advice it has received. Therefore, EPA has decided to apply the VSL that was vetted and endorsed by the SAB in the Guidelines for Preparing Economic Analyses (U.S. EPA, 2000)[457] while they continue efforts to update their guidance on this issue.[MMMMMMM] This approach calculates a mean value across VSL estimates derived from 26 labor market and contingent valuation studies published between 1974 and 1991. The mean VSL across these studies is $6.3 million (2000$). The dollar-per-ton estimates used in this analysis are based on this revised VSL.[NNNNNNN]

The benefit-per-ton estimates are subject to a number of assumptions and uncertainties.

- They do not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors that might lead to an overestimate or underestimate of the actual benefits of controlling fine particulates in specific locations. Please refer to Chapter 6.3.1 for the description of the agency's quantification and monetization of PM- and ozone-related health impacts for the final standards.
- This analysis assumes that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because $PM_{2.5}$ produced via transported precursors emitted from stationary sources may differ significantly from direct $PM_{2.5}$ released from engines and other industrial sources. At the present time, however, no clear scientific grounds exist for supporting differential effects estimates by particle type.
- This analysis assumes that the health impact function for fine particles is linear within the range of ambient concentrations under consideration. Thus, the estimates include health

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[MMMMMMM] In the update of the Economic Guidelines (U.S. EPA, 2011), EPA retained the VSL endorsed by the SAB with the understanding that further updates to the mortality risk valuation guidance would be forthcoming in the near future. The update of the Economic Guidelines is available on the Internet at http://yosemite.epa.gov/ee/epa/eed.nsf/pages/Guidelines.html/$file/Guidelines.pdf.

[NNNNNNN] This value differs from the Department of Transportation's most recent estimate of the value of preventing transportation-related fatalities, which is $6.1 million when expressed in today's (2011) dollars.

benefits from reducing fine particles in areas with varied initial concentrations of $PM_{2.5}$, including both regions that are in attainment with fine particle standard and those that do not meet the standard, down to the lowest modeled concentrations.

- There are several health benefits categories that EPA was unable to quantify due to limitations associated with using benefits-per-ton estimates, several of which could be substantial. Because NO_X and VOC emissions are also precursors to ozone, changes in NO_X and VOC would also impact ozone formation and the health effects associated with ozone exposure. Benefits-per-ton estimates for ozone do not exist due to issues associated with the complexity of the atmospheric air chemistry and nonlinearities associated with ozone formation. The PM-related benefits-per-ton estimates also do not include any human welfare or ecological benefits. Please refer to Chapter 6.3.1 for a description of the unquantified co-pollutant benefits associated with this rulemaking.

As mentioned above, emissions changes and benefits-per-ton estimates alone are not a good indication of local or regional air quality and health impacts, as the localized impacts associated with the rulemaking may vary significantly. Additionally, the atmospheric chemistry related to ambient concentrations of $PM_{2.5}$, ozone and air toxics is very complex. Full-scale photochemical modeling is therefore necessary to provide the needed spatial and temporal detail to more completely and accurately estimate the changes in ambient levels of these pollutants and their associated health and welfare impacts. For this final rule, EPA conducted a national-scale air quality modeling analysis for 2030 to analyze the impacts of the standards on $PM_{2.5}$, ozone, and selected air toxics.

6.4 Changes in Atmospheric CO_2 Concentrations, Global Mean Temperature, Sea Level Rise, and Ocean pH Associated with the Final Rule's GHG Emissions Reductions

6.4.1 Introduction

The impact of GHG emissions on the climate has been reviewed in the NPRM, as well as in the MYs 2012-2016 light-duty rulemaking and the heavy-duty GHG rulemaking. See 76 FR at 75096; 75 FR at 25491; 76 FR at 57294. This section briefly discusses again the issue of climate impacts noting the context of transportation emissions.

Once emitted, GHGs that are the subject of this regulation can remain in the atmosphere for decades to millennia, meaning that 1) their concentrations become well-mixed throughout the global atmosphere regardless of emission origin, and 2) their effects on climate are long lasting. GHG emissions come mainly from the combustion of fossil fuels (coal, oil, and gas), with additional contributions from the clearing of forests, agricultural activities, cement production, and some industrial activities. Transportation activities, in aggregate, were the second largest contributor to total U.S. GHG emissions in 2010 (27 percent of total domestic emissions).[458]

The Administrator relied on thorough and peer-reviewed assessments of climate change science prepared by the Intergovernmental Panel on Climate Change ("IPCC"), the United States Global Change Research Program ("USGCRP"), and the National Research Council of the National Academies ("NRC")[459] as the primary scientific and technical basis for the Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act (74 FR 66496, December 15, 2009). These assessments comprehensively address the scientific issues the Administrator had to examine, providing her both data and information on a wide range of issues pertinent to the Endangerment Finding. These assessments have been rigorously reviewed by the expert community, and also by United States government agencies and scientists, including by EPA itself.

Based on these assessments, the Administrator determined that greenhouse gases cause warming; that levels of greenhouse gases are increasing in the atmosphere due to human activity; the climate is warming; recent warming has been attributed to the increase in greenhouse gases; and that warming of the climate threatens human health and welfare. The Administrator further found that emissions of well-mixed greenhouse gases from new motor vehicles and engines contribute to the air pollution that endangers public health and welfare. Specifically, the Administrator found under section 202 (a) of the Act that six greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride) taken in combination endanger both the public health and the public welfare of current and future generations, and further found that the combined emissions of these greenhouse gases from new motor vehicles and engines contribute to the greenhouse gas air pollution that endangers public health and welfare. The D.C. Circuit recently emphatically upheld the reasonableness of all of these conclusions. See Coalition for Responsible Regulation v. EPA,No. 09-1322 (June 26, 2012) (D.C. Circuit) slip op. p. 30 (upholding all of EPA's findings and stating "EPA had before it substantial record evidence that anthropogenic emissions of greenhouse gases 'very likely' caused warming of the climate over the last several decades. EPA further had evidence of current and future effects of this warming on public health and welfare. Relying again upon substantial scientific evidence, EPA determined that anthropogenically induced climate change threatens both public health and public welfare. It found that extreme weather events, changes in air quality, increases in food- and water-borne pathogens, and increases in temperatures are likely to have adverse health effects. The record also supports EPA's conclusion that climate change endangers human welfare by creating risk to food production and agriculture, forestry, energy, infrastructure, ecosystems, and wildlife. Substantial evidence further supported EPA's conclusion that the warming resulting from the greenhouse gas emissions could be expected to create risks to water resources and in general to coastal areas as a result of expected increase in sea level.")

More recent assessments have reached similar conclusions to those of the assessments upon which the Administrator relied. In May 2010, the NRC published its comprehensive assessment, "Advancing the Science of Climate Change."[460] It concluded that "climate change is occurring, is caused largely by human activities, and poses significant risks for—and in many cases is already affecting—a broad range of human and natural systems." Furthermore, the NRC stated that this conclusion is based on findings that are "consistent with the conclusions of recent assessments by the U.S. Global Change Research Program, the Intergovernmental Panel on Climate Change's Fourth Assessment Report, and other assessments of the state of scientific knowledge on climate change." These are the same assessments that served as the primary scientific references underlying the Administrator's Endangerment Finding. Another NRC assessment, "Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millenia", was published in 2011. This report found that climate change due to carbon dioxide emissions will persist for many centuries. The report also estimates a number of specific climate change impacts, finding that every degree Celsius (C) of warming could lead to increases in the heaviest 15% of daily rainfalls of 3 to 10%, decreases of 5 to 15% in yields for a number of crops (absent adaptation measures that do not presently exist), decreases of Arctic sea ice extent of 25% in September and 15% annually averaged, along with changes in precipitation and streamflow of 5 to 10% in many regions and river basins (increases in some regions, decreases in others). The assessment also found that for an increase of 4 degrees C nearly all land areas would experience summers warmer than all but 5% of summers in the 20^{th} century, that for an increase of 1 to 2 degrees C the area burnt by wildfires in western North America will likely more than double, that for an increase of 3 degrees C the sea level will rise 1.6 to 3.3 feet by 2100, and that coral bleaching and erosion will increase due both to warming and ocean acidification,. The assessment notes that many important aspects of climate change are difficult to quantify but that the risk of adverse impacts is likely to increase with increasing temperature, and that the risk of abrupt climate changes can be expected to increase with the duration and magnitude of the warming.

In the 2010 report cited above, the NRC stated that some of the largest potential risks associated with future climate change may come not from relatively smooth changes that are reasonably well understood, but from extreme events, abrupt changes, and surprises that might occur when climate or environmental system thresholds are crossed. Examples cited as warranting more research include the release of large quantities of GHGs stored in permafrost (frozen soils) across the Arctic, rapid disintegration of the major ice sheets, irreversible drying and desertification in the subtropics, changes in ocean circulation, and the rapid release of destabilized methane hydrates in the oceans.

On ocean acidification, the same report noted the potential for broad, “catastrophic” impacts on marine ecosystems. Ocean acidity has increased 25 percent since pre-industrial times, and is projected to continue increasing. By the time atmospheric CO_2 content doubles over its preindustrial value, there would be virtually no place left in the ocean that can sustain coral reef growth. Ocean acidification could have dramatic consequences for polar food webs including salmon, the report said.

Importantly, these recent NRC assessments represent another independent and critical inquiry of the state of climate change science, separate and apart from the previous IPCC and USGCRP assessments.

Based on modeling analysis performed by the EPA, reductions in CO_2 and other GHG emissions associated with this final rule will affect future climate change. Since GHGs are well-mixed in the atmosphere and have long atmospheric lifetimes, changes in GHG emissions will affect atmospheric concentrations of greenhouse gases and future climate for decades to millennia, depending on the gas. This section provides estimates of the projected change in atmospheric CO_2 concentrations based on the emission reductions estimated for this rule, compared to the reference case. In addition, this section analyzes the response to the changes in GHG concentrations of the following climate-related variables: global mean temperature, sea level rise, and ocean pH. See Chapter 4 in this RIA for the estimated net GHG emissions reductions over time.[OOOOOOO]

6.4.2 Projected Change in Atmospheric CO_2 Concentrations, Global Mean Surface Temperature and Sea Level Rise

To assess the impact of the emissions reductions from the finalrule, EPA estimated changes in projected atmospheric CO_2 concentrations, global mean surface temperature and sea-level rise to 2100 using the GCAM (Global Change Assessment Model, formerly MiniCAM), integrated assessment model[PPPPPPP,461] coupled with the MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change) simple climate model.[QQQQQQQ,462,463] GCAM was used to create the globally and temporally consistent set of climate relevant emissions required for running MAGICC. MAGICC was then used to estimate the projected change in relevant climate variables over time. Given the magnitude of the estimated emissions reductions associated with this rule, a simple climate model such as MAGICC is appropriate for estimating the atmospheric and climate response.

6.4.2.1 Methodology

Emissions reductions associated with this rule were evaluated with respect to a reference case. An emissions scenario was developed by applying the estimated emissions reductions from the rule to the GCAM reference (no climate policy) scenario (used as the basis for the Representative Concentration Pathway RCP4.5).[464] Specifically, the annual upstream and downstream CO_2, N_2O, CH_4, HFC-134a, NOx, CO, and SO_2 emissions reductions estimated from this rule were applied as net reductions to the GCAM global baseline net emissions for each

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[OOOOOOO] Due to timing constraints, the modeling analysis in this section was conducted with preliminary estimates of the emissions reductions projected from the final rule, which were highly similar to the final estimates presented in Chapter 4 of this RIA. For example, the final projected CO_2 emissions reductions for most years in the 2017-2050 time period were roughly one-tenth of a percent smaller than the preliminary estimates. The preliminary emissions reduction projections are available in the docket (see "Emissions for MAGICC modeling" in Docket EPA-HQ-OAR-2010-0799).

[PPPPPPP] GCAM is a long-term, global integrated assessment model of energy, economy, agriculture and land use that considers the sources of emissions of a suite of greenhouse gases (GHG's), emitted in 14 globally disaggregated regions, the fate of emissions to the atmosphere, and the consequences of changing concentrations of greenhouse related gases for climate change. GCAM begins with a representation of demographic and economic developments in each region and combines these with assumptions about technology development to describe an internally consistent representation of energy, agriculture, land-use, and economic developments that in turn shape global emissions.

[QQQQQQQ] MAGICC consists of a suite of coupled gas-cycle, climate and ice-melt models integrated into a single framework. The framework allows the user to determine changes in greenhouse-gas concentrations, global-mean surface air temperature and sea-level resulting from anthropogenic emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), reactive gases (CO, NOx, VOCs), the halocarbons (e.g. HCFCs, HFCs, PFCs) and sulfur dioxide (SO_2). MAGICC emulates the global-mean temperature responses of more sophisticated coupled Atmosphere/Ocean General Circulation Models (AOGCMs) with high accuracy.

substance.[RRRRRRR] The emissions reductions past calendar year 2050 for all emissions were scaled with total U.S. road transportation fuel consumption from the GCAM reference scenario. Road transport fuel consumption past 2050 does not change significantly and thus emissions reductions remain relatively constant from 2050 through 2100.

The GCAM reference scenario[465] depicts a world in which global population reaches a maximum of more than 9 billion in 2065 and then declines to 8.7 billion in 2100 while global GDP grows by an order of magnitude and global energy consumption triples. The reference scenario includes no explicit policies to limit carbon emissions, and therefore fossil fuels continue to dominate global energy consumption, despite substantial growth in nuclear and renewable energy. Atmospheric CO_2 concentrations rise throughout the century and reach 760 to 820 ppmv by 2100, depending on climatic parameters, with total radiative forcing increasing more than 5 Watts per square meter (W/m^2) above 1990 levels by 2100. Forest land declines in the reference scenario to accommodate increases in land use for food and bioenergy crops. Even with the assumed agricultural productivity increases, the amount of land devoted to crops increases in the first half of the century due to increases in population and income (higher income drives increases in land-intensive meat consumption). After 2050 the rate of growth in food demand slows, in part due to declining population. As a result the amount of cropland and also land use change (LUC) emissions decline as agricultural crop productivity continues to increase.

The GCAM reference scenario uses non-CO_2 GHG and non-GHG emissions implemented as described in Smith and Wigley (2006); land-use change emissions as described in Wise et al. (2009); and updated base-year estimates of global GHG emissions. This scenario was created as part of the Climate Change Science Program (CCSP) effort to develop a set of long-term global emissions scenarios that incorporate an update of economic and technology data and utilize improved scenario development tools compared to the IPCC Special Report on Emissions Scenarios (SRES) (IPCC 2000).

Using MAGICC 5.3 v2,[466] the change in atmospheric CO_2 concentrations, global mean temperature, and sea level were projected at five-year time steps to 2100 for both the reference (no climate policy) scenario and the emissions reduction scenario specific to the rule. To capture some of the uncertainty in the climate system, the changes in projected atmospheric CO_2 concentrations, global mean temperature and sea level were estimated across the most current Intergovernmental Panel on Climate Change (IPCC) range of climate sensitivities, 1.5°C to 6.0°C.[SSSSSSS] The range as illustrated in Chapter 10, Box 10.2, Figure 2 of the IPCC's Working

[RRRRRRR] Due to timing constraints, the modeling analysis in this section was conducted with preliminary estimates of the emissions reductions projected from the final rule, which were highly similar to the final estimates presented in Chapter 4 of this RIA. For example, the final projected CO_2 emissions reductions for most years in the 2017-2050 time period were roughly one-tenth of a percent smaller than the preliminary estimates. The preliminary emissions reduction projections are available in the docket (see "Emissions for MAGICC modeling" in Docket EPA-HQ-OAR-2010-0799), and the files used as inputs for the MAGICC model are also available (see "MAGICC Input File (policy)" and "MAGICC Input File (reference)").

[SSSSSSS] In IPCC reports, equilibrium climate sensitivity refers to the equilibrium change in the annual mean global surface temperature following a doubling of the atmospheric equivalent carbon dioxide concentration. The IPCC states that climate sensitivity is "likely" to be in the range of 2°C to 4.5°C, "very unlikely" to be less than 1.5°C, and

Group I is approximately consistent with the 10-90% probability distribution of the individual cumulative distributions of climate sensitivity.[467] Other uncertainties, such as uncertainties regarding the carbon cycle, ocean heat uptake, reference emissions scenarios, or aerosol forcing, were not addressed.

MAGICC calculates the forcing response at the global scale from changes in atmospheric concentrations of CO_2, CH_4, N_2O, HFCs, and tropospheric ozone. It also includes the effects of temperature changes on stratospheric ozone and the effects of CH_4 emissions on stratospheric water vapor. Changes in CH_4, NOx, VOC, and CO emissions affect both O_3 concentrations and CH_4 concentrations. MAGICC includes the relative climate forcing effects of changes in sulfate concentrations due to changing SO_2 emissions, including both the direct effect of sulfate particles and the indirect effects related to cloud interactions. However, MAGICC does not calculate the effect of changes in concentrations of other aerosols such as nitrates, black carbon, or organic carbon, making the assumption that the sulfate cooling effect is a proxy for the sum of all the aerosol effects. Therefore, the climate effects of changes in PM2.5 emissions and precursors (besides SO_2) presented in Chapter 4 were not included in the calculations in this chapter. MAGICC also calculates all climate effects at the global scale. This global scale captures the climate effects of the long-lived, well-mixed greenhouse gases, but does not address the fact that short-lived climate forcers such as aerosols and ozone can have effects that vary with location and timing of emissions. Black carbon in particular is known to cause a positive forcing or warming effect by absorbing incoming solar radiation, but there are uncertainties about the magnitude of that warming effect and the interaction of black carbon (and other co-emitted aerosol species) with clouds. See 77 FR 38890, 38991-993 (June 29, 2012). While black carbon is likely to be an important contributor to climate change, it would be premature to include quantification of black carbon climate impacts in an analysis of the standards. See generally, EPA, Response to Comments to the Endangerment Finding Vol. 9 section 9.1.6.1[468], the discussion of black carbon in the endangerment finding at 74 FR at 66520, EPA's discussion in the recent proposal to revise the PM NAAQS (77 FR at 38991-993), and the recently published EPA Report to Congress on Black Carbon[469]. Additionally, the magnitude of PM2.5 emissions changes (and therefore, black carbon emission changes) related to these standards are small in comparison to the changes in the pollutants which have been included in the MAGICC model simulations.

To compute the changes in atmospheric CO_2 concentration, global mean temperature, and sea level rise specifically attributable to the impacts of the rule, the emissions reductions from this rule were applied to the GCAM reference emissions scenario. As a result of the emissions reductions from the rule relative to the reference case, by 2100 the concentration of atmospheric CO_2 is projected to be reduced by approximately 3.2 to 3.6 parts per million by volume (ppmv), the global mean temperature is projected to be reduced by approximately 0.007-0.018°C, and global mean sea level rise is projected to be reduced by approximately 0.07-0.16 cm[TTTTTTT]. For

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"values substantially higher than 4.5°C cannot be excluded." IPCC WGI, 2007, *Climate Change 2007 - The Physical Science Basis,* Contribution of Working Group I to the Fourth Assessment Report of the IPCC, http://www.ipcc.ch/.
[TTTTTTT] More complete results from the MAGICC modeling can be found in the docket (see " Supporting Document for MAGICC Analysis " in Docket EPA-HQ-OAR-2010-0799).

sea level rise, the calculations in MAGICC do not include the possible effects of accelerated ice flow in Greenland and/or Antarctica.

Figure 6.4-1 provides the results over time for the estimated reductions in atmospheric CO_2 concentration associated with the rule compared to the reference case. Figure 6.4-2 provides the estimated change in projected global mean temperatures associated with the rule. Figure 6.4-3 provides the estimated reductions in global mean sea level rise associated with the rule. The range of reductions in global mean temperature and sea level rise due to uncertainty in climate sensitivity is larger than that for CO_2 concentrations because CO_2 concentrations are only weakly coupled to climate sensitivity through the dependence on temperature of the rate of ocean absorption of CO_2, whereas the magnitude of temperature change response to CO_2 changes (and therefore sea level rise) is more tightly coupled to climate sensitivity in the MAGICC model.

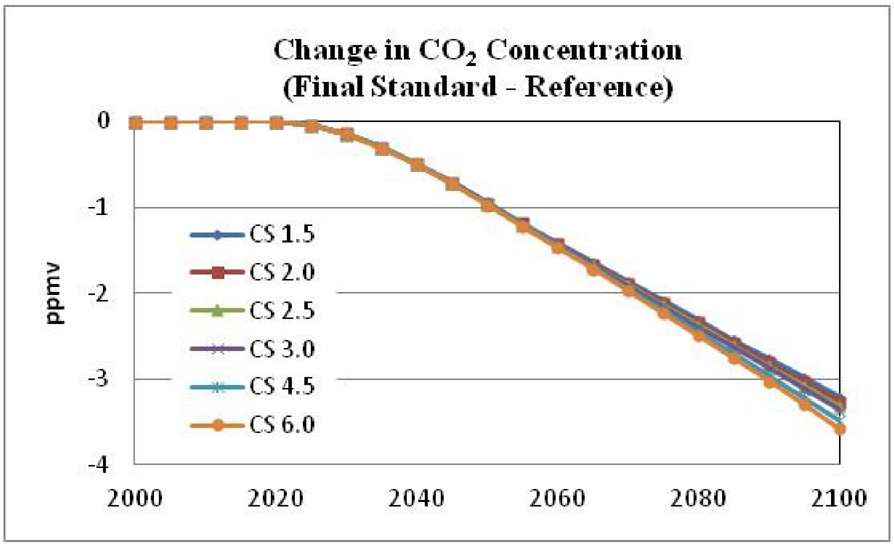

Figure 6.4-1 Projected Reductions in Atmospheric CO_2 Concentrations (parts per million by volume) from the MY 2017-2025 Standards (climate sensitivity (CS) cases ranging from 1.5-6.0°C)

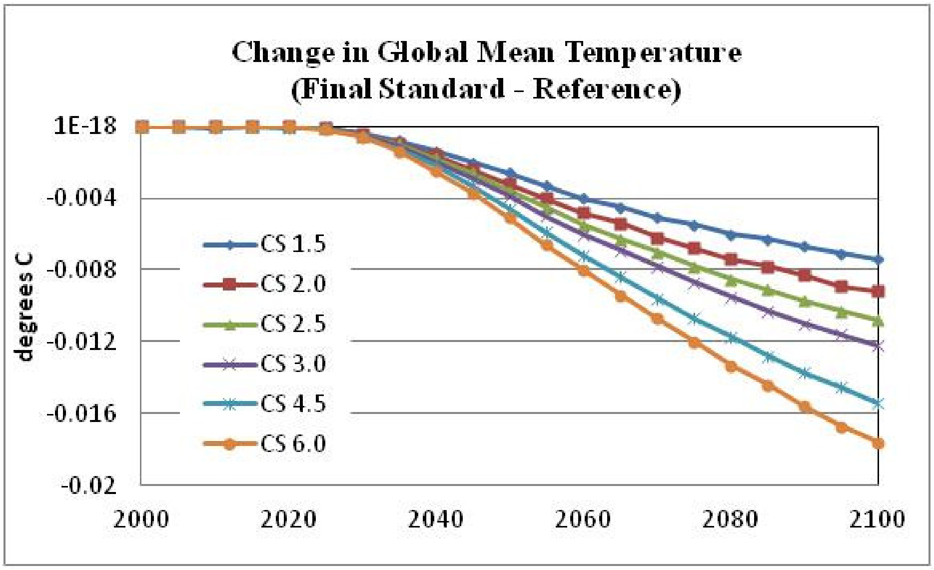

Figure 6.4-2 Projected Reductions in Global Mean Surface Temperatures from MY 2017-2025 Standards (climate sensitivity (CS) cases ranging from 1.5-6.0°C)

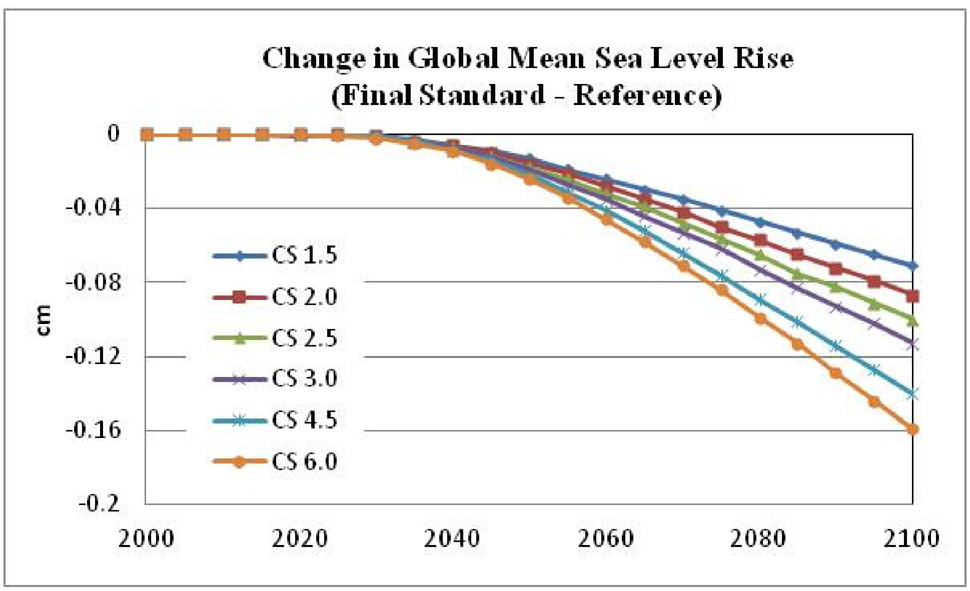

Figure 6.4-3 Projected Reductions in Global Mean Sea Level Rise from the MY 2017-2025 Standards (climate sensitivity (CS) cases ranging from 1.5-6.0°C)

The results in Figure 6.4-2 and Figure 6.4-3 show reductions in the projected global mean temperature and sea level respectively, across all climate sensitivities. The projected reductions are small relative to the overall expected increase in temperature (1.8 – 4.8 ºC) and sea level rise (23 – 56 cm) projected by the baseline GCAM reference case simulated by MAGICC from 1990 to 2100. However, this is to be expected given the magnitude of emissions reductions expected from the rule in the context of global emissions. Again, it should be noted that the calculations in MAGICC do not include the possible effects of accelerated ice flow in Greenland and/or Antarctica: the recent NRC report estimated a likely sea level increase for the business-as-usual A1B SRES scenario of 0.5 to 1.0 meters, almost double the estimate from MAGICC, so projected reductions in sea level rise may be similarly underestimated.[470] If other uncertainties besides climate sensitivity were included in the analysis, the resulting ranges of projected changes would likely be slightly larger.

6.4.3 Projected Change in Ocean pH

For this rule, EPA analyzes another key climate-related variable and calculates projected change in ocean pH for tropical waters. For this analysis, changes in ocean pH are related to the change in the atmospheric concentration of carbon dioxide (CO_2) resulting from the emissions reductions associated with the rule.[UUUUUUU] EPA used the program developed for CO2 System Calculations CO2SYS,[471] version 1.05, a program which performs calculations relating parameters of the carbon dioxide (CO_2) system in seawater. The program was developed by Ernie Lewis at Brookhaven National Laboratory and Doug Wallace at the Institut für Meereskunde in Germany, supported by the U.S. Department of Energy, Office of Biological and Environmental Research, under Contract No. DE-ACO2-76CH00016.

The CO2SYS program uses two of the four measurable parameters of the CO_2 system [total alkalinity (TA), total inorganic CO_2 (TC), pH, and either fugacity (fCO_2) or partial pressure of CO_2 (pCO_2)] to calculate the other two parameters given a specific set of input conditions (temperature and pressure) and output conditions chosen by the user. EPA utilized the DOS version (Lewis and Wallace, 1998)[472] of the program to compute pH for three scenarios: the reference scenario at a climate sensitivity of 3 degrees for which the CO_2 concentrations was calculated to be 784.868 in 2100, the rule relative to the baseline with a CO_2 concentration of 781.503, and a calculation for 1990 with a CO_2 concentration of 353.633.

Using the set of seawater parameters detailed below, the EPA calculated pH levels for the three scenarios. The pH of the emissions standards relative to the reference scenario pH was +0.0017 pH units (more basic). For comparison, the difference between the reference scenario in 2100 and the pH in 1990 was -0.30 pH units (more acidic).

The CO2SYS program required the input of a number of variables and constants for each scenario for calculating the result for both the reference case and the rule's emissions reduction

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[UUUUUUU] Due to timing constraints, the modeling analysis in this section was conducted with preliminary estimates of the CO_2 emissions reductions projected from the final rule, which were highly similar to the final estimates presented in Chapter 4 of this RIA. The final projected CO_2 emissions reductions for most years in the 2017-2050 time period were roughly one-tenth of a percent smaller than the preliminary estimates. The preliminary CO_2 emissions reduction projections are available in the docket (see "Emissions for MAGICC modeling" in Docket EPA-HQ-OAR-2010-0799).

case. EPA used the following inputs, with justification and references for these inputs provided in brackets:

1) Input mode: Single-input [This simply means that the program calculates pH for one set of input variables at a time, instead of a batch of variables. The choice has no affect on results].

2) Choice of constants: Mehrbach et al. (1973)[473], refit by Dickson and Millero (1987)[474]

3) Choice of fCO2 or pCO2: pCO2 [pCO2 is the partial pressure of CO2 and can be converted to fugacity (fCO2) if desired]

4) Choice of KSO4: Dickson (1990)[475] [Lewis and Wallace (1998)[476] recommend using the equation of Dickson (1990) for this dissociation constant. The model also allows the use of the equation of Khoo et al. (1977).[477] Switching this parameter to Khoo et al. (1977) instead of Dickson (1990) had no effect on the calculated result].

5) Choice of pH scale: Total scale [The model allows pH outputs to be provided on the total scale, the seawater scale, the free scale, and the National Bureau of Standards (NBS) scale. The various pH scales can be interrelated using equations provided by Lewis and Wallace (1998)].

The program provides several choices of constants for saltwater that are needed for the calculations. EPA calculated pH values using all choices and found that in all cases the choice had an indistinguishable effect on the results. In addition, EPA ran the model using a variety of other required input values to test whether the model was sensitive to these inputs. EPA found the model was not sensitive to these inputs in terms of the incremental change in pH calculated for each climate sensitivity case. The input values are derived from certified reference materials of sterilized natural sea water (Dickson, 2003, 2005, and 2009).[478] Based on the projected atmospheric CO_2 concentration reductions that would result from this rule (3.37 ppmv for a climate sensitivity of 3.0), the modeling program calculates an increase in ocean pH of approximately 0.0017 pH units in 2100. Thus, this analysis indicates the projected decrease in atmospheric CO_2 concentrations from the standards yields an increase in ocean pH (i.e., a reduction in the expected acidification of ocean pH in the reference case). Table 6.4-1 contains the projected changes in ocean pH based the change in atmospheric CO_2 concentrations that were derived from the MAGICC modeling.

Table 6.4-1 Impact of the MY 2017-2025 Standards On Ocean pH

CLIMATE SENSITIVITY	DIFFERENCE IN CO_2 IN 2100	YEAR	PROJECTED pH CHANGE
3.0	-3.37 ppm	2100	+0.0017

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6.4.4 Summary of Climate Analyses

EPA's analysis of the impact of the emissions reductions from this rule on global climate conditions is intended to quantify these potential reductions using the best available science. While EPA's modeling results of the impact of this rule alone show small differences in climate effects (CO_2 concentration, global mean temperature, sea level rise, and ocean pH), in comparison to the total projected changes, they yield results that are repeatable and directionally consistent within the modeling frameworks used. The results are summarized in Table 6.4-2, Impact of MY 2017-2025 GHG Standards On Projected Changes in Global Climate.

These projected reductions are proportionally representative of changes to U.S. GHG emissions in the transportation sector. While not formally estimated for this rule, a reduction in projected global mean temperature change, sea level rise, and ocean acidification implies a reduction in the risks associated with climate change. The figures for these variables illustrate that across a range of climate sensitivities projected global mean temperature and sea level increase less in the emissions reduction scenario than in the reference (no climate policy) case, and the ocean does not become as acidic as it does in the reference case. The benefits of GHG emissions reductions can be characterized both qualitatively and quantitatively, some of which can be monetized (see Chapter 7). There are substantial uncertainties in modeling the global risks of climate change, which complicates quantification and cost-benefits assessments. Changes in climate variables such as temperature are a meaningful proxy for changes in the risk of most potential impacts--including those that can be monetized, and those that have not been monetized but can be quantified in physical terms (e.g., water availability), as well as those that have not yet been quantified or are extremely difficult to quantify (e.g., forest disturbance and catastrophic events such as collapse of large ice sheets and subsequent sea level rise).

Table 6.4-2 Impact of MY 2017-2025 GHG Standards On Projected Changes in Global Climate (based on a range of climate sensitivities from 1.5-6°C)

VARIABLE	UNITS	YEAR	PROJECTED CHANGE
Atmospheric CO_2 Concentration	ppmv	2100	-3.21 to -3.58
Global Mean Surface Temperature	ºC	2100	-0.0074 to -0.0176
Sea Level Rise	cm	2100	-0.071 to -0.159
Ocean pH	pH units	2100	+0.0017[a]

[a] The value for projected change in ocean pH is based on a climate sensitivity of 3.0.

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7 Other Economic and Social Impacts

This Chapter presents a summary of the total costs and benefits of EPA's final GHG standards.

For several reasons, the estimates for costs and benefits presented by NHTSA and EPA, while consistent, are not directly comparable, and thus should not be expected to be identical. Most important, NHTSA and EPA's standards will require different fuel efficiency improvements. EPA's final GHG standard is more stringent in part reflecting our projections regarding manufacturers' use of air conditioning leakage credits, which result from reductions in air conditioning-related emissions of HFCs. NHTSA is finalizing standards at levels of stringency that assume improvements in the efficiency of air conditioning systems, but that do not account for reductions in HFCs, which are not related to fuel economy or energy conservation. In addition, the CAFE and GHG standards offer somewhat different program flexibilities and provisions, and the agencies' analyses differ in their accounting for these flexibilities (examples include the treatment of EVs, dual-fueled vehicles, and transfer of credits between car and truck fleets), primarily because NHTSA is statutorily prohibited from considering some flexibilities when establishing CAFE standards,[VVVVVVV] while EPA is not limited in establishing standards under the Clean Air Act. Also, manufacturers may opt to pay a civil penalty in lieu of actually meeting CAFE standards, but they cannot pay civil penalties to avoid complying with EPA's GHG standards. Some manufacturers have traditionally paid CAFE penalties instead of complying with the CAFE standards. These differences contribute to differences in the agencies' respective estimates of costs and benefits resulting from the new standards. Nevertheless, it is important to note that NHTSA and EPA have reasonably harmonized the programs, and the continuation of the National Program will result in significant cost and other advantages for the automobile industry by allowing them to manufacture one fleet of vehicles across the U.S., rather than comply with potentially multiple state standards that may occur in the absence of the National Program. We also note that this summary of costs and benefits of EPA's GHG standards does not change the fact that both the CAFE and GHG standards, jointly, will be the source of the benefits and costs of the National Program. These costs and benefits are appropriately analyzed separately by each agency and should not be added together.

For the reader's reference, Table 7.1-1 below summarizes the values of a number of joint economic and other values that the agencies used to estimate the overall costs and benefits associated with each agency's standard. Note, however, that the values presented in this table are summaries of the inputs used for the agencies' respective models. See Joint TSD Chapter 4 for expanded discussion and details on each of these joint economic and other values.

This Chapter also includes an expanded description of the agency's approach to the monetization of GHG emission reductions and benefits from less frequent refueling. Though the underlying monetary unit values for CO_2 reductions are consistent with those used in

[VVVVVVV] *See* 49 U.S.C. 32902(h).

NHTSA's analysis of the final CAFE standards, the specific stream of CO_2-related benefits are unique to each program and EPA's benefits are therefore presented in section 7.1. While EPA's methodology for estimating benefits due to reduced refueling time are similar to NHTSA's, the agencies' assumptions for fuel tank sizing are unique, as described in section 7.2, to ensure internal consistency in the respective technology penetration models.

Table 7.1-1 Joint Economic and other Values for Benefits Computations (2010$)

VMT Rebound Effect	10%
"Gap" between test and on-road MPG for liquid-fueled vehicles	20%
"Gap" between test and on-road wall electricity consumption for electric and plug-in hybrid electric vehicles	30%
Annual growth in average vehicle use	0.6%
Fuel Prices (2017-50 average, $/gallon)	
Retail gasoline price	$4.13
Pre-tax gasoline price	$3.78
Economic Benefits from Reducing Oil Imports ($/gallon)	
"Monopsony" Component	$ 0.00
Macroeconomic Disruption Component	$ 0.197 in 2025
Military/SPR Component	$ 0.00
Total Economic Costs ($/gallon)	$ 0.197 in 2025
Emission Damage Costs (2020, $/short ton, 3% discount rate)	
Carbon monoxide	$ 0
Nitrogen oxides (NO_X) – vehicle use	$ 5,600
Nitrogen oxides (NO_X) – fuel production and distribution	$ 5,400
Particulate matter ($PM_{2.5}$) – vehicle use	$ 310,000
Particulate matter ($PM_{2.5}$) – fuel production and distribution	$ 250,000
Sulfur dioxide (SO_2)	$ 33,000
Annual CO_2 Damage Cost (per metric ton)	Variable, depending on discount rate and year (see RIA Chapter 7.1 below)
External Costs from Additional Automobile Use ($/vehicle-mile)	
Congestion	$ 0.056
Accidents	$ 0.024
Noise	$ 0.001
Total External Costs	$ 0.081
External Costs from Additional Light Truck Use	

($/vehicle-mile)	
Congestion	$0.050
Accidents	$0.027
Noise	$0.001
Total External Costs	$ 0.078
Discount Rates Applied to Future Benefits	3%, 7%

7.1 Monetized GHG Estimates

We assigned a dollar value to reductions in carbon dioxide (CO_2) emissions using recent estimates of the "social cost of carbon" (SCC) in the primary benefits analysis for this rule. The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change. The SCC estimates used in this analysis were developed through an interagency process that included EPA, DOT/NHTSA, and other executive branch entities, and concluded in February 2010. The SCC Technical Support Document (SCC TSD) provides a complete discussion of the methods used to develop these SCC estimates.[479]

The interagency group selected four SCC values for use in regulatory analyses, which we have applied in this analysis: $5, $22, $37, and $68 per metric ton of CO_2 emissions[wwwwwww] in the year 2010, and in 2010 dollars. The first three values are based on the average SCC from three integrated assessment models, at discount rates of 5, 3, and 2.5 percent, respectively. SCCs at several discount rates are included because the literature shows that the SCC is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context. The fourth value is the 95th percentile of the SCC from all three models at a 3 percent discount rate. It is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. Low probability, high impact events are incorporated into all of the SCC values through explicit consideration of their effects in two of the three models as well as the use of a probability density function for equilibrium climate sensitivity in all three models. Treating climate sensitivity probabilistically allows the estimation of SCC at higher temperature outcomes, which lead to higher projections of damages.

The SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. Note that the interagency group estimated the growth rate of the

[wwwwwww] The SCC estimates were converted from 2008 dollars to 2010 dollars using a GDP price deflator (1.02). (EPA originally updated the interagency SCC estimates from 2007 to 2008 dollars in the 2012-2016 light-duty GHG rulemaking using a GDP price deflator of 1.021). All price deflators were obtained from the Bureau of Economic Analysis, National Income and Product Accounts Table 1.1.4, *Price Indexes for Gross Domestic Product*.

SCC directly using the three integrated assessment models rather than assuming a constant annual growth rate. This helps to ensure that the estimates are internally consistent with other modeling assumptions. Table 7.1-2 presents the SCC estimates used in this analysis.

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A recent report from the National Academies of Science (NRC 2009) points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages.[480] As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

The interagency group noted a number of limitations to the SCC analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. The limited amount of research linking climate impacts to economic damages makes the interagency modeling exercise even more difficult.

Commenters generally expressed support for using SCC to value reductions in CO_2 emissions, while also discussing its limitations and offering recommendations directed at improving estimates. One commenter, though, disagreed with the use of SCC. However, as discussed in III.H.6 and IV.X of the preamble, the SCC estimates were developed using a defensible set of input assumptions that are grounded in the existing literature. As noted in the SCC TSD, the U.S. government intends to revise these estimates over time, taking into account new research findings that were not available in 2010. See the preamble (III.H.6) and EPA's Response to Comments document (section 18.4.1) for a summary of the public comments and EPA's detailed response.

Applying the global SCC estimates, shown in Table 7.1-2, to the estimated reductions in CO_2 emissions under the final standards, we estimate the dollar value of the CO_2-related benefits for each analysis year in our primary benefits analysis. For internal consistency, the annual benefits are discounted back to net present value terms using the same discount rate as each SCC estimate (i.e. 5%, 3%, and 2.5%) rather than 3% and 7%.[XXXXXXX] The SCC estimates and the associated CO_2 benefit estimates for each calendar year are shown in Tables 7.1-3.

[XXXXXXX] It is possible that other benefits or costs of this rule unrelated to CO_2 emissions will be discounted at rates that differ from those used to develop the SCC estimates.

Table 7.1-2 Social Cost of CO_2 2017-2050[a] (2010 dollars)

YEAR	DISCOUNT RATE AND STATISTIC			
	5% AVERAGE	3% AVERAGE	2.5% AVERAGE	3% 95TH PERCENTILE
2017	$6	$26	$41	$79
2020	$7	$27	$43	$84
2025	$9	$31	$48	$94
2030	$10	$34	$52	$104
2035	$12	$37	$56	$114
2040	$13	$41	$61	$124
2045	$15	$44	$64	$133
2050	$16	$47	$68	$142

[a] The SCC values are dollar-year and emissions-year specific.

Table 7.1-3 Undiscounted Annual Upstream and Downstream CO_2 Benefits for the Given SCC Value, and CO_2 Benefits Discounted back to 2012, Calendar Year Analysis[a] (Millions of 2010 dollars)

YEAR	5% (AVERAGE SCC = $6 IN 2017)	3% (AVERAGE SCC = $26 IN 2017)	2.5% (AVERAGE SCC = $41 IN 2017)	3% (95TH PERCENTILE = $79 IN 2017)
2017	$13.6	$54.6	$87.3	$167
2018	$44.3	$176	$280	$538
2019	$93.3	$365	$581	$1,120
2020	$164	$633	$1,000	$1,940
2021	$273	$1,040	$1,640	$3,180
2022	$419	$1,560	$2,460	$4,790
2023	$600	$2,200	$3,450	$6,750
2024	$819	$2,960	$4,620	$9,070
2025	$1,080	$3,840	$5,970	$11,800
2026	$1,350	$4,740	$7,330	$14,500
2027	$1,620	$5,640	$8,710	$17,300
2028	$1,910	$6,560	$10,100	$20,100
2029	$2,200	$7,480	$11,500	$22,900
2030	$2,500	$8,410	$12,900	$25,700
2031	$2,810	$9,340	$14,200	$28,500
2032	$3,110	$10,200	$15,600	$31,300
2033	$3,420	$11,100	$16,900	$34,000
2034	$3,720	$12,000	$18,200	$36,700
2035	$4,030	$12,900	$19,400	$39,300
2036	$4,330	$13,800	$20,700	$41,900
2037	$4,630	$14,600	$21,900	$44,500
2038	$4,930	$15,400	$23,100	$47,000
2039	$5,220	$16,200	$24,200	$49,400
2040	$5,510	$17,000	$25,400	$51,800
2041	$5,810	$17,800	$26,400	$54,100
2042	$6,100	$18,500	$27,400	$56,300
2043	$6,390	$19,200	$28,400	$58,500

2044	$6,690	$20,000	$29,400	$60,700
2045	$6,980	$20,700	$30,300	$62,800
2046	$7,280	$21,400	$31,300	$65,000
2047	$7,590	$22,200	$32,300	$67,300
2048	$7,900	$22,900	$33,300	$69,500
2049	$8,220	$23,700	$34,300	$71,800
2050	$8,540	$24,400	$35,400	$74,100
NPV[b]	$32,400	$170,000	$290,000	$519,000

[a] Except for the last row (net present value), the SCC values are dollar-year and emissions-year specific.
[b] Net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to SCC TSD for more detail.

One limitation relevant to the primary benefits analysis is that it does not include the valuation of non-CO_2 GHG impacts (i.e., CH_4, N_2O, and HFCs). The interagency group did not directly estimate the social costs of non-CO_2 GHG emissions when it developed the current social cost of CO_2 values. Moreover, the group determined that it would not transform the CO_2 estimates into estimates for non-CO_2 GHGs using global warming potentials (GWPs), which measure the ability of different gases to trap heat in the atmosphere (i.e., radiative forcing per unit of mass) over a particular timeframe relative to CO_2. Recognizing that non-CO_2 GHG impacts associated with this rulemaking (net reductions in CH_4, N_2O, and HFCs) would provide economic benefits to society, however, EPA requested comment on a methodology to value such impacts. Several commenters strongly recommended that EPA value non-CO_2 GHG impacts associated with this final rule. See the preamble (III.H.6) and EPA's Response to Comments document (section 18.4.1) for a summary of the public comments and EPA's detailed response.

One way to approximate the value of marginal non-CO_2 GHG emission reductions in the absence of direct model estimates is to convert the reductions to CO_2-equivalents which may then be valued using the SCC. Conversion to CO_2-e is typically done using the GWP for the non-CO_2 gas; we refer to this method as the "GWP approach." The GWP is an aggregate measure that approximates the additional energy trapped in the atmosphere over a given timeframe from a perturbation of a non-CO_2 gas relative to CO_2. The time horizon most commonly used is 100 years. One potential problem with utilizing temporally aggregated statistics, such as the GWPs, is that the additional radiative forcing from the GHG perturbation is not constant over time and any differences in temporal dynamics between gases will be lost.

While the GWP approach provides an approximation of the monetized value of the non-CO_2 GHG reductions anticipated from this rule, it produces estimates that are less accurate than those obtained from direct model computations for a variety of reasons, including the differences in atmospheric lifetime of non-CO_2 gases relative to CO_2. This is a potentially confounding issue given that the social cost of GHGs is based on a discounted stream of damages—i.e., they are not constant over time—and that are non-linear in temperature. For example, CH_4 has an expected adjusted atmospheric lifetime of about 12 years and associated GWP of 25 (IPCC Fourth Assessment Report (AR4) 100-year GWP estimate). Gases with a relatively shorter lifetime, such as methane, have impacts that occur primarily in the near term and thus are not discounted as heavily as those caused by longer-lived gases, such as CO_2, while the GWP treats additional forcing the same independent of when it occurs in time. Furthermore, the baseline temperature change is lower in the near term and therefore the additional warming from relatively short-lived gases will have a lower marginal impact relative to longer-lived gases that have an impact further out in the future when baseline warming is higher. The GWP also relies on an arbitrary time horizon and constant concentration scenario, both of which are inconsistent with the assumptions used by the SCC interagency workgroup. Finally, impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike CH_4, N_2O, or HFCs, will result in CO_2 passive fertilization to plants.

A limited number of studies in the published literature explore the differences in the social benefit estimates from the GWP approach and direct modeling. One recent working paper (Marten and Newbold, 2011) found that the GWP-weighted benefit estimates for CH_4 and N_2O are likely to be lower than those that would be derived using a directly modeled social cost of these gases for a variety of reasons.[481] This conclusion is reached using the 100 year GWP coefficients as put forth in the IPCC Fourth Assessment Report (CH_4 is 25, N_2O is 298). The GWP reflects only the integrated radiative forcing of a gas over 100 years. In contrast, the directly modeled social cost differs from the GWP because the differences in timing of the warming between gases are explicitly modeled, the non-linear effects of temperature change on economic damages are included, and rather than treating all impacts over a hundred years equally, the modeled social cost applies a discount rate but calculates impacts through the year 2300.

EPA also undertook a literature search for estimates of the marginal social cost of non-CO_2 GHGs. A range of these estimates are available in published literature (Fankhauser (1994)[482], Kandlikar (1995)[483], Hammitt et al. (1996)[484], Tol et al. (2003)[485], Tol (2004)[486], Hope (2005)[487] and Hope and Newbery (2008)[488]. Most of these estimates are based upon modeling assumptions that are dated and inconsistent with the current SCC estimates. Some of these studies focused on, for example, marginal methane reductions in the 1990s and early 2000s and report estimates for only the single year of interest specific to the study. The assumptions underlying the social cost of non-CO_2 GHG estimates available in the literature differ from those agreed upon by the SCC interagency group and in many cases use older versions of the integrated assessment models. Without additional analysis, the non-CO_2 GHG benefit estimates available in the current literature are not acceptable to use to value the non-CO_2 GHG reductions finalized in this rulemaking.

In the absence of direct model estimates from the interagency analysis, EPA has conducted a sensitivity analysis using the GWP approach to estimate the benefits associated with reductions of three non-CO_2 GHGs in each calendar year. These estimates are presented for illustrative purposes and therefore not included in the total benefits estimate for the rulemaking. EPA recently used this approach to estimate the CH_4 benefits in the New Source Performance Standards final rule for oil and gas exploration (77 FR at 49535) and views the GWP approach as an interim method for analysis until we develop values for non-CO_2

GHGs.[YYYYYYY] Estimates for this rulemaking are given below for illustrative purposes and represent the CO_2-e estimate of CH_4, N_2O, and HFC reductions multiplied by the SCC estimates. CO_2-e is calculated using the AR4 100-year GWP of each gas: CH_4 (25), N_2O (298), and HFC-134a (1,430).[ZZZZZZZ] The total net present value of the annual 2017 through 2050 GHG benefits for this rulemaking would increase by about $3 billion to $50 billion, depending on discount rate, or roughly 10 percent if these non-CO_2 estimates were included. Given the magnitude of this increase in the context of the total costs and benefits considered in this rule and other critical decision factors related to technical issues, inclusion of these estimates in the primary analysis would not affect any of the decisions regarding the appropriateness of the standards EPA is adopting here. The estimates are provided in the tables below.

Table 7.1-4 Undiscounted Annual Upstream and Downstream Non-CO_2 GHG Benefits for the Given SCC Value, and Non-CO_2 GHG Benefits Discounted back to 2012, Calendar Year Analysis[a] (Millions of 2010 dollars)

YEAR	EMISSION REDUCTIONS (MMT CO2-E)			TOTAL NON-CO2 GHG BENEFITS ($ MILLIONS)			
	CH4	N2O	HFC-134A	5% (Ave)	3% (Ave)	2.5% (Ave)	3% (95th)
2017	0.0	0.00	0.2	$2	$7	$12	$22
2018	0.2	0.00	0.9	$7	$29	$46	$88
2019	0.3	0.01	2.0	$16	$62	$99	$191
2020	0.5	0.01	3.4	$28	$107	$170	$330
2021	0.9	0.02	5.1	$44	$168	$265	$514
2022	1.3	0.03	6.8	$62	$233	$366	$713
2023	1.8	0.04	8.4	$82	$301	$472	$923
2024	2.3	0.05	10.0	$103	$374	$583	$1,140
2025	3.0	0.06	11.6	$126	$450	$699	$1,380
2026	3.5	0.07	13.1	$150	$527	$816	$1,610
2027	4.1	0.08	14.6	$174	$604	$933	$1,850
2028	4.7	0.09	16.0	$199	$682	$1,050	$2,090
2029	5.2	0.10	17.4	$224	$760	$1,170	$2,320
2030	5.8	0.11	18.7	$250	$838	$1,280	$2,560

[YYYYYYY] See http://www.epa.gov/airquality/oilandgas/actions.html for details about the final oil and gas NSPS rule.

[ZZZZZZZ] As in the MY 2012-2016 LD rules and in the MY 2014-2018 MD and HD rule, the global warming potentials (GWP) used in this rulemaking are consistent with the 100-year time frame values in the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). At this time, the 100-year GWP values from the 1995 IPCC Second Assessment Report (SAR) are used in the official U.S. GHG inventory submission to the United Nations Framework Convention on Climate Change (UNFCCC) (per the reporting requirements under that international convention) . The UNFCCC recently agreed on revisions to the national GHG inventory reporting requirements, and will begin using the 100-year GWP values from AR4 for inventory submissions in the future. According to the AR4, CH_4 has a 100-year GWP of 25, N_2O has a 100-year GWP of 298, and HFC-134a has a 100-year GWP of 1430.

2031	6.3	0.12	19.9	$275	$916	$1,400	$2,800
2032	6.7	0.13	21.1	$301	$992	$1,510	$3,030
2033	7.2	0.14	22.2	$327	$1,070	$1,620	$3,250
2034	7.6	0.15	23.2	$353	$1,140	$1,720	$3,480
2035	8.0	0.15	24.2	$378	$1,210	$1,830	$3,690
2036	8.4	0.16	25.1	$403	$1,280	$1,930	$3,910
2037	8.7	0.16	25.9	$429	$1,350	$2,030	$4,120
2038	9.1	0.17	26.7	$453	$1,420	$2,120	$4,320
2039	9.4	0.17	27.4	$478	$1,490	$2,220	$4,520
2040	9.7	0.18	28.2	$503	$1,550	$2,310	$4,720
2041	9.9	0.18	28.8	$527	$1,610	$2,400	$4,910
2042	10.2	0.19	29.5	$552	$1,680	$2,480	$5,090
2043	10.5	0.19	30.1	$578	$1,740	$2,560	$5,280
2044	10.7	0.19	30.8	$603	$1,800	$2,650	$5,470
2045	10.9	0.20	31.4	$629	$1,860	$2,730	$5,660
2046	11.2	0.20	32.0	$655	$1,930	$2,820	$5,850
2047	11.4	0.21	32.6	$682	$1,990	$2,910	$6,050
2048	11.6	0.21	33.3	$710	$2,060	$2,990	$6,240
2049	11.9	0.21	33.9	$738	$2,120	$3,080	$6,450
2050	12.1	0.22	34.6	$767	$2,190	$3,170	$6,650
NPV[b]				$3,120	$16,300	$27,700	$49,600

[a] Except for the last row (net present value), the SCC values are dollar-year and emissions-year specific.
[b] Net present value of reduced GHG emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to SCC TSD for more detail.

In addition to the primary benefits analysis of CO_2 impacts in each calendar year, we conducted a separate analysis of the CO_2 benefits over the model year lifetimes of the 2017 through 2025 model year vehicles. In contrast to the calendar year analysis, the model year lifetime analysis shows the impacts of the final standards on each of these MY fleets over the course of its lifetime. Full details of the inputs to this analysis can be found in Chapter 4 of this RIA. The CO_2 benefits of the full life of each of the nine model years from 2017 through 2025 are shown in Table 7.1-4 through Table 7.1-7 for each of the four different SCC values. The CO_2 benefits are shown for each year in the model year life and in net present value. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency.

Table 7.1-5 Undiscounted Annual Upstream and Downstream CO_2 Benefits for the 5% (Average SCC) Value, CO_2 Benefits Discounted back to the 1st Year of each MY, and Sum of Values Across MYs, Model Year Analysis[a] (Millions of 2010 dollars)

YEAR	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	SUM
2017	$14	$0	$0	$0	$0	$0	$0	$0	$0	
2018	$14	$31	$0	$0	$0	$0	$0	$0	$0	
2019	$14	$31	$49	$0	$0	$0	$0	$0	$0	
2020	$13	$31	$49	$71	$0	$0	$0	$0	$0	
2021	$14	$31	$49	$71	$109	$0	$0	$0	$0	
2022	$14	$31	$49	$72	$108	$145	$0	$0	$0	
2023	$14	$31	$50	$71	$109	$144	$181	$0	$0	
2024	$13	$31	$50	$72	$109	$145	$180	$220	$0	

2025	$12	$28	$49	$72	$109	$144	$180	$219	$262	
2026	$12	$28	$46	$71	$109	$144	$179	$219	$260	
2027	$12	$27	$45	$66	$106	$144	$179	$217	$260	
2028	$11	$26	$44	$64	$100	$140	$179	$217	$258	
2029	$11	$25	$42	$63	$98	$131	$174	$217	$257	
2030	$10	$23	$40	$60	$94	$128	$162	$210	$256	
2031	$9	$22	$37	$57	$90	$124	$159	$196	$248	
2032	$8	$20	$35	$53	$85	$118	$153	$192	$232	
2033	$7	$18	$32	$49	$80	$111	$145	$185	$226	
2034	$6	$16	$29	$45	$74	$104	$137	$175	$218	
2035	$5	$14	$25	$41	$68	$96	$128	$165	$206	
2036	$4	$12	$22	$36	$61	$89	$119	$154	$194	
2037	$3	$9	$18	$31	$54	$80	$109	$142	$182	
2038	$3	$8	$15	$26	$47	$71	$99	$131	$168	
2039	$2	$6	$12	$22	$40	$62	$87	$118	$154	
2040	$2	$5	$10	$17	$33	$52	$76	$105	$139	
2041	$1	$4	$8	$14	$27	$44	$64	$91	$123	
2042	$1	$3	$7	$12	$22	$35	$54	$77	$107	
2043	$1	$3	$6	$10	$18	$29	$44	$64	$90	
2044	$1	$3	$5	$8	$15	$24	$36	$53	$75	
2045	$1	$2	$5	$7	$13	$20	$30	$43	$62	
2046	$1	$2	$4	$7	$12	$17	$25	$36	$50	
2047	$0	$2	$3	$6	$11	$16	$22	$30	$42	
2048	$0	$1	$3	$5	$10	$14	$19	$26	$35	
2049	$0	$1	$2	$5	$8	$13	$18	$23	$30	
2050	$0	$1	$2	$3	$8	$11	$16	$21	$27	
NPV, 5%	$152	$344	$551	$794	$1,210	$1,590	$1,970	$2,380	$2,820	$11,800

[a] The SCC values are dollar-year and emissions-year specific. The full vehicle lifetimes for vehicles extend beyond 2050, see TSD Chapter 4 for details. As a result, annual data extend beyond calendar year 2050 (i.e., estimates go to year 2053 for the 2017MY and to 2061 for the 2025MY). These data are not shown but are included in the NPV values. In the absence of SCC estimates for years beyond 2050, EPA has used the SCC for year 2050 to calculate CO2 benefits in years 2051 through 2061. As discussed above, the SCC increases over time, meaning that the year 2050 SCC value is lower than the directly modeled estimates of SCC for years after 2050.

Table 7.1-6 Undiscounted Annual Upstream and Downstream CO_2 Benefits for the 3% (Average SCC) SCC Value, CO_2 Benefits Discounted back tothe 1st Year of each MY, and Sum of Values Across MYs, Model Year Analysis[a] (Millions of 2010 dollars)

YEAR	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	SUM
2017	$55	$0	$0	$0	$0	$0	$0	$0	$0	
2018	$54	$122	$0	$0	$0	$0	$0	$0	$0	
2019	$53	$119	$193	$0	$0	$0	$0	$0	$0	
2020	$52	$118	$188	$274	$0	$0	$0	$0	$0	
2021	$52	$116	$187	$269	$413	$0	$0	$0	$0	
2022	$51	$115	$184	$267	$405	$541	$0	$0	$0	
2023	$50	$114	$182	$262	$401	$530	$665	$0	$0	
2024	$45	$111	$181	$260	$394	$525	$650	$798	$0	
2025	$44	$101	$175	$257	$390	$514	$643	$780	$936	
2026	$43	$99	$160	$248	$385	$509	$631	$771	$915	
2027	$40	$95	$156	$228	$370	$502	$623	$755	$904	
2028	$38	$90	$149	$221	$342	$482	$615	$746	$885	
2029	$36	$84	$141	$212	$331	$445	$590	$736	$874	
2030	$33	$78	$133	$200	$317	$431	$545	$705	$862	
2031	$30	$72	$123	$188	$298	$412	$528	$652	$825	
2032	$27	$66	$113	$175	$279	$388	$504	$631	$762	
2033	$23	$59	$103	$161	$260	$363	$474	$602	$738	
2034	$20	$52	$93	$147	$238	$337	$443	$566	$703	
2035	$16	$44	$81	$132	$217	$309	$411	$529	$661	
2036	$13	$37	$70	$115	$195	$282	$377	$491	$618	
2037	$10	$30	$58	$99	$172	$253	$343	$449	$573	
2038	$8	$24	$47	$82	$148	$223	$308	$409	$524	
2039	$6	$19	$38	$67	$124	$192	$272	$367	$478	
2040	$5	$16	$30	$54	$102	$161	$234	$324	$428	
2041	$4	$13	$25	$43	$83	$133	$196	$279	$377	
2042	$4	$11	$20	$35	$67	$108	$162	$233	$324	
2043	$3	$9	$17	$29	$55	$87	$131	$193	$272	
2044	$3	$8	$15	$24	$46	$72	$106	$157	$225	
2045	$2	$7	$13	$21	$39	$60	$89	$127	$182	
2046	$2	$6	$12	$19	$34	$51	$73	$106	$148	
2047	$1	$6	$10	$17	$32	$45	$63	$88	$123	
2048	$1	$3	$9	$15	$28	$42	$56	$75	$102	
2049	$1	$3	$6	$13	$24	$36	$51	$67	$88	
2050	$1	$3	$5	$8	$22	$32	$45	$61	$78	
NPV, 3%	$642	$1,440	$2,270	$3,230	$4,850	$6,330	$7,740	$9,260	$10,800	$46,600

[a] The SCC values are dollar-year and emissions-year specific. The full vehicle lifetimes for vehicles extend beyond 2050, see TSD 4 for details. As a result, annual data extend beyond calendar year 2050 (i.e., estimates go to year 2053 for the 2017MY and to 2061 for the 2025MY). These data are not shown but are included in the NPV values. In the absence of SCC estimates for years beyond 2050, EPA has used the SCC for year 2050 to calculate CO2 benefits in years 2051 through 2061. As discussed above, the SCC increases over time, meaning that the year 2050 SCC value is lower than the directly modeled estimates of SCC for years after 2050.

Table 7.1-7 Undiscounted Annual Upstream and Downstream CO_2 Benefits for the from 2.5% (Average SCC) SCC Value, CO_2 Benefits Discounted back tothe 1st Year of each MY, and Sum of Values Across MYs, Model Year Analysis[a] (Millions of 2010 dollars)

YEAR	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	SUM
2017	$87	$0	$0	$0	$0	$0	$0	$0	$0	
2018	$85	$195	$0	$0	$0	$0	$0	$0	$0	
2019	$84	$190	$307	$0	$0	$0	$0	$0	$0	
2020	$82	$187	$299	$434	$0	$0	$0	$0	$0	
2021	$81	$183	$296	$425	$653	$0	$0	$0	$0	
2022	$80	$181	$289	$420	$637	$851	$0	$0	$0	
2023	$78	$179	$286	$411	$629	$829	$1,040	$0	$0	
2024	$71	$173	$282	$405	$614	$818	$1,010	$1,240	$0	
2025	$69	$157	$271	$399	$606	$799	$1,000	$1,210	$1,450	
2026	$66	$152	$248	$385	$596	$788	$976	$1,190	$1,420	
2027	$62	$146	$240	$352	$571	$775	$962	$1,170	$1,390	
2028	$59	$138	$230	$340	$525	$741	$946	$1,150	$1,360	
2029	$55	$129	$216	$325	$508	$683	$904	$1,130	$1,340	
2030	$50	$120	$203	$306	$484	$659	$833	$1,080	$1,320	
2031	$46	$110	$188	$287	$454	$628	$804	$993	$1,260	
2032	$41	$100	$172	$266	$425	$589	$765	$958	$1,160	
2033	$36	$89	$157	$244	$393	$550	$718	$912	$1,120	
2034	$30	$78	$140	$222	$360	$510	$670	$855	$1,060	
2035	$25	$67	$123	$198	$327	$466	$620	$798	$996	
2036	$20	$55	$105	$173	$293	$424	$567	$738	$929	
2037	$15	$45	$87	$148	$257	$379	$515	$674	$860	
2038	$12	$36	$71	$123	$221	$333	$461	$613	$785	
2039	$10	$28	$57	$100	$185	$286	$405	$548	$713	
2040	$8	$23	$45	$80	$152	$240	$349	$482	$638	
2041	$6	$19	$37	$64	$123	$197	$291	$414	$560	
2042	$5	$16	$30	$52	$99	$159	$240	$346	$480	
2043	$5	$14	$25	$43	$82	$128	$194	$285	$401	
2044	$4	$12	$22	$36	$67	$106	$156	$230	$331	
2045	$3	$11	$20	$31	$57	$88	$130	$186	$268	
2046	$3	$9	$17	$28	$50	$75	$107	$155	$216	
2047	$1	$8	$15	$24	$46	$66	$92	$128	$180	
2048	$1	$5	$13	$21	$40	$60	$81	$109	$149	
2049	$1	$4	$8	$19	$35	$53	$74	$97	$127	
2050	$1	$4	$8	$12	$32	$47	$65	$89	$113	
NPV, 2.5%	$1,040	$2,320	$3,660	$5,190	$7,760	$10,100	$12,300	$14,700	$17,100	$74,100

[a] The SCC values are dollar-year and emissions-year specific. The full vehicle lifetimes for vehicles extend beyond 2050, see TSD 4 for details. As a result, annual data extend beyond calendar year 2050 (i.e., estimates go to year 2053 for the 2017MY and to 2061 for the 2025MY). These data are not shown but are included in the NPV values. In the absence of SCC estimates for years beyond 2050, EPA has used the SCC for year 2050 to calculate CO2 benefits in years 2051 through 2061. As discussed above, the SCC increases over time, meaning that the year 2050 SCC value is lower than the directly modeled estimates of SCC for years after 2050.

Table 7.1-8 Undiscounted Annual Upstream and Downstream CO_2 Benefits for the 3% (95th Percentile) SCC Value, CO_2 Benefits Discounted back tothe 1st Year of each MY, and Sum of Values Across MYs, Model Year Analysis[a] (Millions of 2010 dollars)

YEAR	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	SUM
2017	$167	$0	$0	$0	$0	$0	$0	$0	$0	
2018	$164	$374	$0	$0	$0	$0	$0	$0	$0	
2019	$163	$366	$592	$0	$0	$0	$0	$0	$0	
2020	$159	$363	$578	$841	$0	$0	$0	$0	$0	
2021	$158	$356	$575	$825	$1,270	$0	$0	$0	$0	
2022	$157	$353	$564	$819	$1,240	$1,660	$0	$0	$0	
2023	$153	$349	$559	$804	$1,230	$1,620	$2,040	$0	$0	
2024	$139	$339	$553	$795	$1,210	$1,610	$1,990	$2,440	$0	
2025	$135	$310	$535	$786	$1,190	$1,570	$1,970	$2,390	$2,860	
2026	$130	$301	$490	$760	$1,180	$1,560	$1,930	$2,360	$2,800	
2027	$124	$289	$476	$697	$1,130	$1,540	$1,910	$2,310	$2,760	
2028	$116	$273	$456	$676	$1,040	$1,470	$1,880	$2,280	$2,700	
2029	$109	$257	$431	$648	$1,010	$1,360	$1,800	$2,250	$2,670	
2030	$100	$239	$405	$612	$967	$1,320	$1,660	$2,150	$2,630	
2031	$91	$220	$377	$574	$910	$1,260	$1,610	$1,990	$2,520	
2032	$82	$201	$346	$534	$853	$1,180	$1,540	$1,920	$2,330	
2033	$71	$180	$316	$490	$792	$1,110	$1,450	$1,840	$2,250	
2034	$61	$158	$283	$447	$726	$1,030	$1,350	$1,720	$2,140	
2035	$50	$135	$248	$401	$661	$942	$1,250	$1,610	$2,010	
2036	$40	$112	$212	$352	$594	$858	$1,150	$1,500	$1,880	
2037	$31	$91	$176	$301	$522	$770	$1,050	$1,370	$1,750	
2038	$25	$73	$144	$250	$450	$678	$939	$1,250	$1,600	
2039	$20	$58	$115	$205	$376	$584	$827	$1,120	$1,450	
2040	$16	$47	$92	$164	$311	$490	$712	$985	$1,300	
2041	$13	$39	$75	$131	$251	$404	$597	$847	$1,150	
2042	$11	$32	$62	$107	$202	$327	$493	$710	$986	
2043	$10	$28	$52	$88	$168	$264	$399	$587	$826	
2044	$8	$25	$45	$74	$139	$220	$323	$476	$684	
2045	$7	$22	$41	$65	$118	$182	$269	$385	$554	
2046	$6	$19	$35	$58	$105	$155	$223	$321	$448	
2047	$3	$17	$31	$51	$96	$137	$191	$266	$374	
2048	$3	$10	$28	$45	$84	$126	$169	$228	$310	
2049	$2	$9	$17	$40	$74	$110	$155	$202	$266	
2050	$2	$8	$16	$25	$67	$97	$136	$186	$236	
NPV, 3%	$1,970	$4,390	$6,950	$9,880	$14,800	$19,300	$23,600	$28,300	$33,000	$142,000

[a] The SCC values are dollar-year and emissions-year specific. The full vehicle lifetimes for vehicles extend beyond 2050, see TSD 4 for details. As a result, annual data extend beyond calendar year 2050 (i.e., estimates go to year 2053 for the 2017MY and to 2061 for the 2025MY). These data are not shown but are included in the NPV values. In the absence of SCC estimates for years beyond 2050, EPA has used the SCC for year 2050 to calculate CO2 benefits in years 2051 through 2061. As discussed above, the SCC increases over time, meaning that the year 2050 SCC value is lower than the directly modeled estimates of SCC for years after 2050.

7.2 The Benefits Due to Reduced Refueling Time

The total time spent pumping and paying for fuel, and driving to and from fueling stations, represents an economic cost to drivers and other vehicle occupants. Increased driving range provides a benefit to individuals arising from the value of the time saved when refueling cycles are eliminated. As described in this section, the EPA calculates this benefit by applying DOT-recommended values of travel time savings to estimates of how much time is saved.

NHTSA submitted the refueling benefits section of Chapter 4 of the NPRM Joint TSD to peer review. The three reviewers were generally supportive of the analysis methodology, while one reviewer made several suggestions for potentially improving the quality of the results. EPA believed that one of these suggestions, if implemented, would have the potential to substantially influence the results. Therefore EPA conducted a supplemental analysis to evaluate the feasibility of forecasting the range of future vehicles by performing a regression on the historical data for fuel economy and tank size. Based on the results of this supplemental analysis, which is described in this section, and considering recent trends in the range and fuel tank size of newly released vehicles, EPA has judged that there is not sufficient justification for modifying the NPRM methodology.

7.2.1 Relationship between tank size, fuel economy, and range

The increases in fuel economy resulting from this rule are expected to lead to some increase in vehicle driving range. The extent of this increase depends on manufacturers' decisions to apply reduced fuel consumption requirements towards increasing range, rather than reducing tank size while maintaining range. In MY 2010, fuel tanks were sized such that the average driving range was 537 miles for passenger cars and 511 miles for light trucks, as shown in Figure 7.2-1 below. Nearly all MY 2010 vehicles have a driving range of at least 350 miles, and many vehicles, in particular cars with high fuel economy, have ranges much greater than this.

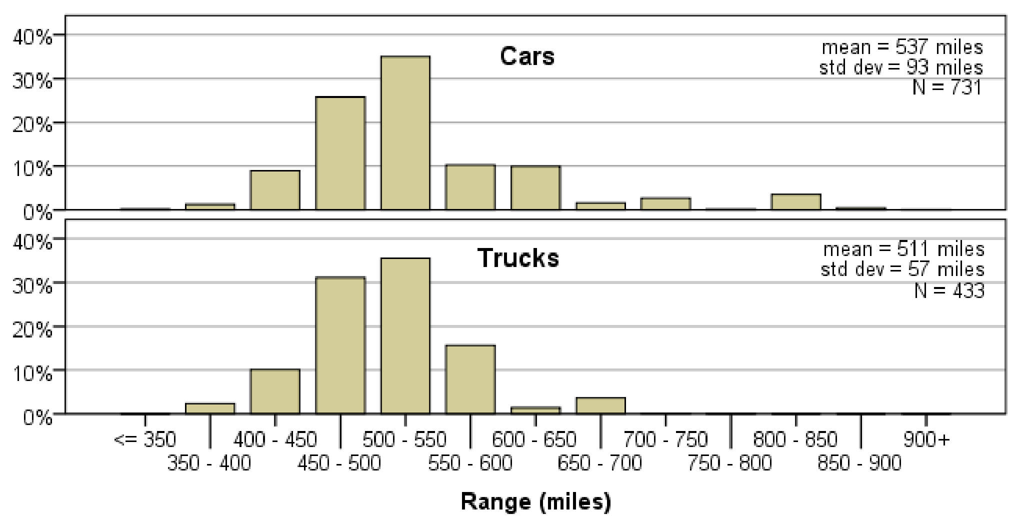

Figure 7.2-1 Distribution of driving range for MY 2010 vehicles (sales-weighted)

For the final rule, EPA investigated the relationship between range and fuel economy, using data for MY 2010 vehicles summarized above. The goal of this analysis was to forecast manufacturer decisions regarding tank size and range, given the fuel economy improvements that will occur as a result of this rule. At vehicle redesign, manufacturers typically size fuel tanks considering the available packaging space, driving range, cargo and passenger space (utility), mass targets, and other factors. As fuel economy improves, manufacturers may opt at the time of vehicle redesign to reduce tank size in order to achieve moderate mass reduction at a small cost savings, while sacrificing some customer utility from the foregone improvements in range.

EPA performed a regression of range vs. fuel economy using several strategies of categorizing vehicles, including vehicle type (car or truck), market class, and footprint. Of these categorizing strategies, the analysis showed that a clear range vs. fuel economy relationship is most evident when vehicles with similar footprint values are grouped. The apparent relationship between vehicle footprint and manufacturer tank-sizing decisions is consistent with the limitation imposed on manufacturers for fuel tank packaging, which depends the under-floor space available. Fuel tanks are often designed by manufacturers to be used across multiple vehicle configurations sharing a platform. EPA assumes that manufacturers make tank-sizing decisions considering the least efficient vehicle on a shared tank platform, since that vehicle configuration will have the lowest range. Therefore, only these vehicles were included in the regression analysis, the results of which are presented in Figure 7.2-2 and Table 7.2-1 below. Note that within each footprint category, the difference between car and truck groups was not found to be statistically significant, so both vehicle types were considered together.

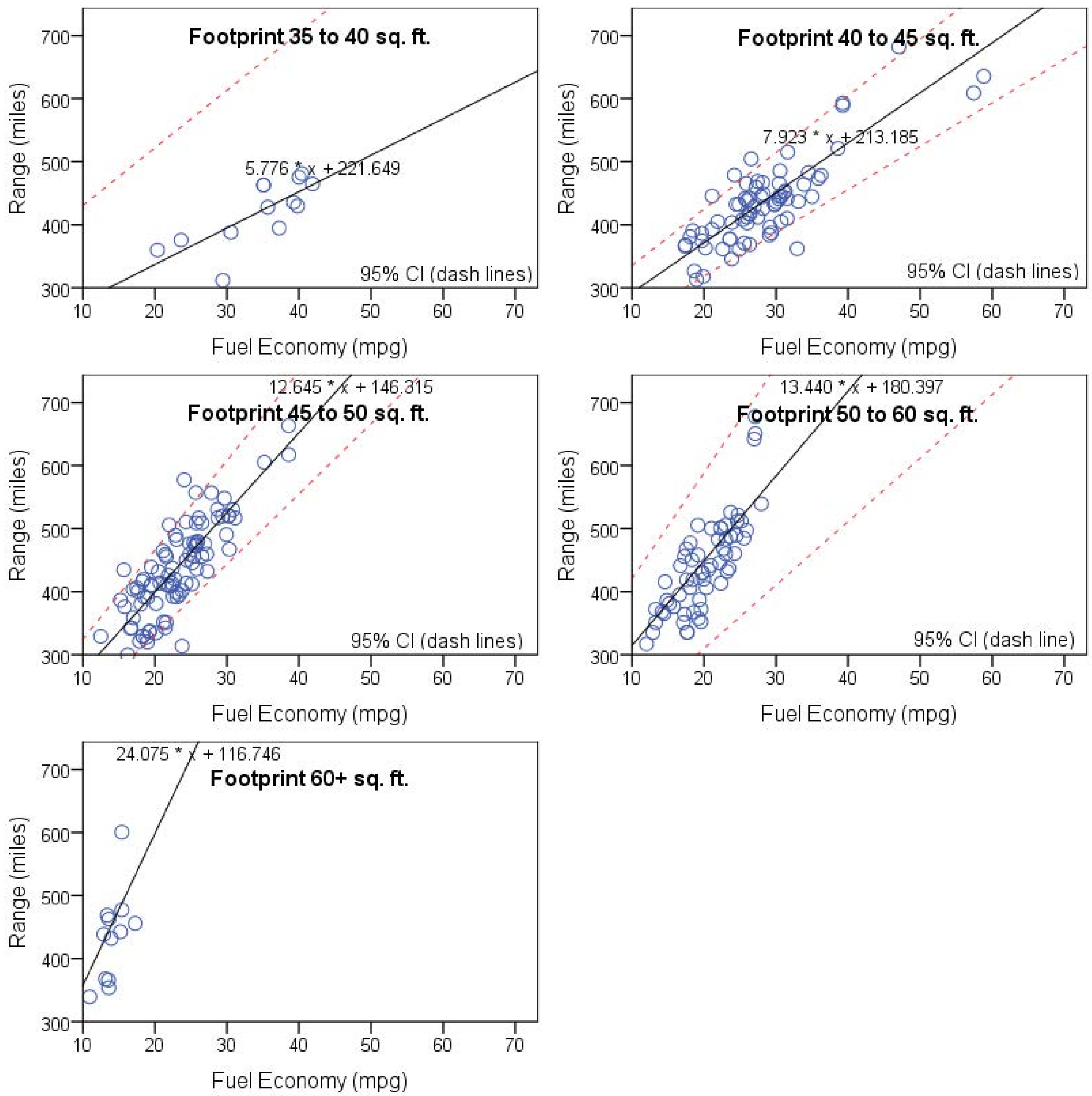

Figure 7.2-2 MY 2010 range vs. fuel economy, by footprint category

Table 7.2-1 Range vs. Fuel Economy Regression Coefficients

Footprint Category	Fuel Economy (mpg) (sales-weighted)		Regression Coefficients $y = m * x + b$			
	Average	Std. Dev.	m	b	R^2	p (F-test)
35-40	39.2	3.1	5.8	221.6	0.57	0.000
40-45	36.4	11.0	7.9	213.2	0.76	0.000
45-50	22.8	5.4	12.6	146.3	0.76	0.000
50-60	28.7	3.6	13.4	180.4	0.51	0.000
60+	17.0	3.0	24.1	116.7	0.40	0.028
Total	29.6	9.8	-	-		

The proportion of an increase in fuel economy that is applied towards increasing range can be expressed by the equation below. For MY 2010 vehicles, manufacture range and tank sizing decisions were estimated using regression coefficients from Table 7.2-1, centered about the sales-weighted average for each footprint category. The results, summarized in Table 7.2-2 below, forecast that over the entire fleet of new vehicles, 65 percent of fuel economy improvements will be applied towards increasing range.

$$Proportion\ of\ \ fuel\ economy\ increase\ used\ for\ range\ increase =$$

$$\frac{(range_2 - range_1)\Big/range_1}{(fuel\ economy_2 - fuel\ economy_1)\Big/fuel\ economy_1}$$

Table 7.2-2 Proportion of Range to Fuel Economy Increases, Based on Regression of MY 2010 Vehicles

Footprint Category	%Range Increase / %Fuel Economy Increase
35-40	0.51
40-45	0.58
45-50	0.71
50-60	0.63
60+	0.78
Average (sales-weighted)	**0.65**

The method of forecasting manufacturing tank sizing and range decisions for future vehicles based on historical data from MY 2010 has several limitations. First, many of the MY 2010 vehicle platforms were designed years earlier. More recent evidence shows that manufacturers are beginning to market vehicle range as an important vehicle attribute. Second, performing a regression across vehicle platforms does not account for all the factors a manufacturer considers when redesigning a vehicle. For example, maintaining the current fuel tank size for a new platform designed by a particular manufacturer, which may be similar in layout to the previous generation, is simplified since the under-floor packaging space is already available.

The EPA investigated the most recently redesigned platforms for some of the highest volume vehicles, and comparing the first model year of the previous generation vehicle, calculated the proportion of fuel economy increase used to increase vehicle range. Changes in fuel economy and range between generations for the least efficient vehicle configuration in each platform are shown Figure 7.2-3 below. The results of this analysis are summarized in Table 7.2-3. A value of one indicates that tank size was maintained between generations, while values less than one and greater than one indicate tank size reductions, and increases, respectively. Among these recently redesigned platforms, manufacturers have in some cases reduced tank size (Toyota Camry, Ford Focus), while in other cases have maintained (Honda Civic, Toyota Sienna), or even increased tank size (Jeep Grand Cherokee, Chevrolet Cruze.)

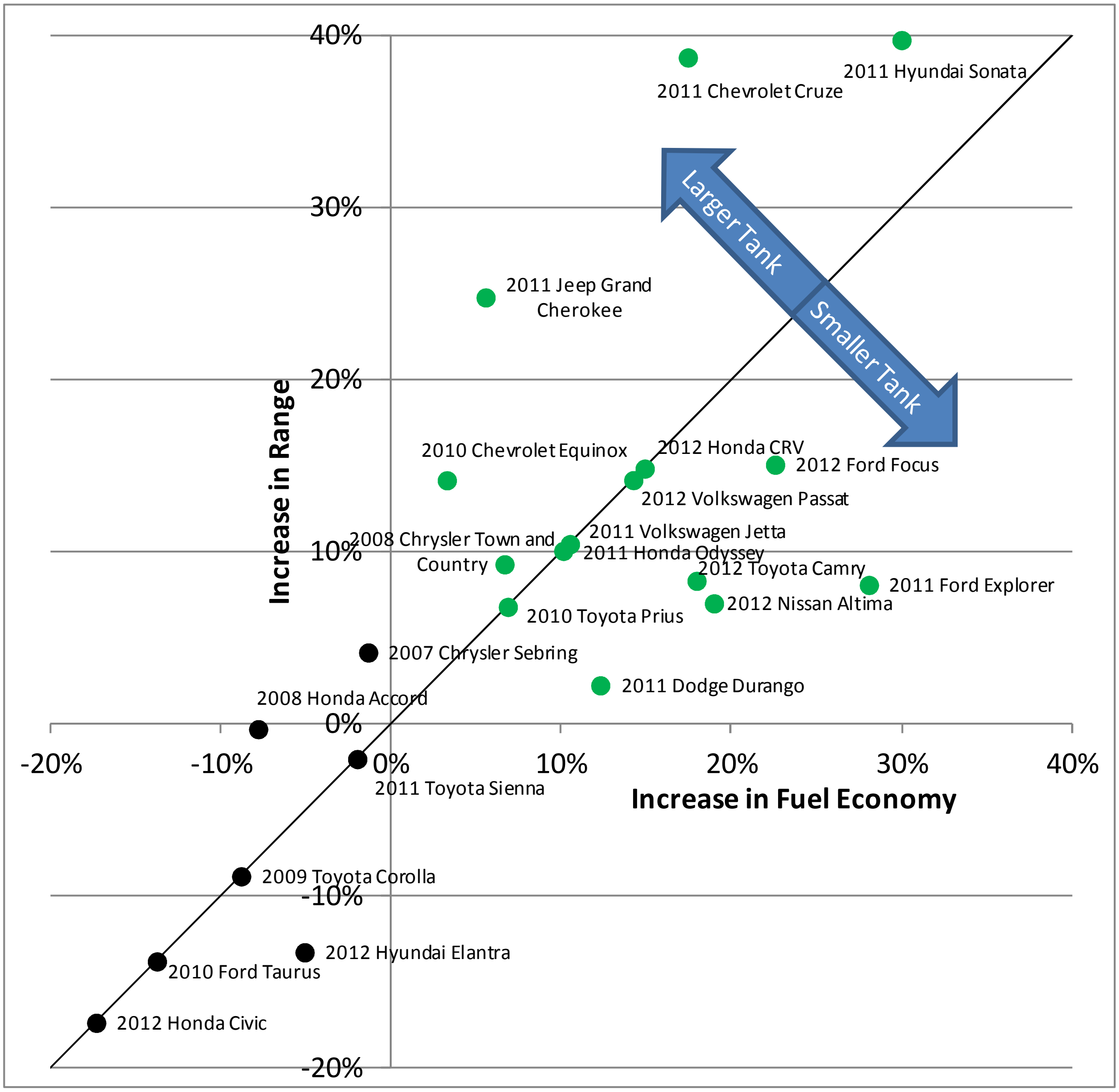

Figure 7.2-3 Increases in range and fuel economy from previous generation for recent platform redesigns (least efficient vehicle configurations only)

Table 7.2-3 Proportion of Range to Fuel Economy Increases, Based on Recent Platform Redesigns

Footprint Category	%Range Increase / %Fuel Economy Increase
2008 Chrysler Town and Country	1.40
2011 Ford Explorer	0.29[a]
2012 Ford Focus	0.67
2012 Toyota Camry	0.47
2012 Nissan Altima	0.37
2011 Dodge Durango	0.19[b]
2011 Jeep Grand Cherokee	4.49[b]
2011 Hyundai Sonata	1.33
2012 Honda CRV	1.00
2011 Chevrolet Cruze	2.23
2011 Volkswagen Jetta	1.00
2012 Volkswagen Passat	1.00
2010 Toyota Prius	1.00
2011 Honda Odyssey	1.00
2010 Chevrolet Equinox	4.36
Average	**1.39**

[a] 2011 Ford Explorer redesign shares platform with 2010 Ford Taurus
[b]:2011 Dodge Durango redesign shares platform with 2011 Jeep Grand Cherokee

Both the regression performed on MY 2010 vehicles, and the investigation of recent platform changes show a clear correlation between increasing range and increasing fuel economy. While the regression analysis indicates that range does not increase in the same proportion as fuel economy increases, the recent evidence of within-manufacturer tank sizing decisions indicates that in some cases, range increases are at least proportional, to fuel economy increases. As a result of this conflicting evidence, and the lack of evidence supporting a quantitative method of forecasting manufacturer decisions to reduce tank size, EPA maintains the NPRM assumption of constant tank size for the final rule.

7.2.2 Calculation of benefits value

EPA calculates the economic value of those time savings by applying DOT-recommended values of travel time savings to our estimates of how much time is saved.[489] The value of travel time depends on average hourly valuations of personal and business time, which are functions of total hourly compensation costs to employers. The total hourly compensation cost to employers, inclusive of benefits, in 2010$ is $29.68.[AAAAAAAA] Table 7.2-4 demonstrates the EPA and NHTSA approach to estimating the value of travel time ($/hour) for both urban and rural (intercity) driving. This approach relies on the use of DOT-

[AAAAAAAA] Total hourly employer compensation costs for 2009 (average of quarterly observations). See http://www.bls.gov/ect/. NHTSA previously used a value of $25.50 for the total hourly compensation cost (*see*, *e.g.*, 75 FR at 25588, fn. 619) during 2008 expressed in 2007$. This earlier figure is deprecated by the availability of more current economic data.

recommended weights that assign a lesser valuation to personal travel time than to business travel time, as well as weights that adjust for the distribution between personal and business travel.

Table 7.2-4 Estimating the Value of Travel Time For Urban and Rural (Intercity) Travel ($/hour)

Urban Travel			
	Personal travel	**Business Travel**	**Total**
Wage Rate ($/hour)	$29.68	$29.68	-
DOT-Recommended Value of Travel Time Savings, as % of Wage Rate	50%	100%	-
Hourly Valuation (=Wage Rate * DOT-Recommended Value)	$14.84	$29.68	-
% of Total Urban Travel	94.4%	5.6%	100%
Hourly Valuation (Adjusted for % of Total Urban Travel)	$14.01	$1.66	**15.67**
Rural (Intercity) Travel			
	Personal travel	**Business Travel**	**Total**
Wage Rate ($/hour)	$29.68	$29.68	-
DOT-Recommended Value of Travel Time Savings, as % of Wage Rate	70%	100%	-
Hourly Valuation (=Wage Rate * DOT-Recommended Value)	$20.77	$29.68	-
% of Total Rural Travel	87.0%	13.0%	100%
Hourly Valuation (Adjusted for % of Total Rural Travel)	$18.07	$3.86	**21.93**

The estimates of the hourly value of urban and rural travel time ($15.67 and $21.93, respectively) shown in Table 7.2-4 must be adjusted to account for the nationwide ratio of urban to rural driving. By applying this adjustment (as shown in Table 7.2-5), an overall estimate of the hourly value of travel time – independent of urban or rural status – may be produced. Note that up to this point, all calculations discussed assume only one adult occupant per vehicle. To fully estimate the average value of vehicle travel time, the presence of additional adult passengers during refueling trips must be accounted for. EPA applies such an adjustment as shown in Table 7.2-5; this adjustment is performed separately for passenger cars and for light trucks, yielding occupancy-adjusted valuations of vehicle travel time during refueling trips for each fleet.

Table 7.2-5 Estimating the Value of Travel Time for Light-Duty Vehicles ($/hour)

	Unweighted Value of Travel Time ($/hour)	Weight (% of Total Miles Driven)[BBBBBBBB]	Weighted Value of Travel Time ($/hour)
Urban Travel	$15.67	67.1%	$10.51
Rural Travel	$21.93	32.9%	$7.22
Total	--	100.0%	$17.73
	Passenger Cars	**Light Trucks**	
Average Vehicle Occupancy During Refueling Trips (persons)[CCCCCCCC]	1.21	1.23	
Weighted Value of Travel Time ($/hour)	$17.73	$17.73	
Occupancy-Adjusted Value of Vehicle Travel Time During Refueling Trips ($/hour)	**$21.45**	**$21.81**	

EPA is using NHTSA's estimates of the amount of refueling time saved using (preliminary) survey data gathered as part of the 2010-2011 National Automotive Sampling System's Tire Pressure Monitoring System (TPMS) study.[DDDDDDDD] The relevant TPMS survey data on average refueling trip characteristics are presented below in Table 7.2-6, and a more complete description of the study is available in Chapter 4 of the NPRM Joint TSD.

[BBBBBBBB] Weights used for urban vs. rural travel are computed using cumulative 2011 estimates of urban vs. rural miles driven provided by the Federal Highway Administration. *Available at* http://www.fhwa.dot.gov/policyinformation/travel_monitoring/tvt.cfm (last accessed 04/27/2012).

[CCCCCCCC] Source: National Automotive Sampling System 2010-2011 Tire Pressure Monitoring System (TPMS) study. See next page for further background on the TPMS study. TPMS data are preliminary at this time and rates are subject to change pending availability of finalized TPMS data. Average occupancy rates shown here are specific to refueling trips, and do not include children under 16 years of age.

[DDDDDDDD] TPMS data are preliminary and not yet published. Estimates derived from TPMS data are therefore preliminary and subject to change. Observational and interview data are from distinct subsamples, each consisting of approximately 7,000 vehicles. For more information on the National Automotive Sampling System and to access TPMS data when they are made available, see http://www.nhtsa.gov/NASS.

Table 7.2-6 Average Refueling Trip Characteristics for Passenger Cars and Light Trucks

	Gallons of Fuel Purchased	Round-Trip Distance to/from Fueling Station (miles)	Round-Trip Time to/from Fueling Station (minutes)	Time to Fill and Pay (minutes)	Total Time (minutes)
Passenger Cars	9.8	0.97	2.28	4.10	6.38
Light Trucks	13.0	1.08	2.53	4.30	6.83

As an illustration of how we estimate the value of extended refueling range, assume a small light truck model has an average fuel tank size of approximately 20 gallons, and a baseline actual on-road fuel economy of 24 mpg. TPMS survey data indicate that drivers who indicated the primary reason for their refueling trips was a low reading on the gas gauge typically refuel when their tanks are 35 percent full (*i.e.,* 13.0 gallons as shown in Table 7.2-6, with 7.0 gallons in reserve). By this measure, a typical driver would have an effective driving range of 312 miles (= 13.0 gallons x 24 mpg) before he or she is likely to refuel. Increasing this model's actual on-road fuel economy from 24 to 25 mpg would therefore extend its effective driving range to 325 miles (= 13.0 gallons x 25 mpg). Assuming that the truck is driven 12,000 miles/year,[EEEEEEEE] this 1 mpg improvement in actual on-road fuel economy reduces the expected number of refueling trips per year from 38.5 (= 12,000 miles per year / 312 miles per refueling) to 36.9 (= 12,000 miles per year / 325 miles per refueling), or 1.6 refuelings per year. If a typical fueling cycle for a light truck requires a total of 6.83 minutes, then the annual value of time saved due to that 1 mpg improvement would amount to $3.94 (= (6.83/60) x $21.62 x 1.6).

In the analysis, we repeat this calculation for each future calendar year that light-duty vehicles of each model year affected by the alternative standards considered in this rule would remain in service. The resulting cumulative lifetime valuations of time savings account for both the reduction over time in the number of vehicles of a given model year that remain in service and the reduction in the number of miles (VMT) driven by those that stay in service. We also adjust the value of time savings that will occur in future years both to account for expected annual growth in real wages and to apply a discount rate to determine the net present value of time saved.[FFFFFFFF] A final adjustment is made to account for evidence from the

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[EEEEEEEE] Source of annual vehicle mileage: U.S. Department of Transportation, Federal Highway Administration, 2009 National Household Travel Survey (NHTS). See http://nhts.ornl.gov/2009/pub/stt.pdf (table 22, p.48). 12,000 miles/year is an approximation of a light duty vehicle's annual mileage during its initial decade of use (the period in which the bulk of benefits are realized).

[FFFFFFFF] A 1.1 percent annual rate of growth in real wages is used to adjust the value of travel time per vehicle ($/hour) for future years for which a given model is expected to remain in service. This rate is supported by a BLS analysis of growth in real wages from 2000 – 2009. See http://www.bls.gov/opub/ted/2011/ted_20110224.htm.

TPMS study which suggests that 40 percent of refueling trips are for reasons other than a low reading on the gas gauge. It is therefore assumed that only 60 percent of the theoretical refueling time savings will be realized, as we assume that owners who refuel on a fixed schedule will continue to do. The assumption that the 40 percent of refueling trips that occur for reasons other than a low reading on the gas gauge will not realize a refueling time savings may be a conservative assumption. Results are calculated separately for a given model year's fleet of passenger cars and that year's fleet of light trucks. Valuations of both fleets' benefits are then summed to determine the benefit across all light-duty vehicles.

Since a reduction in the expected number of annual refueling trips leads to a decrease in miles driven to and from fueling stations, we can also calculate the value of consumers' fuel savings associated with this decrease. As shown in Table 7.2-6, the typical incremental round-trip mileage per refueling cycle is 1.08 miles for light trucks and 0.97 miles for passenger cars. Going back to the earlier example of a light truck model, a decrease of 1.6 in the number of refuelings per year leads to a reduction of 1.73 miles driven per year (= 1.6 refuelings x 1.08 miles driven per refueling). Again, if this model's actual on-road fuel economy was 24 mpg, the reduction in miles driven yields an annual savings of approximately 0.07 gallons of fuel (= 1.73 miles / 24 mpg), which at $3.77/gallon[GGGGGGGG] results in a savings of $0.27 per year to the owner. Note that this example is illustrative only of the approach used to quantify this benefit; in practice, the value of this benefit is modeled using fuel price forecasts for each year the given fleet will remain in service, and unlike the above example excludes fuel taxes from the computation of the total social benefit, as taxes are transfer payments.

The annual savings to each consumer shown in the above example may seem like a small amount, but the reader should recognize that the valuation of the cumulative lifetime benefit of this savings to owners is determined separately for passenger car and light truck fleets and then aggregated to show the net benefit across all light-duty vehicles – which is much more significant at the macro level. Calculations of benefits realized in future years are adjusted for expected real growth in the price of gasoline, for the decline in the number of vehicles of a given model year that remain in service as they age, for the decrease in the number of miles (VMT) driven by those that stay in service, and for the percentage of refueling trips that occur for reasons other than a low reading on the gas gauge; a discount rate is also applied in the valuation of future benefits. EPA considered using this direct estimation approach to quantify the value of this benefit by model year, however the value of this benefit is implicitly captured in the separate measure of overall valuation of fuel savings, and therefore direct estimates of this benefit are not added to net benefits calculations.

The reduction in miles driven to and from fueling stations results in other benefits, such as a reduction in greenhouse gas emissions – CO_2 in particular, reductions in evaporative emissions from refuelings, and reduced wear on vehicles. However, estimates of the values of

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[GGGGGGGG] Estimate of $3.77/gallon is in 2010$. This figure is an average of forecasted cost per gallon (including taxes, as individual consumers consider reduced tax expenditures to be savings) for motor gasoline for years 2017 to 2027. Source of price forecasts: U.S. Energy Information Administration, Annual Energy Outlook Early Release 2012.

these benefits indicate that both are extremely minor in the context of the overall valuation of benefits associated with gains in vehicle driving range, so quantitative valuations of these additional benefits are not included within this analysis.

7.3 Summary of Costs and Benefits of the MYs 2017-2025 Final Rule

In this section, EPA presents a summary of costs, benefits, and net benefits of the final program. Table 7.3-1 shows the estimated annual monetized costs of the final program for the indicated calendar years. The table also shows the net present values of those costs for the calendar years 2012-2050 using both 3 percent and 7 percent discount rates.[HHHHHHHH] Table 7.3-2 shows the estimated annual monetized fuel savings of the final program. The table also shows the net present values of those fuel savings for the same calendar years using both 3 percent and 7 percent discount rates. In this table, the aggregate value of fuel savings is calculated using pre-tax fuel prices since savings in fuel taxes do not represent a reduction in the value of economic resources utilized in producing and consuming fuel. Note that fuel savings shown here result from reductions in fleet-wide fuel use. Thus, they grow over time as an increasing fraction of the fleet meets the 2025 standards. Table 7.3-3 shows the annual reductions in petroleum-based imports and the monetized energy security benefits of the final program for the indicated calendar years. The table also shows the net present values of monetized energy security benefits for the calendar years 2012-2050 using both 3 percent and 7 percent discount rates.

Table 7.3-1 Undiscounted Annual Costs & Costs of the Final Program Discounted Back to 2012 at 3% and 7% Discount Rates (Millions, 2010$) [a]

	2017	2020	2030	2040	2050	NPV, Years 2012-2050, 3% Discount Rate	NPV, Years 2012-2050, 7% Discount Rate
Technology Costs	$2,440	$8,860	$33,700	$37,400	$42,000	$521,000	$231,000
Maintenance Costs	$37	$330	$2,260	$3,630	$4,540	$39,500	$15,600
Vehicle Program Costs	$2,470	$9,190	$35,900	$41,000	$46,500	$561,000	$247,000

Note:
[a] Technology costs for separate light-duty vehicle segments can be found in Chapter 5 of this RIA. Annual costs shown are undiscounted values.

[HHHHHHHH] For the estimation of the stream of costs and benefits, we assume that after implementation of the proposed MY 2017-2025 standards, the 2025 standards apply to each year out to 2050.

Table 7.3-2 Undiscounted Annual Fuel Savings & Final Program Fuel Savings Discounted Back to 2012 at 3% and 7% Discount Rates (Millions, 2010$) [a]

	2017	2020	2030	2040	2050	NPV, Years 2012-2050, 3% Discount Rate	NPV, Years 2012-2050, 7% Discount Rate
Fuel Savings (pre-tax)	$651	$7,430	$86,400	$155,000	$212,000	$1,600,000	$607,000

Note:
[a] Fuel savings for separate light-duty vehicle segments can be found in Chapter 5 of this RIA. Annual costs shown are undiscounted values.

Table 7.3-3 Undiscounted Annual Energy Security Benefits, & Final Program Benefits Discounted back to 2012 at 3% and 7% Discount Rates (Millions, 2010$)[a]

	2017	2020	2030	2040	2050	NPV, Years 2012-2050, 3% Discount Rate	NPV, Years 2012-2050, 7% Discount Rate
Petroleum-based imports reduced (mmb)	4.5	48.6	520	880	1,103		
Monetized benefits	$33	$371	$4,560	$8,320	$10,400	$84,500	$32,200

Note:
[a] When conducting its analysis, Oak Ridge National Laboratory (ORNL) estimated energy security premiums by quantifying two components of the economic cost of importing petroleum into the U.S. (in addition to the purchase price of petroleum itself): monopsony and macroeconomic disruption costs. For this rule, EPA worked with ORNL to update the energy security premiums by incorporating the AEO 2012 Early Release oil price forecasts and market trends. The components of ORNL's energy security premiums and their values are discussed in detail in the Joint TSD Chapter 4.2.8. EPA did not include the monopsony cost component in our cost-benefit analysis (see discussion in Section III.H.8.c). The ORNL analysis did not include military or SPR costs nor did EPA quantify them for this rule (see discussion in Section III.H.8.e). Based upon the ORNL analysis, EPA has developed estimates of energy security premiums (i.e., $/barrel of imported crude oil and finished petroleum products) for 2020, 2025, 2030 and 2035. The method and estimated premiums are discussed in detail in Chapter 4 of the Joint TSD along with our approach for estimating the reductions in petroleum-based imports. The energy security benefit (macroeconomic disruption component only) is estimated to be $8.26/barrel or about $0.197/gallon in 2025. EPA linearly interpolated the premium values for the years 2017 through 2035, using the 2015 and 2035 values as endpoints and the 2020, 2025, and 2030 values as midpoints. Since ORNL uses AEO 2012 forecasts that end in 2035, EPA assumes that the post-2035 energy security premium do not change through 2050. Annual costs shown are undiscounted values.

Table 7.3-4 presents estimated annual monetized benefits for the indicated calendar years. The table also shows the net present values of those benefits for the calendar years 2012-2050 using both 3 percent and 7 percent discount rates. The table shows the benefits of reduced CO_2 emissions—and consequently the annual quantified benefits (*i.e.*, total benefits)—for each of four SCC values estimated by the interagency working group. As discussed above in section 7.1 of this RIA, there are some limitations to the SCC analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion.

In addition, these monetized CO_2 benefits exclude the value of net reductions in non-CO_2 GHG emissions (CH_4, N_2O, HFC) expected under this action. As discussed in Chapter 7.1 of this RIA, EPA applied the GWP approach to estimate the benefits associated with reductions of CH_4, N_2O, HFC in each calendar year in a sensitivity analysis. In sum, the sensitivity analysis suggests that the total net present value of the annual 2017 through 2050 GHG benefits for this rulemaking would increase by about $3 billion to $50 billion, depending on discount rate, or roughly 10 percent if these non-CO2 estimates were included. Given the magnitude of this increase in the context of the total costs and benefits considered in this rule and other critical decision factors related to technical issues, inclusion of these estimates in the primary analysis would not affect any of the decisions regarding the appropriateness of the standards EPA is adopting here. EPA, however, presented these estimates for illustrative purposes and chose not to include them in the primary benefits analysis because of the uncertainties discussed in Chapter 7.1.

Table 7.3-4 Monetized Undiscounted Annual Benefits & Benefits of the Final Program Discounted Back to 2012 at 3% and 7% Discount Rates (Millions, 2010$)

	2017	2020	2030	2040	2050	NPV, Years 2012-2050, 3% Discount Rate[a]	NPV, Years 2012-2050, 7% Discount Rate[a]
Benefits of Reduced CO_2 Emissions at each assumed SCC value [b]							
5% (avg SCC)	$14	$164	$2,500	$5,510	$8,540	$32,400	$32,400
3% (avg SCC)	$55	$633	$8,410	$17,000	$24,400	$170,000	$170,000
2.5% (avg SCC)	$87	$1,000	$12,900	$25,400	$35,400	$290,000	$290,000
3% (95th %ile)	$167	$1,940	$25,700	$51,800	$74,100	$519,000	$519,000
Energy Security Benefits	$33	$371	$4,560	$8,320	$10,400	$84,500	$32,200
Accidents, Congestion, Noise Costs[h]	-$54	-$564	-$5,710	-$9,650	-$12,100	-$101,000	-$39,200
Increased Travel Benefits[g]	$79	$865	$9,560	$17,000	$14,500	$167,000	$64,800
Refueling Time Savings	$25	$282	$3,360	$6,350	$8,870	$64,900	$24,500
Non-GHG Related Health Impacts [c,d,e]	B	B	$920 - $1000	$920 - $1000	$920 - $1000	$9,190	$3,050
Non-CO_2 GHG Impacts[f]	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Total Annual Benefits at each assumed SCC value [b]							
5% (avg SCC)	$97	$1,120	$15,300	$28,500	$31,300	$257,000	$118,000
3% (avg SCC)	$138	$1,590	$21,200	$40,000	$47,200	$395,000	$256,000
2.5% (avg SCC)	$171	$1,960	$25,600	$48,400	$58,100	$515,000	$376,000
3% (95th %ile)	$250	$2,890	$38,500	$74,800	$96,900	$743,000	$604,000

Notes:
[a] Net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate

net present value of SCC for internal consistency. Refer to the SCC TSD for more detail. Annual costs shown are undiscounted values.
[b] RIA Chapter 7.1 notes that SCC increases over time. For the years 2017-2050, the SCC estimates range as follows: for Average SCC at 5%: $6-$16; for Average SCC at 3%: $26-$47; for Average SCC at 2.5%: $41-$68; and for 95th percentile SCC at 3%: $79-$142.
[c] Note that "B" indicates unquantified criteria pollutant benefits in years prior to 2030 (2017-2029). For the final rule, EPA only conducted full-scale photochemical air quality modeling to estimate the rule's $PM_{2.5}$- and ozone-related impacts in the calendar year 2030. For the purposes of estimating a stream of future-year criteria pollutant benefits associated with the final standards, we assume that the annual benefits out to 2050 are equal to, and no less than, those modeled in 2030 as reflected by the stream of estimated future emission reductions. The NPV of criteria pollutant-related benefits should therefore be considered a conservative estimate of the potential benefits associated with the final rule.
[d] The $PM_{2.5}$-related portion of the health benefits presented in this table are based on an estimate of premature mortality derived from the ACS study (Pope et al., 2002). However, EPA's primary method of characterizing PM-related premature mortality is to use both the ACS and the Six Cities study (Laden et al., 2006) to generate a co-equal range of benefits estimates. The decision to present only the ACS-based estimate in this table does not convey any preference for one study over the other. We note that this is also the more conservative of the two estimates - PM-related benefits would be approximately 245 percent (or nearly two-and-a-half times) larger had we used the per-ton benefit values based on the Six Cities study instead. Refer to Chapter 6.3.1 to see the full range of non-GHG related health benefits in Calendar Year 2030.
[e] The range of calendar year non-GHG benefits presented in this table assume either a 3% discount rate in the valuation of PM-related premature mortality ($1,000 million) or a 7% discount rate ($920 million) to account for a twenty-year segmented cessation lag. Note that the benefits estimated using a 3% discount rate were used to calculate the NPV using a 3% discount rate and the benefits estimated using a 7% discount rate were used to calculate the NPV using a 7% discount rate.
[f] EPA applied the GWP approach to estimate the benefits associated with reductions of CH4, N2O, HFC in each calendar year. EPA presented these estimates for illustrative purposes but chose not to include them in the primary benefits analysis. See RIA Chapter 7.1.
[g] Refer to Chapter 4.2.6 of the joint TSD for a description of how increased travel benefits are derived.
[h] Note that accidents, congestion and noise are costs, so the negative values shown represent increased costs which we treat as negative benefits.

Table 7.3-5 presents estimated annual net benefits for the indicated calendar years. The table also shows the net present values of those net benefits for the calendar years 2017-2050 using both 3 percent and 7 percent discount rates. The table includes the benefits of reduced CO_2 emissions (and consequently the annual net benefits) for each of four SCC values considered by EPA.

Table 7.3-5 Undiscounted Annual Monetized Net Benefits & Net Benefits of the Final Program Discounted Back to 2012 at 3% and 7% Discount Rates (Millions, 2010$)

	2017	2020	2030	2040	2050	NPV, 3%[a]	NPV, 7%[a]
Vehicle Program Costs	$2,470	$9,190	$35,900	$41,000	$46,500	$561,000	$247,000
Fuel Savings	$651	$7,430	$86,400	$155,000	$212,000	$1,600,000	$607,000
Total Annual Benefits at each assumed SCC value [b]							
5% (avg SCC)	$97	$1,120	$15,300	$28,500	$31,300	$257,000	$118,000
3% (avg SCC)	$138	$1,590	$21,200	$40,000	$47,200	$395,000	$256,000
2.5% (avg SCC)	$171	$1,960	$25,600	$48,400	$58,100	$515,000	$376,000
3% (95th %ile)	$250	$2,890	$38,500	$74,800	$96,900	$743,000	$604,000
Monetized Net Benefits at each assumed SCC value [c]							

5% (avg SCC)	-$1,690	-$316	$68,000	$146,000	$201,000	$1,290,000	$478,000
3% (avg SCC)	-$1,650	$153	$73,900	$158,000	$217,000	$1,430,000	$616,000
2.5% (avg SCC)	-$1,610	$524	$78,300	$166,000	$228,000	$1,550,000	$736,000
3% (95th %ile)	-$1,530	$1,460	$91,200	$192,000	$267,000	$1,780,000	$964,000

Notes:
[a] Net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail. Annual costs shown are undiscounted values.
[b] RIA Chapter 7.1 notes that SCC increases over time. For the years 2017-2050, the SCC estimates range as follows: for Average SCC at 5%: $6-$16; for Average SCC at 3%: $26-$47; for Average SCC at 2.5%: $41-$68; and for 95[th] percentile SCC at 3%: $79-$142. RIA Chapter 7.1 also presents these SCC estimates.
[c] Net Benefits equal Fuel Savings minus Technology Costs plus Benefits.

EPA also conducted a separate analysis of the total benefits over the model year lifetimes of the 2017 through 2025 model year vehicles. In contrast to the calendar year analysis presented above in Table 7.3-1 through Table 7.3-5, the model year lifetime analysis below shows the impacts of the program on vehicles produced during each of the model years 2017 through 2025 over the course of their expected lifetimes. The net societal benefits over the full lifetimes of vehicles produced during each of the nine model years from 2017 through 2025 are shown in Table 7.3-6 and Tables 7.3-7 at both 3 percent and 7 percent discount rates, respectively.

Table 7.3-6 Monetized Costs, Fuel Savings, Benefits, and Net Benefits Associated with the Lifetimes of 2017-2025 Model Year Light-Duty Vehicles (Millions, 2010$; 3% Discount Rate)[h]

	2017 MY	2018 MY	2019 MY	2020 MY	2021 MY	2022 MY	2023 MY	2024 MY	2025 MY	Sum
Vehicle Program Costs	$2,770	$5,460	$7,720	$10,100	$14,000	$19,900	$25,400	$30,900	$33,600	$150,000
Fuel Savings (pre-tax)	$7,040	$15,500	$24,300	$34,100	$50,400	$64,900	$78,500	$92,900	$107,000	$475,000
Energy Security Benefits	$365	$807	$1,260	$1,780	$2,650	$3,430	$4,170	$4,950	$5,750	$25,200
Accidents, Congestion, Noise Costs[f]	-$548	-$1,150	-$1,770	-$2,440	-$3,480	-$4,420	-$5,270	-$6,160	-$7,040	-$32,300
Increased Travel Benefits[i]	$1,000	$2,180	$3,390	$4,700	$6,840	$8,650	$10,200	$11,900	$13,600	$62,500
Refueling Time Savings	$273	$604	$945	$1,330	$1,970	$2,550	$3,100	$3,680	$4,280	$18,700
$PM_{2.5}$ Related Health Impacts[c,d,e]	$74	$171	$271	$385	$606	$768	$912	$1,060	$1,210	$5,460
Non-CO_2 GHG Impacts[g]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Benefits of Reduced CO_2 Emissions at each assumed SCC value[a, b]										
5% (avg SCC)	$152	$344	$551	$794	$1,210	$1,590	$1,970	$2,380	$2,820	$11,800
3% (avg SCC)	$642	$1,440	$2,270	$3,230	$4,850	$6,330	$7,740	$9,260	$10,800	$46,600
2.5% (avg SCC)	$1,040	$2,320	$3,660	$5,190	$7,760	$10,100	$12,300	$14,700	$17,100	$74,100
3% (95th %ile)	$1,970	$4,390	$6,950	$9,880	$14,800	$19,300	$23,600	$28,300	$33,000	$142,000
Monetized Net Benefits at each assumed SCC value[a, b]										
5% (avg SCC)	$5,590	$13,000	$21,200	$30,500	$46,200	$57,500	$68,100	$79,700	$94,400	$416,000
3% (avg SCC)	$6,080	$14,100	$22,900	$33,000	$49,900	$62,200	$73,900	$86,600	$102,000	$451,000
2.5% (avg SCC)	$6,480	$15,000	$24,300	$34,900	$52,800	$66,000	$78,500	$92,000	$109,000	$479,000
3% (95th %ile)	$7,400	$17,100	$27,600	$39,600	$59,800	$75,200	$89,800	$106,000	$125,000	$547,000

Notes:
[a] Net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.
[b] RIA Chapter 7.1 notes that SCC increases over time. For the years 2017-2050, the SCC estimates range as follows: for Average SCC at 5%: $6-$16; for Average SCC at 3%: $26-$47; for Average SCC at 2.5%: $41-$68; and for 95th percentile SCC at 3%: $79-$142. RIA Chapter 7.1 also presents these SCC estimates.
[c] Note that the $PM_{2.5}$-related co-pollutant impacts associated with Model Year analysis presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate non-GHG impacts. Instead, the $PM_{2.5}$-related benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure. Ideally, human health and environmental benefits would be based on changes in ambient $PM_{2.5}$ and ozone as determined by full-scale air quality modeling. However, EPA was unable to conduct a full-scale air quality modeling for the Model Year analysis. Full scale air quality modeling was conducted for the Calendar Year analysis. See Chapter 6 for a discussion of that analysis.
[d] The $PM_{2.5}$-related health benefits (derived from benefit-per-ton values) presented in this table are based on an estimate of premature mortality derived from the ACS study (Pope et al., 2002). However, EPA's primary method of characterizing PM-related premature mortality is to use both the ACS and the Six Cities study (Laden et al., 2006) to generate a co-equal range of benefits estimates. The decision to present only the ACS-based estimate in this table does not convey any preference for one study over the other. We note that this is also the more conservative of the two estimates - PM-related benefits would be approximately 245 percent (or nearly two-and-a-half times) larger had we used the per-ton benefit values based on the Six Cities study instead. See Chapter 6.3.1.
[e] The $PM_{2.5}$-related health benefits (derived from benefit-per-ton values) presented in this table assume a 3% discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag. If a 7% discount rate had been used, the values would be approximately 9% lower.
.[f] Negative values shown for Accidents, Congestion, and Noise represent disbenefits.
[g] EPA applied the GWP approach to estimate the benefits associated with reductions of CH_4, N_2O, HFC in each calendar year. EPA presented these estimates for illustrative purposes but chose not to include them in the primary benefits analysis. See RIA Chapter 7.1.
[h] Model year values are discounted to the first year of each model year; the "Sum" represents those discounted values summed across model years.
[i] Refer to Chapter 4.2.6 of the joint TSD for a description of how increased travel benefits are derived.

Table 7.3-7 Monetized Costs, Fuel Savings, Benefits, and Net Benefits Associated with the Lifetimes of 2017-2025 Model Year Light-Duty Vehicles (Millions, 2010$; 7% Discount Rate)[h]

	2017 MY	2018 MY	2019 MY	2020 MY	2021 MY	2022 MY	2023 MY	2024 MY	2025 MY	Sum
Vehicle Program Costs	$2,650	$5,220	$7,370	$9,610	$13,300	$19,200	$24,600	$29,900	$32,500	$144,000
Fuel Savings (pre-tax)	$5,410	$11,900	$18,600	$26,100	$38,600	$49,700	$60,100	$71,100	$82,300	$364,000
Energy Security Benefits	$279	$615	$964	$1,360	$2,020	$2,620	$3,180	$3,780	$4,400	$19,200
Accidents, Congestion, Noise Costs [f]	-$425	-$893	-$1,370	-$1,890	-$2,690	-$3,410	-$4,070	-$4,760	-$5,440	-$24,900
Increased Travel Benefits[i]	$761	$1,650	$2,550	$3,530	$5,120	$6,470	$7,640	$8,870	$10,100	$46,700
Refueling Time Savings	$209	$461	$721	$1,020	$1,500	$1,940	$2,360	$2,800	$3,260	$14,300
$PM_{2.5}$ Related Health Impacts[c,d,e]	$59	$136	$215	$305	$478	$607	$721	$840	$959	$4,320
Non-CO_2 GHG Impacts[g]	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Benefits of Reduced CO_2 Emissions at each assumed SCC value [a, b]										
5% (avg SCC)	$152	$344	$551	$794	$1,210	$1,590	$1,970	$2,380	$2,820	$11,800
3% (avg SCC)	$642	$1,440	$2,270	$3,230	$4,850	$6,330	$7,740	$9,260	$10,800	$46,600

2.5% (avg SCC)	$1,040	$2,320	$3,660	$5,190	$7,760	$10,100	$12,300	$14,700	$17,100	$74,100
3% (95th %ile)	$1,970	$4,390	$6,950	$9,880	$14,800	$19,300	$23,600	$28,300	$33,000	$142,000
Monetized Net Benefits at each assumed SCC value [a, b]										
5% (avg SCC)	$3,800	$9,010	$14,900	$21,600	$32,900	$40,300	$47,300	$55,100	$65,800	$291,000
3% (avg SCC)	$4,290	$10,100	$16,600	$24,100	$36,500	$45,000	$53,100	$62,000	$73,800	$326,000
2.5% (avg SCC)	$4,690	$11,000	$18,000	$26,000	$39,400	$48,800	$57,600	$67,400	$80,100	$353,000
3% (95th %ile)	$5,610	$13,100	$21,300	$30,700	$46,500	$58,000	$69,000	$81,000	$96,100	$421,000

Notes:

[a] Net present value of reduced CO_2 emissions is calculated differently than other benefits. The same discount rate used to discount the value of damages from future emissions (SCC at 5, 3, 2.5 percent) is used to calculate net present value of SCC for internal consistency. Refer to the SCC TSD for more detail.

[b] RIA Chapter 7.1 notes that SCC increases over time. For the years 2017-2050, the SCC estimates range as follows: for Average SCC at 5%: $6-$16; for Average SCC at 3%: $26-$47; for Average SCC at 2.5%: $41-$68; and for 95th percentile SCC at 3%: $79-$142. RIA Chapter 7.1 also presents these SCC estimates.

[c] Note that the $PM_{2.5}$-related co-pollutant impacts associated with Model Year analysis presented here do not include the full complement of endpoints that, if quantified and monetized, would change the total monetized estimate non-GHG impacts. Instead, the $PM_{2.5}$-related benefits are based on benefit-per-ton values that reflect only human health impacts associated with reductions in $PM_{2.5}$ exposure. Ideally, human health and environmental benefits would be based on changes in ambient $PM_{2.5}$ and ozone as determined by full-scale air quality modeling. However, EPA was unable to conduct a full-scale air quality modeling for the Model Year analysis. Full scale air quality modeling was conducted for the Calendar Year analysis. See Chapter 6 for a discussion of that analysis.

[d] The $PM_{2.5}$-related health benefits (derived from benefit-per-ton values) presented in this table are based on an estimate of premature mortality derived from the ACS study (Pope et al., 2002). However, EPA's primary method of characterizing PM-related premature mortality is to use both the ACS and the Six Cities study (Laden et al., 2006) to generate a co-equal range of benefits estimates. The decision to present only the ACS-based estimate in this table does not convey any preference for one study over the other. We note that this is also the more conservative of the two estimates - PM-related benefits would be approximately 245 percent (or nearly two-and-a-half times) larger had we used the per-ton benefit values based on the Six Cities study instead. See Chapter 6.3.1

[e] The $PM_{2.5}$-related health benefits (derived from benefit-per-ton values) presented in this table assume a 3% discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag. If a 7% discount rate had been used, the values would be approximately 9% lower.

.[f] Negative values shown for Accidents, Congestion, and Noise represent disbenefits.

[g] EPA applied the GWP approach to estimate the benefits associated with reductions of CH4, N2O, HFC in each calendar year. EPA presented these estimates for illustrative purposes but chose not to include them in the primary benefits analysis. See RIA Chapter 7.1.

[h] Model year values are discounted to the first year of each model year; the "Sum" represents those discounted values summed across model years.

[i] Refer to Chapter 4.2.6 of the joint TSD for a description of how increased travel benefits are derived.

7.4 Summary of Costs and Benefits of the MYs 2012-2016 & 2017-2025 Final Rules

In this section, EPA presents a summary of costs, benefits, and net benefits, along with other impacts such as oil reductions and consumer savings, associated with the combined MYs 2012-2016 and MYs 2017-2025 GHG emission standards. Here we focus on the primary impacts of most interest for the MYs 2012-2016 and MYs 2017-2025 programs. As a reference case, we use the 2011 standards.

It is important to understand that the results presented here are not a simple addition of the results presented in each of the two individual rulemaking analyses, for several reasons. First, the MYs 2012-2016 rule showed MY 2016 costs of $948 while the MYs 2017-2025 rule shows MY 2025 costs of $1836. One cannot add these two costs to arrive at a total control case cost for MY 2025 of $2784. Instead, one must add a MY 2025 cost of meeting the 2016 standard ($719, see RIA Table 3.6-1) to the MY 2025 cost of meeting the 2025 MY standard ($1,836, see RIA Table 3.6-3) to arrive at a total control case cost of $2555. (We describe this in more detail in section 18.2.1 of the Response to Comments document).[IIIIIII]

Similarly, the full MY lifetime benefits from the two rulemakings cannot be added due to the change in reference case for the two rules. While the MYs 2012-2016 rule used the MY 2011 CAFE standards as a reference case, this rulemaking uses the MY 2016 rulemaking as a reference case. Thus, the MY lifetime benefits attributable to bringing the MY 2017 to MY 2025 vehicles to compliance with the MY 2016 standards were not reported in either this rulemaking, or the previous rulemaking. By contrast, as the calendar year analysis inherently includes benefits accruing to additional MYs, the future calendar year (CY) benefits are approximately additive between the two rules – although differences in the analyses (such as changes to fleet projections, fuel prices, and VMT schedules) preclude direct addition of benefits. We present two sets of tables: the first set (section 7.4.1) shows results from our model year lifetime analysis; the second set (section 7.4.2) shows results from our calendar year analysis. Finally, we show results of our consumer cost of ownership analysis.

7.4.1 Model Year Lifetime Results

The results presented here are impacts associated with the lifetime operation of the new vehicles sold in the 14 model years 2012-2025. It is important to note that while the incremental vehicle technology costs associated with any given model year will in fact occur in that same calendar year, the benefits, fuel savings and maintenance costs associated with the given model year of vehicles will be split among all the subsequent calendar years until the last vehicle is retired.

Table 7.4-1 shows the lifetime total fuel reductions for the lifetimes of MYs 2012 through 2025 vehicles. Table 7.4-2 shows the lifetime total CO_2e reductions for the lifetimes of MYs 2012 through 2025 vehicles. Table 7.4-3 shows the lifetime present value monetized fuel savings for the lifetimes of MYs 2012 through 2025 vehicles. In 7.4-3, the present values of the lifetime fuel savings are discounted to the first year of each model year; the sums are those discounted lifetime values summed across model years. Table 7.4-4 shows the lifetime

[IIIIIII] This $2,555 cost is conservative and overstated, as we did not subtract the cost of bringing the MY 2008 baseline to compliance with the MY 2011 standards, but rather used the direct estimate of bringing the MY 2008 vehicles to the MY 2016 technology. In the MYs 2012-2016 rule, we estimated this cost at $89 (See Page 4-18 in EPA-420-R-10-009) per vehicle on average, in 2007 dollars and using MY 2016 technology costs. This cost would be lower in later MYs, and higher in earlier MYs due to the effects of cost learning. We did not repeat the analysis of MY 2011 compliance costs for this rulemaking.

present value monetized fuel savings that vehicles in each model year 2012-2025 will provide, relative to the vehicles were they to meet the MY 2011 CAFE standards rather than the new GHG standards. Note that the savings shown in Table 7.4-4 use retail fuel prices. Table 7.4-5 shows the estimated technology costs per vehicle for each model year 2012-2025 and do not include maintenance costs.

Table 7.4-1 MY Lifetime Fuel Reductions Associated with the MYs 2012-2016 & 2017-2025 Final Rules

Model Year	Fuel (Million gallons)	Oil (Million barrels)
2012	6,740	160
2013	10,300	246
2014	13,500	321
2015	19,100	455
2016	25,700	611
2017	28,700	683
2018	31,400	749
2019	34,600	824
2020	38,800	925
2021	45,200	1,080
2022	50,700	1,210
2023	55,800	1,330
2024	61,100	1,450
2025	66,600	1,580
Total	488,000	11,600

Table 7.4-2 MY Lifetime CO_2e Reductions Associated with the MYs 2012-2016 & 2017-2025 Final Rules

Model Year	CO_2e (Million metric tons)
2012	81
2013	130
2014	160
2015	230
2016	310
2017	340
2018	380
2019	420
2020	470
2021	550
2022	610
2023	670
2024	730
2025	790
Total	5,900

Table 7.4-3 MY Lifetime Present Value Fuel Savings Associated with the MYs 2012-2016 & 2017-2025 Final Rules (2010 dollars)

Model Year	Untaxed, 0% Discount Rate (Billions)	Untaxed, 3% Discount Rate (Billions)	Untaxed, 7% Discount Rate (Billions)	Retail, 0% Discount Rate (Billions)	Retail, 3% Discount Rate (Billions)	Retail, 7% Discount Rate (Billions)
2012	$23	$18	$14	$26	$20	$15
2013	$36	$28	$21	$40	$31	$24
2014	$47	$37	$28	$53	$41	$32
2015	$68	$53	$40	$76	$59	$45
2016	$92	$72	$55	$100	$80	$61
2017	$100	$81	$62	$120	$90	$69
2018	$110	$90	$69	$130	$100	$76
2019	$130	$100	$76	$140	$110	$85
2020	$140	$110	$86	$160	$120	$96
2021	$170	$130	$100	$190	$150	$110
2022	$190	$150	$110	$210	$160	$130
2023	$210	$160	$130	$230	$180	$140
2024	$230	$180	$140	$260	$200	$150
2025	$250	$200	$150	$280	$220	$170
Total	$1,800	$1,400	$1,100	$2,000	$1,600	$1,200

Table 7.4-4 MY Lifetime Present Value Fuel Savings per Vehicle Associated with the MYs 2012-2016 & 2017-2025 Final Rules (2010 dollars)[a]

Model Year	Fuel Savings per Vehicle, 3% Discount Rate ($/vehicle)	Fuel Savings per Vehicle, 7% Discount Rate ($/vehicle)
2012	$1,400	$1,000
2013	$1,900	$1,500
2014	$2,600	$2,000
2015	$3,700	$2,800
2016	$5,000	$3,800
2017	$5,700	$4,400
2018	$6,400	$4,900
2019	$7,100	$5,400
2020	$7,900	$6,000
2021	$9,000	$6,900
2022	$10,000	$7,700
2023	$10,900	$8,400
2024	$11,800	$9,100
2025	$12,700	$9,800

[a] Using retail fuel prices and rebound miles in the control case.

Table 7.4-5 Industry Average Technology Costs per Vehicle Associated with the MYs 2012-2016 & 2017-2025 Final Standards (2010$) [a]

Model Year	Cars	Trucks	Combined
2012	$342	$314	$331
2013	$507	$496	$503
2014	$631	$652	$639
2015	$749	$820	$774
2016	$869	$1,098	$948
2017	$1,044	$1,119	$1,069
2018	$1,179	$1,222	$1,193
2019	$1,284	$1,293	$1,287
2020	$1,377	$1,367	$1,373
2021	$1,478	$1,680	$1,549
2022	$1,776	$2,086	$1,881
2023	$2,040	$2,445	$2,176
2024	$2,291	$2,780	$2,454
2025	$2,381	$2,909	$2,555

[a] This $2,555 cost is conservative and overstated, as we did not subtract the cost of bringing the MY 2008 baseline to compliance with the MY 2011 standards, but rather used the direct estimate of bringing the MY 2008 vehicles to the MY 2016 technology. In the MYs 2012-2016 rule, we estimated this cost at $89 (See Page 4-18 in EPA-420-R-10-009) per vehicle on average, in 2007 dollars and using MY 2016 technology costs. This cost would be lower in later MYs, and higher in earlier MYs due to the effects of cost learning. We did not repeat the analysis of MY 2011 compliance costs for this rulemaking.

7.4.2 Calendar Year Results

The results presented here project the environmental and economic impacts associated with the tailpipe CO_2 standards during specific calendar years out to 2050. This calendar year approach reflects the timeframe when the benefits would be achieved and the costs incurred. Because the EPA CO_2 emissions standards will remain in effect unless and until they are changed, the projected impacts in this calendar year analysis beyond calendar year 2025 reflect vehicles sold in model years after 2025 (e.g., most of the benefits in calendar year 2040 would be due to vehicles sold after MY 2025).

Table 7.4-7 shows the annual fuel and oil reductions for the years 2012 through 2050. Table 7.4-8 shows the annual CO_2e reductions for the years 2012 through 2050. Table 7.4-9 shows the annual monetized fuel savings for the years 2012 through 2050.

Table 7.4-7 Annual Fuel Reductions Associated with the MYs 2012-2016 & 2017-2025 Final Rules

Calendar Year	Fuel (Million gallons)	Oil (Million barrels)	Oil (Million Barrels/day)
2012	529	13	0.0
2013	1,320	31	0.1
2014	2,320	55	0.2
2015	3,730	89	0.2
2016	5,590	133	0.4
2017	7,620	182	0.5
2018	9,780	233	0.6
2019	12,100	288	0.8
2020	14,600	348	1.0
2021	17,500	417	1.1
2022	20,700	493	1.4
2023	24,100	574	1.6
2024	27,700	660	1.8
2025	31,600	752	2.1
2030	49,000	1,170	3.2
2040	72,900	1,740	4.8
2050	89,800	2,140	5.9
Total	1,850,000	44,000	

Table 7.4-8 Annual CO_2e Reductions Associated with the MYs 2012-2016 & 2017-2025 Final Rules

Calendar Year	CO_2e (Million metric tons)
2012	6
2013	16
2014	28
2015	45
2016	68
2017	92
2018	120
2019	150
2020	180
2021	210
2022	250
2023	290
2024	330
2025	380
2030	580
2040	860
2050	1,100
Total	22,000

Table 7.4-9 Annual Fuel Savings and Net Present Values in 2012 Associated with the MYs 2012-2016 & 2017-2025 Final Rules (2010 dollars)

Calendar Year	Untaxed (Billions)	Retail (Billions)
2012	$1.6	$1.8
2013	$3.9	$4.5
2014	$7.3	$8.3
2015	$12	$14
2016	$18	$21
2017	$26	$29
2018	$33	$37
2019	$42	$47
2020	$51	$57
2021	$62	$69
2022	$73	$82
2023	$85	$95
2024	$99	$110
2025	$110	$130
2030	$190	$210
2040	$290	$320
2050	$390	$420
NPV, 3%	$3,400	$3,700
NPV, 7%	$1,400	$1,600

7.4.3 Consumer Cost of Ownership Results

Table 7.4-10 summarizes the consumer cost of ownership for cash purchases of 2025MY vehicles.

Table 7.4-10 Consumer Cost of Ownership Metrics, Cash Purchase of 2025MY Vehicle (2010$)[a]

Metric	3% discount rate	7% discount rate
Increased Lifetime Costs	$3,200	$3,100
Lifetime Fuel Savings[b]	$13,500	$10,400
Lifetime Net Savings	$10,300	$7,200
"Breakeven" payback period	2.3 years	2.4 years

[a] The costs here are slightly conservative and overstated, as we did not subtract the cost of bringing the MY 2008 baseline to compliance with the MY 2011 standards, but rather used the direct estimate of bringing the MY 2008 vehicles to the MY 2016 technology. In the MYs 2012-2016 rule, we estimated this cost at $89 (See Page 4-18 in EPA-420-R-10-009) per vehicle on average, in 2007 dollars and using MY 2016 technology costs. This cost would be lower in later MYs, and higher in earlier MYs due to the effects of cost learning. We did not repeat the analysis of MY 2011 compliance costs for this rulemaking.
[b] Rebound miles are excluded in the control case.

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8 Vehicle Sales and Employment Impacts

8.1 Vehicle Sales Impacts

8.1.1 How Vehicle Sales Impacts were Estimated for this Rule

Predicting the effects of this rule on vehicle sales entails comparing two competing effects. On the one hand, as a result of this rule, the vehicles will become more expensive, which would, by itself, discourage sales. On the other hand, the vehicles will have improved fuel economy and thus lower operating costs, which makes them more attractive to consumers. As discussed in Preamble III.H.1.a, there are many competing hypotheses for why private markets are not providing what appear to be cost-effective energy-saving technologies, for vehicles as well as for other energy-conservation technologies. There are few empirical studies testing these hypotheses, though. The empirical literature does not provide clear evidence on how much of the value of fuel savings consumers consider at the time of vehicle purchase. It also generally does not speak to the efficiency of manufacturing and dealer pricing decisions. Thus, we do not provide quantified estimates of potential sales impacts.

In previous rulemakings, EPA and NHTSA conducted vehicle sales analyses by comparing the up-front costs of the vehicles with the present value of five years' worth of fuel savings. We assumed that the costs for the fuel-saving technologies would be passed along fully to vehicle buyers in the vehicle prices. The up-front vehicle costs were adjusted to take into account several factors that would affect consumer costs: the increased sales tax that consumers would pay, the increase in insurance premiums, the increase in loan payments that buyers would face, and a higher resale value, with all of these factors due to the higher up-front cost of the vehicle. Those calculations resulted in an adjusted increase in costs to consumers. We then assumed that consumers considered the present value of five years of fuel savings in their vehicle purchase, which is consistent with the length of a typical new light-duty vehicle loan, and is similar to the average time that a new vehicle purchaser holds onto the vehicle.[JJJJJJJJ] The present value of fuel savings was subtracted from technology costs to get a net effect on vehicle cost of ownership. We then used a short-run demand elasticity of -1 to convert a change in price into a change in quantity demanded of vehicles.[KKKKKKKK] An elasticity of -1 means that a 1% increase in price leads to a 1% reduction in quantity sold.

We do not here present a vehicle sales analysis using this approach. This rule takes effect for MY 2017-2025. In the intervening years, it is possible that the assumptions underlying this analysis, as well as market conditions, might change. Instead, Chapter 5.5

[JJJJJJJJ] In this rule, the 5-year payback assumption corresponds to an assumption that vehicle buyers take into account between 30 and 50 percent of the present value of lifetime vehicle fuel savings (with the variation depending on discount rate and model year).

[KKKKKKKK] For a durable good such as an auto, the elasticity may be smaller in the long run: though people may be able to change the timing of their purchase when price changes in the short run, they must eventually make the investment. We request comment on whether or when a long-run elasticity should be used for a rule that phases in over time, as well as how to find good estimates for the long –run elasticity.

includes a payback period analysis to estimate the number of years of fuel savings needed to recover the up-front costs of the new technologies. In other words, the payback period identifies the break-even point for new vehicle buyers. As discussed there, the payback period is 3.2 – 3.4 years for new vehicles, and even shorter for used vehicles (just over 1 year for a 5-year-old MY 2025 vehicle). That chapter also includes an assessment of the lifetime costs and benefits that accrue to a vehicle owner.

8.1.2 Consumer Vehicle Choice Modeling[LLLLLLLL]

An alternative to the vehicle sales analysis approach discussed above is the use of consumer vehicle choice models. In this section we describe some of the consumer vehicle choice models EPA has reviewed in the literature, and we describe the models' results and limitations that we have identified. The evidence from consumer vehicle choice models indicates a huge range of estimates for consumers' willingness to pay for additional fuel economy. Because consumer surplus estimates from consumer vehicle choice models depend critically on this value, we would consider any consumer surplus estimates of the effect of our rule from such models to be unreliable. In addition, the predictive ability of consumer vehicle choice models has not been tested. While vehicle choice models are based on sales of existing vehicles, vehicle models are likely to change, both independently and in response to this rule. The models may not predict well in response to these changes. Instead, we compare the value of the fuel savings associated with this rule with the increase in technology costs. EPA will continue its efforts to review the literature and (as described below) to explore the use of consumer choice modeling but, given the known limitations and uncertainties of vehicle choice models, EPA has not conducted an analysis using these models for this rule.

This rule will lead automakers to change characteristics – in particular, the fuel economy -- of the vehicles they produce. These changes will affect the cost of manufacturing the vehicle; as a result, the prices of the vehicles will also change.

In response to these changes, the number and types of vehicles sold is likely to change. When consumers buy vehicles, they consider both their personal characteristics (such as age, family composition, income, and their vehicle needs) and the characteristics of vehicles (e.g., vehicle size, fuel economy, and price). In response to the changes in vehicle characteristics, consumers will reconsider their purchases. Increases in fuel economy are likely to be attractive to consumers, but increases in price, as well as any detrimental changes in other vehicle characteristics, may be deterrents to purchase. As a result, consumers may choose a different vehicle than they would have purchased in the absence of the rule. The changes in prices and vehicle characteristics are likely to influence consumers on multiple market scales: the total number of new vehicles sold; the mix of new vehicles sold; and the effects of the sales on the used vehicle market.

[LLLLLLLL] This section is drawn heavily from Helfand, Gloria, and Ann Wolverton, "Evaluating the Consumer Response to Fuel Economy: A Review of the Literature." International Review of Environmental and Resource Economics 5 (2011): 103-146.

Consumer vehicle choice modeling (CCM) is a method used to predict what vehicles consumers will purchase based on vehicle characteristics and prices. In principle, it should produce more accurate estimates of total compliance costs compared to models that hold fleet mix constant, since it predicts changes in the fleet mix that can affect total compliance costs. It can also be used to measure changes in consumer surplus, the benefit that consumers perceive from a good over and above the purchase price. (Consumer surplus is the difference between what consumers would be willing to pay for a good, represented by the demand curve, and the amount they actually pay. For instance, if a consumer were willing to pay $30,000 for a new vehicle, but ended up paying $25,000, the $5000 difference would be called consumer surplus.)

A number of consumer vehicle choice models have been developed. They vary in the methods used, the data sources, the factors included in the models, the research questions they are designed to answer, and the results of the models related to the effects of fuel economy on consumer decisions. This section will give some background on these differences among the models.

8.1.2.1 Methods

Consumer choice models (CCMs) of vehicle purchases typically use a form of discrete choice modeling. Discrete choice models seek to explain discrete rather than continuous decisions. An example of a continuous decision is how many pounds of food a farm might grow: the pounds of food can take any numerical value. Discrete decisions can take only a limited set of values. The decision to purchase a vehicle, for instance, can only take two values, yes or no. Vehicle purchases are typically modeled as discrete choices, where the choice is whether to purchase a specified vehicle. The result of these models is a prediction of the probability that a consumer will purchase a specified vehicle. A minor variant on discrete choice models estimates the market share (a continuous variable between 0 and 1) for each vehicle. Because the market share is, essentially, the probability that consumers will purchase a specific vehicle, these approaches are similar in process; they differ mostly in the kinds of data that they use.

The primary methods used to model vehicle choices are nested logit and mixed logit.[MMMMMMMM] In a nested logit, the model is structured in layers. For instance, the first layer may be the choice of whether to buy a new or used vehicle. Given that the person chooses a new vehicle, the second layer may be whether to buy a car or a truck. Given that the person chooses a car, the third layer may be the choice among an economy, midsize, or luxury car. Examples of nested logit models include Goldberg,[490] Greene et al.,[491] and McManus.[492]

In a mixed logit, personal characteristics of consumers play a larger role than in nested logit. While nested logit can look at the effects of a change in average consumer characteristics, mixed logit allows consideration of the effects of the distribution of consumer

[MMMMMMMM] Logit refers to a statistical analysis method used for analyzing the factors that affect discrete choices (i.e., yes/no decisions or the choice among a countable number of options).

characteristics. As a result, mixed logit can be used to examine the distributional effects on various socioeconomic groups, which nested logit is not designed to do. Examples of mixed logit models include Berry, Levinsohn, and Pakes,[493] Bento et al.,[494] and Train and Winston.[495]

While discrete choice modeling appears to be the primary method for consumer choice modeling, others (such as Kleit[496] and Austin and Dinan[497]) have used a matrix of demand elasticities to estimate the effects of changes in cost. The discrete choice models can produce such elasticities. Kleit as well as Austin and Dinan used the elasticities from an internal GM vehicle choice model.

8.1.2.2 Data Sources

The predictions of vehicle purchases from CCMs are based on consumer and vehicle characteristics. The CCMs identify the effects of changing the characteristics on the purchase decisions. These effects are typically called the parameters or coefficients of the models. For instance, the model parameters might predict that an increase in a person's income of 10% would increase the probability of her purchasing vehicle A by 5%, and decrease the probability of her purchasing vehicle B by 10%.

The parameters in CCMs can be developed either from original data sources (estimated models), or using values taken from other studies (calibrated models).

Estimated models use datasets on consumer purchase patterns, consumer characteristics, and vehicle characteristics to develop their original sets of parameters. The datasets used in these studies sometimes come from surveys of individuals' behaviors.[498] Because they draw on the behavior of individuals, they provide what is sometimes called micro-level data. Other studies, that estimate market shares instead of discrete purchase decisions, use aggregated data that can cover long time periods.[499]

Calibrated models rely on existing studies for their parameters. Researchers may draw on results from a number of estimated models, or even from research other than CCM, to choose the parameters of the models. The Fuel Economy Regulatory Analysis Model developed for the Energy Information Administration[500] and the New Vehicle Market Model developed by NERA Economic Consulting[501] are examples of calibrated models.

8.1.2.3 Factors Included in the Models

Consumer choice models vary in their complexity and levels of analysis. Some focus only on the new vehicle market;[502] others consider the choice between new vehicles and an outside good (possibly including a used vehicle);[503] others explicitly consider the relationship between the new and used vehicle markets.[504] Some models include consideration of vehicle miles traveled,[505] though most do not.

The models vary in their inclusion of both consumer and vehicle information. One model includes only vehicle price and the distribution of income in the population influencing choice;[506] others include varying numbers and kinds of vehicle and consumer attributes.

Some models include only the consumer side of the vehicle market;[507] others seek to represent both consumer and producer decisions.[508] Models that include only the consumer side are suitable for reflecting consumer choices, but they do not allow for revisions of vehicle characteristics in response to consumer preferences. Including producer behavior allows for vehicle characteristics such as price and fuel economy to be the result of market forces rather than characteristics of the existing fleet. For instance, in the context of "feebates" (subsidizing fuel-efficient cars with revenue collected by taxing fuel-inefficient vehicles), Greene et al. estimated that 95% of the increase in fuel economy was due to addition of technology rather than changes in vehicles sold.[509] Including auto maker response is a complex exercise. Auto makers are commonly considered to have market power; they can influence the prices that consumers pay to increase their profits. As a result, the price increases that consumers face may reflect strategic factors that could make them higher or lower than the technology costs. In addition, auto makers may seek to influence consumer preferences through marketing and advertising.[510] Even those vehicle choice models that include a producer model may not include much detail, due to computational limits: it is unusual for models to allow both buyers and producers to choose one vehicle characteristic, much less multiple characteristics.[511]

8.1.2.4 Research Questions for the Models

Consumer choice models have been developed to analyze many different research and policy questions. In part, these models have been developed to advance the state of economic modeling. The work of Berry, Levinsohn, and Pakes,[512] for instance, is often cited outside the motor vehicle context for its incorporation of multiple new modeling issues into its framework. In addition, because the vehicle sector is a major part of the U.S. economy and involved in many public policy discussions, research questions cover a wide gamut. These topics have included the effects of voluntary export restraints on Japanese vehicles compared to tariffs and quotas,[513] the market acceptability of alternative-fuel vehicles,[514] the effects of introduction and exit of vehicles from markets,[515] causes of the decline in market shares of U.S. automakers,[516] and the effects of gasoline taxes[517] and "feebates"[518] (subsidizing fuel-efficient cars with revenue collected by taxing fuel-inefficient vehicles).

8.1.2.5 The Effect of Fuel Economy on Consumer Decisions

Consumer vehicle choice models typically consider the effect of fuel economy on vehicle purchase decisions. Fuel economy can appear in various forms in these models.

Some models[519] incorporate fuel economy through its effects on the cost of owning a vehicle. With assumptions on the number of miles traveled per year and the cost of fuel, it is possible to estimate the fuel savings (and perhaps other operating costs) associated with a more fuel-efficient vehicle. Those savings are considered to reduce the cost of owning a vehicle: effectively, they reduce the purchase price. This approach relies on the assumption that, when purchasing vehicles, consumers can estimate the fuel savings that they expect to receive from a more fuel-efficient vehicle and consider the savings equivalent to a reduction in purchase price. The vehicle sales method described in Chapter 8.1.1 uses a variant on this approach, in which it is assumed that consumers consider some fraction of future fuel savings. Turrentine and Kurani[520] question this assumption; they find, in fact, that consumers do not make this calculation when they purchase a vehicle. The question remains, then, how or whether consumers take fuel economy into account when they purchase their vehicles.

Most estimated consumer choice models, instead of making assumptions about how consumers incorporate fuel economy into their decisions, use data on consumer behavior to identify that effect. In some models, miles per gallon is one of the vehicle characteristics included to explain purchase decisions. Other models use fuel consumption per mile, the inverse of miles per gallon, as a measure.[521] Since consumers pay for gallons of fuel, then this measure can assess fuel savings relatively directly.[522] Yet other models multiply fuel consumption per mile by the cost of fuel to get the cost of driving a mile,[523] or they divide fuel economy by fuel cost to get miles per dollar.[524] It is worth noting that these last two measures assume that consumers respond the same way to an increase in fuel economy as they do to a decrease in the price of fuel when each has the same effect on cost per mile driven.[NNNNNNNN] On the one hand, while this assumption does not rely on as complex a calculation as the present value of fuel savings that Turrentine and Kurani examined, it suggests a calculating consumer. On the other hand, using a form of cost per mile is a way to recognize the role of fuel prices in consumers' purchase of fuel economy: recent research[525] presents results that higher fuel prices play a major role in that decision.

Greene and Liu,[526] in a paper published in 1988, reviewed 10 papers using consumer vehicle choice models and estimated for each one how much consumers would be willing to pay at time of purchase to reduce vehicle operating costs by $1 per year. They found that people were willing to pay between $0.74 and $25.97 for a $1 decrease in annual operating costs for a vehicle. This is clearly a very wide range: while the lowest estimate suggests that people are not willing to pay $1 once to get $1 per year reduced costs of operating their vehicles, the maximum suggests a willingness to pay 35 times as high. For comparison, the present value of saving $1 per year for 15 years at a 3% discount rate is $11.94, while a 7% discount rate produces a present value of $8.78. While this study is quite old, it suggests that, at least as of that time, consumer vehicle choice models produced widely varying estimates of the value of reduced vehicle operating costs.

A newer literature review from David Greene[527] suggests continued lack of convergence on the value of increased fuel economy to consumers. Of 27 studies, willingness to pay for fuel economy as a percent of the expected value of fuel savings varied from highly positive to highly negative. Significant numbers of studies found that consumers overvalued fuel economy, undervalued fuel economy, or roughly valued fuel economy correctly relative to fuel savings. Part of the difficulty may be, as these papers note, that fuel economy may be correlated (either positively or negatively) with other vehicle attributes, such as size, power, or quality, not all of which may be included in the analyses; as a result, "fuel economy" may in fact represent several characteristics at the same time. Indeed, Gramlich[528] includes both

[NNNNNNNN] Likewise, these measures assume consumers respond the same way to increases and decreases in cost per mile of driving, as well as if those increases and decreases are large shocks rather than small, gradual changes. The issue of potential asymmetric consumer response to increased fuel efficiency compared to other types of changes to the cost of driving also arises and is discussed in the context of the VMT rebound effect (see Section III.H.4 of the Preamble and Chapter 4.2.5 of the TSD).

fuel cost (dollars per mile) and miles per gallon in his analysis, with the argument that miles per gallon measures other undesirable quality attributes, while fuel cost picks up the consumer's demand for improved fuel economy. Greene finds that, while some of the variation may be explainable due to issues in some of the studies, the variation shows up in studies that appear to be well conducted. As a result, further work needs to be conducted before it is possible to identify the role of fuel economy in consumer purchase decisions.

Some studies[529] argue that automakers could increase profits by increasing fuel economy because the amount that consumers are willing to pay for increased fuel economy outweighs the costs of that improvement. Other studies[530] have found that increasing fuel economy standards imposes welfare losses on consumers and producers, because consumers should already be buying as much fuel economy as they want. In the course of reaching this result, though, at least one of these studies[531] notes that its baseline model implies that consumers are willing to buy more fuel economy than producers have provided; they have to adjust their model to eliminate these "negative-cost" fuel economy improvements.

The models do not appear to yield very consistent results on the role of fuel economy in consumer and producer decisions.

8.1.2.6 Why Market Outcomes May Not Reflect Full Appreciation for Fuel Economy that Pays for Itself

A detailed and wide ranging literature attempts to explain why market outcomes for energy-using products appear to reflect under-investment in energy saving technologies that – at least using a present value calculation based on engineering estimates – appear to pay for themselves. Existing research does not provide a definitive answer to this question. Potential explanations are bounded by two scenarios. On the one hand, purely private benefits of fuel economy (fuel savings, time savings, increases in driving time) must be accompanied by private losses of the same magnitude. However, if there is no such private loss, or if it is small or insignificant, then there is a market or behavioral failure.

This disconnect between net present value estimates of energy-conserving cost savings and what consumers actually spend on energy conservation is often referred to as the Energy Paradox,[532] since consumers appear to undervalue a wide range of investments in energy conservation. There are many possible explanations for the paradox discussed in the literature.[533] Some explanations point to costs or aspects of consumer decision-making unaccounted for in a simple present value calculation, while others point to potential behavioral or market failures. There is little empirical literature to help the analyst determine which combination of hypothesis offers the most credible explanation. Some possibilities include:

- 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.

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

- 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 be especially averse to the short-term losses associated with the higher prices of energy efficient products relative to the future fuel savings (the behavioral phenomenon of "loss aversion").

- 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.[oooooooo]

The extent to which fuel economy is optimized relative to other, potentially more salient vehicle attributes (such as engine horsepower and seating capacity) in market outcomes for new vehicles remains an important area of uncertainty. There are significant challenges involved in effectively interpreting and anticipating consumer preferences for various vehicle attributes and amenities. There are significant lead times to market, potential return to scale limits on the range of options provided for a given attribute or amenity, market transaction frictional factors, and other factors inherent to the nature of these costly durable goods which may contribute to imperfect satisfaction of market demand for fuel economy among a highly heterogeneous customer base. Both sides of the market would be expected to attempt to maximize the utility they gain from these transactions; they presumably rely heavily in their calculations on the uncertain benefits of savings from fuel economy improvements, and yet market outcomes may still appear to reflect potential foregone opportunities to increase utility. We remain interested in these market dynamics, their

[oooooooo] For instance, in MY 2010, the range of fuel economy (combined city and highway) available among all listed 6-cylinder minivans was 18 to 20 miles per gallon. With a manual-transmission 4-cylinder minivan, it is possible to get 24 mpg. See http://www.fueleconomy.gov, which is jointly maintained by the U.S. Department of Energy and the EPA.

underlying causes, and their potential significance for assessing the potential incremental effects of pollution control standards.

8.1.2.7 Electric Vehicles and Other New Vehicles

Modeling the introduction of new vehicles can be a greater challenge than modeling the existing vehicle market, because the modeler does not have data on how many of the new vehicles consumers buy. Nevertheless, it can be possible to estimate the effects of new vehicle introduction by identifying characteristics for the new vehicles and using those in a vehicle choice model. For instance, as discussed above, the models can estimate effects on the vehicle market when vehicles change their fuel economy or price. If the model incorporates other vehicle attributes important to the new vehicles, such as size, performance, or range, then the effect of the introduction can be modeled by applying the parameters for those features to the new vehicle characteristics.

As discussed above, some models rely on vehicle price as the primary or only explanatory variable. Even in these models, it is possible, with some additional information, to consider the effects of new vehicle introduction. The first step is to find a vehicle similar on as many dimensions as possible to the new vehicle. For instance, if the change is to create an electric vehicle (EV) version of an existing model, then the existing model serves as the base vehicle. Next, it is necessary to measure the changes in vehicle attributes of interest to potential vehicle buyers. For an EV, changes in vehicle driving range and cost of fueling may be two such attributes. The next requirement is information on the value to consumers of the attributes that change between the new and the base vehicle. Multiplying the value for that attribute by the change in the attribute provides an estimate of the benefit or cost associated with changing that characteristic. That amount can then be added to or subtracted from the vehicle purchase price to give an adjusted purchase price reflecting the changed characteristic. This procedure is just an extension of the approach, discussed above, used to incorporate fuel economy improvements into vehicle choice models, by calculating future fuel savings and subtracting them (either in whole or a fraction) from vehicle purchase price.

Incorporating new vehicles into a vehicle choice model, then, requires estimates of the changes in key attributes from conventional vehicles, and estimates of the value, also called the willingness to pay (WTP), that consumers put on those attributes.

Electric vehicles (EVs) will have a number of changes in vehicle characteristics from any baseline model. EVs are likely to have a smaller driving range between refuelings than conventional vehicles, due to the large battery capacity needed to increase range. The ability to recharge at home may be a convenient, desirable feature for people who have garages with electric hookups, but not for people who park on the street. If an infrastructure develops for recharging vehicles with the convenience approaching that of buying gasoline, range or home recharging may become less of a barrier to purchase. The reduced tailpipe emissions and reduced noise may be attractive features to some consumers.[PPPPPPPP] They may have different

[PPPPPPPP] For instance, Hidrue et al. (Hidrue, Michael K., George R. Parsons, Willett Kempton, and Meryl P. Gardner. "Willingness to Pay for Electric Vehicles and their Attributes." Resource and Energy Economics performance or storage capacity. If sufficient data were available, the changes in these attributes, combined with WTP for each of the attributes, could be used to adjust the purchase price of the baseline vehicle to estimate consumers' WTP for the electric version of a vehicle. Greene (2001), for instance, used this approach for a model that simulates choice, not only for EVs, but also for other alternative-fuel vehicles.[534] In that model, he considers only one base vehicle, a passenger car, but considers the effect on WTP of fuel cost per mile, range, acceleration, and several other vehicle attributes.

Vehicle driving range has received attention because of the current paucity of recharging infrastructure: if the driver of an EV gets low on fuel, it may be difficult to find a place to recharge. Because range appears to be a major factor in EV acceptability -- indeed, a factor in the development of plug-in hybrid-electric vehicles is responding to this concern -- it is starting to draw attention in the research community.

In several studies, researchers have used stated preference conjoint analysis to estimate the effect of vehicle range on consumer vehicle choice. In a conjoint analysis, consumers are given a choice between several vehicles with different attributes. One choice might be, for instance, between a baseline car and another car with higher range and a higher purchase price. The choices that consumers make (e.g., how much higher does the purchase price have to be for the consumer not to choose more range?) provide data that can be used to estimate the role of vehicle attributes in the consumer's choice. Stated preference analysis is sometimes considered less reliable than actual market behavior, because what people say they will do in hypothetical situations may not match what they would do in actual situations. On the other hand, stated preference methods can be used to study goods where market data do not exist, such as future market products undergoing development (marketing studies often use stated preference methods), or environmental goods. Because electric vehicles are not in widespread enough use for market studies, stated preference studies are, at this point, one of the few options to examine consumer behavior relating to these vehicles.

Table 8.1-1 summarizes results from several conjoint studies that include the effects of extending range (in the table, from 150 to 300 miles, to present standardized results). Variation of results in the table is from income or other demographic factors, not from confidence intervals. The results suggest that the value of additional range varies among consumers, and the amount of that variation is changing (perhaps shrinking) in more recent studies.

33(3) (2011): 686-705) find that some consumers are willing to pay $5100 more for vehicles with 95% lower emissions than the vehicles they otherwise aim to purchase.

Table 8.1-1 Willingness to Pay for Increasing Range Calculated from Various Studies

Study (Date)	Value of extending range from 150 to 300 miles (dollar year)	Value of additional range in 2010$[a]
Bunch et al. (1993)[b]	$7,600 (1991$)	$11,300
Kavelek (1996) for California Energy Commission[c]	$2600 - $41,900 (1993$)	$3700 - $59,400
Resource Systems Group (2009) for California Energy Commission[d]	$2900 - $7500 (2009$)	$2900 - $7600
Hess et al. (2009), using the same data as Resource Systems Group (2009)[e]	$2400 - $8500 (2009$)	$2400 - $8600
Hidrue et al. (2011)[f]	$3800 - $10,400 (2009$)	$3800 - $10,500

[a]Values adjusted to 2010$ using the Bureau of Economic Analysis GDP deflator.
[b]Bunch, David S., Mark Bradley, Thomas F. Golob, and Ryuichi Kitamura. "Demand for Clean-Fuel Vehicles in California: A Discrete-Choice Stated Preference Pilot Project." Transportation Research Part A 27A(3) (1993): 237-253. The value of range was, in their model, assumed to be the same for all people.
[c]Kavelek, Chris. "CALCARS: The California Conventional and Alternative Fuel Response Simulator." Demand Analysis Office, California Energy Commission, April 1996. The variation in values is due to willingness to pay (WTP) varying by income levels and for one-car and two-car households. The coefficient on range for one-car households was not statistically significantly different from zero (t-statistic = 1.5), but it was for 2-car households (t-statistic = 3.02). The minima and maxima presented here represent the values across both ownership and income categories.
[d]Resource Systems Groups, Inc. "Transportation Fuel Demand Forecast Household and Commercial Fleet Survey Task 8 Report: Logistic Regression Analysis and Results." Prepared for California Energy Commission, June 2009.
[e]Hess, S., T. Adler, M. Fowler and A. Bahreinian "The Use of Cross-nested Logit Models for Multi-Dimensional Choice Processes: The Case of the Demand for Alternative Fuel Vehicles," *Proceedings of the 2009 European Transport Conference*, Leiden, Netherlands, 2009. This study uses the same data as the Resource Systems Group study. The coefficient on range was not statistically significantly different from zero in these regressions: t-statistics varied from 1.29 to 1.52. The variation in values is due to willingness to pay (WTP) varying by income levels and statistical specification. The minima and maxima presented here represent the values across both income categories and specifications.
[f]Hidrue, Michael K., George R. Parsons, Willett Kempton, and Meryl P. Gardner. "Willingness to Pay for Electric Vehicles and their Attributes." Resource and Energy Economics 33(3) (2011): 686-705. The range of values is due to the model separating consumers into "gasoline vehicle-oriented" and "electric vehicle-oriented" groups. The EV-oriented group has higher WTP for additional range.

Driving range may be a major factor in consumers' decisions on EVs, but it is not the only attribute that may be important to potential buyers (e.g., as noted, Hidrue et al. find that some consumers appear willing to pay substantially for reduced tailpipe emissions). A model that does not incorporate the other factors important to consumers' decisions may not perform well in predicting vehicle purchases. In addition, as mentioned above, and as seen in Table 8.1-1, it is likely that the WTP values for attributes of EVs will change over time, particularly if EVs are used more widely, the infrastructure to fuel the vehicles becomes more accessible, and consumers develop more familiarity and understanding of the vehicles. Thus, challenges associated with predicting market shares for EVs are even more serious than those already serious challenges associated with predicting market shares for conventional vehicles.

8.1.2.8 EPA Exploration of Vehicle Choice Modeling

In order to develop greater understanding of these models, EPA is developing a vehicle choice model, although not for this rulemaking. In its current form, the model assumes that the vehicle fleet and all characteristics of each vehicle, except vehicle prices and fuel economy, stay the same. The model will predict changes in the vehicle fleet, at the individual-configuration level and at more aggregated levels, in response to changes in vehicle fuel economy and price.

The EPA model uses a nested logit structure common in the vehicle choice modeling literature, as discussed above in Chapter 8.1.2.1. “Nesting” refers to the decision-tree structure of the model, and “logit” refers to the fact that the choices are discrete (i.e., yes/no decisions about which vehicles to purchase, instead of continuous values).

The nesting involves a hierarchy of choices. In its current form, at the initial decision node, consumers choose between buying a new vehicle or not. Conditional on choosing a new vehicle, consumers then choose between passenger vehicles, cargo vehicles, and ultra-luxury vehicles. The next set of choices subdivides each of these categories into vehicle type (e.g., standard car, minivan, SUV, etc.). Next, the vehicle types are divided into classes (small, medium, and large SUVs, for instance), and then, at the bottom, are the individual vehicle configurations.

At this bottom level, vehicles that are similar to each other (such as standard subcompacts, or prestige large vehicles) end up in the same “nest.” Substitution within a nest is considered much more likely than substitution across nests, because the vehicles within a nest are more similar to each other than vehicles in different nests. For instance, a person is more likely to substitute between a Chevrolet Aveo and a Toyota Yaris than between an Aveo and a pickup truck. In addition, substitution is greater at low decision nodes (such as individual configurations) than at higher decision nodes (such as the buy/no buy decision), because there are more choices at lower levels than at higher levels.

Parameters for the model (including demand elasticities and the value of fuel economy in purchase decisions) were selected based on a review of values found in the literature on vehicle choice modeling. As discussed above, a number of studies have estimated these parameters. Those estimates, combined with some theoretical requirements,[QQQQQQQQ] assist in assigning values for the parameters. The model will allow individual users to change those parameters.

The fuel economy of a vehicle is used to adjust the price of the vehicle, using a version of the procedure discussed in Chapter 8.1.2.7: the value that the consumer places on fuel economy is multiplied by the change in fuel economy and incorporated into the “effective

[QQQQQQQQ] The theory of nested logit requires that the price slopes (the change in utility as vehicle full price changes, a measure of consumer responsiveness to price changes) must be higher in absolute value for lower nests. This condition reflects the point, discussed above, that substitution is greater at lower decision notes than at higher ones.

price" of the vehicle. In practice, implementing this calculation involves calculating the change in expenditures on fuel based on schedules of VMT, vehicle survival, and fuel prices in the future consistent with those in OMEGA. As discussed in Chapter 8.1.2.5, there is no consensus value for consumers' willingness to pay for improved fuel economy: estimates vary tremendously. The model assumes that consumers will use some years of discounted fuel savings, with the modeler able to input both the number of years and the discount rate to be used in the analysis.

The vehicle choice model takes as inputs an initial fleet of vehicles (including the initial sales and fuel economy) in the absence of standards, the cost of technologies added to each vehicle to comply with standards, and the change in fuel economy. With the initial sales mix, for each vehicle, the model calculates a vehicle-specific constant that summarizes the value of all attributes of the vehicle other than price and fuel economy. This constant ensures that the model will predict changes in consumer response that would result only from changes in price and fuel economy. This constant substitutes for estimating the effects of changes in all other vehicle characteristics; the underlying assumption is that these other vehicle characteristics do not change.[RRRRRRRR] For instance, it assumes that a Ford Escape will not change in size, power, or accessories; the only changes will be to its cost and its fuel economy.

The model assumes that the increase in vehicle cost associated with increased technology is fully passed through as an increase in vehicle price, and some years of fuel savings (which the modeler may select) offset this price increase. It then calculates changes in total fleet size and in sales mix, at the individual-configuration level and at the level of vehicle class, due to the changes in fuel economy and vehicle prices. It also calculates changes in consumer surplus associated with the changes in fuel economy and vehicle prices.

The model has undergone peer review.[535] The reviewers were generally supportive of the model structure and parameters, with two major qualifications.

First, peer reviewers recommended that the model should interact closely with OMEGA, EPA's technology cost and effectiveness model, and its appropriate use may depend on that interaction. For instance, it is possible that the predicted changes in fleet mix will lead to predictions of vehicle sales for auto makers that do not meet the standards, because the mix and volume of vehicles sold changed from the initial levels. To correct this problem, it is necessary to feed the new fleet mix back into OMEGA (which calculates costs and compliance) and get a new set of output, which is then fed back into the vehicle choice model. OMEGA increases technologies, and thus costs, to improve compliance; those adjustments would then again affect vehicle demand. We expect that this iterative process would converge to a fleet mix that would meet standards. Performing this iteration requires development of an interface between the vehicle choice model and OMEGA to ensure accurate transmission of data between the models. At this time, the vehicle choice model

[RRRRRRRR] As explained in Section III.D of the preamble, as part of the technology cost analysis for the rule, the agencies have estimated the cost of maintaining all vehicle utility, with minor exceptions.

takes output from OMEGA, but the results of the modeling do not feed easily back into OMEGA. Building this interface is an expected part of our future modeling work.

Second, the peer review raised the issue of the uncertainties surrounding the model parameters and suggested the development of capacity to conduct uncertainty analysis. As discussed in Section 8.1.2.5, the role of fuel economy in consumer decisions is one source of uncertainty; the price slopes used for the different nests are also not known with certainty. EPA agrees that use of the model should involve, at the least, sensitivity analysis over key parameters, and we plan to investigate greater incorporation of uncertainty analysis in the model.

We note as well that the current model does not take EVs or other alternatively fueled vehicles into account. As discussed in Section 8.1.2.7, the values for willingness to pay for features such as range and different refueling infrastructures appear to be subject to great uncertainty. EPA's current model does not include these vehicles, because we are seeking to gain experience and confidence with the modeling where it is likely to work best before we investigate modeling where more uncertainty is involved. The incorporation of new vehicles of any kind in the modeling is another area for future work.

As discussed in Preamble Section III.H.1, EPA is not using its preliminary consumer choice model in this rulemaking because we believe it needs further development and testing before we have confidence in its use. As the peer reviewers noted, it has not yet been integrated with OMEGA, an important step for ensuring that changes in the vehicle fleet estimated by the model will result in a fleet compliant with the standards. In addition, concerns remain that vehicle choice models have rarely been validated against real-world data. In response to these concerns, we would expect any use of the model to involve, at the least, a number of sensitivity analyses to examine the robustness of results to key parameters. We will continue model development and testing to understand better the results and limitations of using the model.

8.1.2.9 Summary and Additional Considerations

Consumer vehicle choice modeling in principle could provide a great deal of useful information for regulatory analysis, helping to answer some of the central questions about relevant effects on consumer welfare. In practice, the advantages depend on the success of models in predicting changes in fleet size and mix.

First, consumer vehicle choice modeling has the potential to describe more accurately the impact of a policy, by identifying market shifts. More accurate description of the market resulting from a policy can improve other estimates of policy impacts, such as the change in total vehicle emissions or vehicle miles traveled. The predictive ability of models, though, is not proven.

Vehicle choice models can incorporate the effects on consumer decisions of changes in vehicle characteristics, if there are estimates of the value that consumers put on changes in those characteristics. These willingness-to-pay values may, however, be sensitive to the ways they are estimated, as indicated in the discussion of the value that consumers place on fuel economy in their purchase decisions. Especially for characteristics associated with advanced technology vehicles, such as EVs, the willingness-to-pay values may change over time as consumers develop more experience with the vehicles and these characteristics. Models based on current estimates may not predict well for the future.

Consumer choice modeling has the potential to improve estimates of the compliance costs of a rule. Consumers can either accept the new costs and vehicle characteristics, or they can change which vehicles they buy. Using a vehicle choice model is likely to reduce estimated compliance costs: because the model allows consumers to choose among accepting the new vehicle, buying a different vehicle, or not buying a vehicle, the model assumes that consumers have additional options, which improves their welfare relative to the assumption that consumers will not change their buying behavior.

An additional complication associated with consumer choice modeling is accurate prediction of producers' responses to the rule. While it is possible to include auto makers' decisions (for instance, on setting prices) into vehicle choices, computational limits affect the richness of these models. In addition, the pricing paths predicted by these models have not, to our knowledge, been tested against actual behavior; and auto makers may not pass along vehicle costs in the same way in the future as they have in the past. Technology costs, while an accurate measure of the opportunity cost of resources to society, may overestimate or underestimate the effect on the prices that consumers face.

Consumer choice models can be used to calculate consumer surplus impacts on vehicle purchase decisions. Because these values are based on the estimates of changes in vehicle sales and fleet mix, consumer surplus measures may not be accurate if the changes in vehicle sales and fleet mix are not well estimated.

Principles of welfare analysis can be useful for understanding the role of consumer vehicle choice models in benefit-cost analysis. In particular, except for EVs, the technology cost estimates developed in this rule take into account the costs to hold other vehicle attributes, such as size and performance, constant. In addition, the analysis assumes that the full technology costs are passed along to vehicle buyers. With these assumptions, because welfare losses are monetary estimates of how much buyers would have to be compensated to be made as well off as in the absence of the change,[SSSSSSSS] the price increase measures the loss to the buyer.[TTTTTTTT] Assuming that the full technology cost gets passed along to the

[SSSSSSSS] This approach describes the economic concept of compensating variation, a payment of money after a change that would make a consumer as well off after the change as before it. A related concept, equivalent variation, estimates the income change that would be an alternative to the change taking place. The difference between them is whether the consumer's point of reference is her welfare before the change (compensating variation) or after the change (equivalent variation). In practice, these two measures are typically very close together.

[TTTTTTTT] Indeed, it is likely to be an overestimate of the loss to the buyer, because the buyer has choices other than buying the same vehicle with a higher price; she could choose a different vehicle, or decide not to buy a new vehicle. The buyer would choose one of those options only if the alternative involves less loss than paying the higher price. Thus, the increase in price that the buyer faces would be the upper bound of loss of consumer buyer as an increase in price, the technology cost thus measures the welfare loss to the buyer. Increasing fuel economy would have to lead to other changes in the vehicles that buyers find undesirable for there to be additional losses not included in the technology costs.

Given the current limitations in modeling the role of fuel economy in vehicle purchase decisions, and limitations in modeling market responses to the new regulations, in this rule EPA holds constant the vehicle fleet size and mix in its calculations of the impacts of this rule, and compares the fuel and other savings that consumers will receive with the technology costs of the vehicles. EPA continues to explore options for including consumer and producer choice in modeling the impacts of fuel economy-related regulations. This effort includes further review of existing consumer vehicle choice models, the estimates of consumers' willingness to pay for increased fuel economy, and overall effects on consumer welfare, as well as EPA's further development of its vehicle choice model for use in the future.

8.1.3 Impact of the Rule on Affordability of Vehicles and Low-Income Households

Because this rule is expected to increase the up-front costs of vehicles, with the fuel savings that recover those costs coming in over time, questions have arisen about the effects of this rule on whether access to credit may limit consumers' ability to purchase new vehicles, on low-income households, and on the availability of low-priced vehicles. Section III.H.11.b. of the Preamble discusses these issues in the context of public comments received on the rule; here we provide some background and information on sources of data in that discussion.

When a lender is deciding whether to issue a loan to a prospective vehicle buyer, the amount of the vehicle loan and the person's income are two major factors in the loan application. If lenders in fact restrict themselves to consideration of only those two factors, then the higher up-front costs of the new vehicles subject to this rule would reduce buyers' abilities to get loans. The fuel savings would not come into play to counter-balance this cost, even though, as shown in the payback period analysis (RIA Chapter 5.5), the fuel savings exceed the increased loan payments from the first month of the loan. Thus, if lenders do not take fuel savings into account in providing loans, people who are borrowing near the limit of their abilities to borrow will either have to change what vehicles they buy, or not buy vehicles at all.

On the other hand, some evidence suggests that the loan market may evolve to take fuel savings into greater account in the lending decision. Some lenders currently give discounts for loans to purchase more fuel-efficient vehicles.[536] An internet search on the term "green auto loan" produced more than 50 lending institutions that provide reduced loan rates for more fuel-efficient vehicles.[537] Indeed, it is possible (though unknown at this time) that the auto loan market may evolve to include further consideration of fuel savings, as those savings play a significant factor in offsetting the increase in up-front costs of vehicles.

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welfare, unless there are other changes to the vehicle due to the fuel economy improvements that make the vehicle less desirable to buyers.

It is possible that future trends in the auto loan market may affect future vehicle sales. It is also possible that some people who have significant debt loads may not be able to get financing for some of these new vehicles; they may have to buy different vehicles (including used vehicles) or delay purchase. For others who borrow on credit, though, as discussed in RIA Chapter 5.5, the fuel savings are expected to outweigh the increased loan costs from the time of vehicle purchase. The rule thus may make vehicles more affordable to the public, by reducing consumers' vulnerability to fuel price jumps.

The effects of this rule on low-income households depends on its impacts, not only in the new vehicle market, but also in the used vehicle market. Two sources of information on vehicle ownership by income are the 2010 Consumer Expenditure Survey (CES) conducted by the Bureau of Labor Statistics,[538] and the 2007 Survey of Consumer Finances (SCF) conducted by the Federal Reserve System.[539] The Consumer Expenditure Survey data indicate that, though the average household spent more on vehicle purchases ($2,588) than on gasoline and oil ($2,132), households in the bottom 40 percent of income spent more on fuel ($1,304) than on vehicles ($1,106); in addition, they spent more on used vehicles ($756) than on new vehicles ($330). Households in the lowest 20 percent of income spent only $127 on new vehicles, $497 on used vehicles, and $1,009 on fuel. These data suggest that the used-vehicle market is more important for low-income households than the new-vehicle market, and that they are more vulnerable to changes in fuel prices than they are to changes in vehicle prices. The Survey of Consumer Finances asks households about purchase information in a number of categories, including vehicles. For the 2007 survey, we identified the households in the survey who had bought MY 2007 or 2008 vehicles, and further looked at the income categories for those consumers. Those with income less than $35,200 (the maximum income for those in the bottom 40 percent of income in the CES) bought about 17 percent of new vehicles; those with income below $18,400 (the bottom quintile) bought fewer than 2 percent of new vehicles. These data further support the idea that low-income households are more affected by the impact of the rule on the used-vehicle market than on the new-vehicle market.

The effect of this rule on the used vehicle market will be related to its effects on new vehicle prices, the fuel efficiency of new vehicle models, the fuel efficiency of used vehicles, and the total sales of new vehicles. If the value of fuel savings resulting from improved fuel efficiency to the typical potential buyer of a new vehicle outweighs the average increase in new models' prices, sales of new vehicles could rise, and the used vehicle market may increase in volume as new vehicle buyers sell their older vehicles. In this case, low-income households are likely to benefit from the increased availability of used vehicles. However, if potential buyers value future fuel savings resulting from the increased fuel efficiency of new models at less than the increase in their average selling price, sales of new vehicles will decline, and the used vehicle market may decrease in volume as people hold onto their vehicles longer. In this case, low-income households are likely to face increased costs due to reduced availability of used vehicles. Because, as discussed in 8.1.1, we have not estimated the effects of the rule on the new vehicle market, and because we do not have a good model of the relationship between the new and used vehicle markets, we do not have estimates of the impact of this rule on the used vehicle market. However, due to the significant effect of the rule on fuel savings, especially for used vehicles (see RIA Chapter 5.5), we expect low-income households to benefit from the more rapid payback period for used vehicles, though some of this benefit may be affected by the net effect of this rule on the prices and availability of used vehicles.

The low-priced vehicle segment of the market may also deserve consideration, because it may be an entry point for first-car buyers. Vehicles in the low-priced (economy-class) segment will bear technology costs needed to meet the new standards, but it is not known how manufacturers will decide to pass on these costs across their vehicle fleets, including in the low-priced vehicle segment. If manufacturers decide to pass on the full cost of compliance in this segment, then it is possible that consumers who might barely afford new vehicles may be priced out of the new-vehicle market or may not have access to loans. As discussed above, the rule's impacts on availability of loans is unclear, because some lenders do factor fuel economy into their loans, and it is possible that this trend may expand. In addition, auto makers have some flexibility in how both technologies and price changes are applied to these vehicles; auto makers have ways to keep some vehicles in the low-priced vehicle segment if they so choose. Though the rule is expected to increase the prices of these vehicles, the degrees of price increase and the impacts of the price increases, especially when combined with the fuel savings that will accompany these changes, are much less clear.

In summary, we recognize that this rule may have impacts on consumers' access to loans for new vehicles, on low-income households, and on the market for low-priced vehicles; less clear are the directions of these effects. Lenders who only consider consumers' debt-to-income ratios may reduce consumers' abilities to purchase more expensive vehicles, but some lenders already take the fuel efficiency of vehicles into account. Low-income households will benefit from reduced fuel costs; we do not estimate the direction of effects of this rule on used vehicle prices, which are more relevant for low-income households than effects on new vehicles. The effects of this rule on low-priced vehicles depends on how manufacturers add technologies and price vehicles in this segment; they have flexibility to keep some vehicles in this segment if they so wish.

8.2 Employment Impacts

8.2.1 Introduction

Although analysis of employment impacts is not part of a cost-benefit analysis (except to the extent that labor costs contribute to costs), employment impacts of federal rules are of particular concern in the current economic climate of sizeable unemployment. When President Obama requested that the agencies develop this program, he sought a program that would "strengthen the [auto] industry and enhance job creation in the United States."[540,UUUUUUUU] The recently issued Executive Order 13563, "Improving Regulation and Regulatory Review" (January 18, 2011), states, "Our regulatory system must protect public health, welfare, safety, and our environment while promoting economic growth, innovation,

[UUUUUUUU] The May 21, 2010 Presidential Memorandum also requested that EPA and NHTSA, in developing the technical assessment to inform the rulemaking process (which was issued by the agencies and CARB on September 30, 2010), include, among other things, the "impacts on jobs and the automotive manufacturing base in the United States."

competitiveness, and job creation" (emphasis added). EPA is accordingly providing partial estimates of the effects of this rule on domestic employment in the auto manufacturing and parts sectors, while qualitatively discussing how it may affect employment in other sectors more generally.

This rule is expected to affect employment in the United States through the regulated sector – the auto manufacturing industry – and through several related sectors, specifically, industries that supply the auto manufacturing industry (e.g., vehicle parts), auto dealers, the fuel refining and supply sectors, and the general retail sector. According to the U.S. Bureau of Labor Statistics, in 2010, about 677,000 people in the U.S. were employed in Motor Vehicle and Parts Manufacturing Sector (NAICS 3361, 3362, and 3363). About 129,000 people in the U.S. were employed in the Automobile and Light Truck Manufacturing Sector (NAICS 33611) in December 2010; this is the directly regulated sector, since it encompasses the auto manufacturers that are responsible for complying with the standards.[541] Changes in light duty vehicle sales, discussed in Chapter 8.1.1, could affect employment for auto dealers. The employment effects of this rule are expected to expand beyond the regulated sector. Though some of the parts used to achieve the standards are likely to be built by auto manufacturers themselves, the auto parts manufacturing sector also plays a significant role in providing those parts, and will also be affected by changes in vehicle sales. As discussed in Chapter 5.4 of this RIA, this rule is expected to reduce the amount of fuel these vehicles use, and thus affect the petroleum refinery and supply industries. Finally, since the net reduction in cost associated with this rule is expected to lead to lower household expenditures on fuel net of vehicle costs, consumers then will have additional discretionary income that can be spent on other goods and services.

When the economy is at full employment, an environmental regulation is unlikely to have much impact on net overall U.S. employment; instead, labor would primarily be shifted from one sector to another. These shifts in employment impose an opportunity cost on society, approximated by the wages of the employees, as regulation diverts workers from other activities in the economy. In this situation, any effects on net employment are likely to be transitory as workers change jobs (e.g., some workers may need to be retrained or require time to search for new jobs, while shortages in some sectors or regions could bid up wages to attract workers).

On the other hand, if a regulation comes into effect during a period of high unemployment, a change in labor demand due to regulation may affect net overall U.S. employment because the labor market is not in equilibrium. In such a period, both positive and negative employment effects are possible.[VVVVVVVV] Schmalansee and Stavins point out that net positive employment effects are possible in the near term when the economy is at less than full employment due to the potential hiring of idle labor resources by the regulated sector to meet new requirements (e.g., to install new equipment) and new economic activity in sectors related to the regulated sector.[542] In the longer run, the net effect on employment is more difficult to predict and will depend on the way in which the related industries respond to

[VVVVVVVV] Masur and Posner, available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1920441 the regulatory requirements. As Schmalansee and Stavins note, it is possible that the magnitude of the effect on employment could vary over time, region, and sector, and positive effects on employment in some regions or sectors could be offset by negative effects in other regions or sectors. For this reason, they urge caution in reporting partial employment effects since it can "paint an inaccurate picture of net employment impacts if not placed in the broader economic context."

It is assumed that the official unemployment rate will have declined to 5.3 percent by the time by the time this rule takes effect and so the effect of the regulation on labor will be to shift workers from one sector to another.[wwwwwwwww] Those shifts in employment impose an opportunity cost on society, approximated by the wages of the employees, as regulation diverts workers from other activities in the economy. In this situation, as discussed above, any effects on net employment are likely to be transitory. It is also possible that the state of the economy will be such that positive or negative employment effects will occur.

A number of different approaches have been used in published literature to conduct employment analysis. This section describes some of the common methods, as well as some of their limitations.

8.2.2 Approaches to Quantitative Employment Analysis

Measuring the employment impacts of a policy depend on a number of inputs and assumptions. For instance, as discussed, assumptions about the overall state of unemployment in the economy play a major role in measured job impacts. The inputs to the models commonly are the changes in quantities or expenditures in the affected sectors; model results may vary in different studies depending on the assumptions about the levels of those inputs, and which sectors receive those changes. Which sectors are included in the study can also affect the results. For instance, a study of this program that looks only at employment impacts in the refinery sector may find negative effects, because consumers will purchase less gasoline; a study that looks only at the auto parts sector, on the other hand, may find positive impacts, because the program will require redesigned or additional parts for vehicles. In both instances, these would only be partial perspectives on the overall change in national employment due to Federal regulation.

8.2.2.1 Conceptual Framework for Employment Impacts in the Regulated Sector

One study by Morgenstern, Pizer, and Shih[543] provides a retrospective look at the impacts of regulation in employment in the regulated sectors by estimating the effects on employment of spending on pollution abatement for four highly polluting/regulated U.S. industries (pulp and paper, plastics, steel, and petroleum refining) using data for six years between 1979 and 1991. The paper provides a theoretical framework that can be useful for examining the impacts of a regulatory change on the regulated sector in the medium to longer

[wwwwwwwww] Office of Management and Budget, "Fiscal Year 2012 Mid-Session Review: Budget of the U.S. Government." http://www.whitehouse.gov/sites/default/files/omb/budget/fy2012/assets/12msr.pdf , p. 10.

term. In particular, it identifies three separate ways that employment levels may change in the regulated industry in response to a new (or more stringent) regulation.

- *Demand effect*: higher production costs due to the regulation will lead to higher market prices; higher prices in turn reduce demand for the good, reducing the demand for labor to make that good. In the authors' words, the "extent of this effect depends on the cost increase passed on to consumers as well as the demand elasticity of industry output."

- *Cost effect*: as costs go up, plants add more capital and labor (holding other factors constant), with potentially positive effects on employment. In the authors' words, as "production costs rise, more inputs, including labor, are used to produce the same amount of output."

- *Factor shift effect*: post-regulation production technologies may be more or less labor-intensive (i.e., more/less labor is required per dollar of output). In the authors' words, "environmental activities may be more labor intensive than conventional production," meaning that "the amount of labor per dollar of output will rise," though it is also possible that "cleaner operations could involve automation and less employment, for example."

According to the authors, the "demand effect" is expected to have a negative effect on employment,[xxxxxxxx] the "cost effect" to have a positive effect on employment, and the "factor shift effect" to have an ambiguous effect on employment. Without more information with respect to the magnitudes of these competing effects, it is not possible to predict the total effect environmental regulation will have on employment levels in a regulated sector.

The authors conclude that increased abatement expenditures generally have not caused a significant change in employment in those sectors. More specifically, their results show that, on average across the industries studied, each additional $1 million spent on pollution abatement results in a (statistically insignificant) net increase of 1.5 jobs.

This approach to employment analysis has the advantage of carefully controlling for many possibly confounding effects in order to separate the effect of changes in regulatory costs on employment. It was, however, conducted for only four sectors. It could also be very difficult to update the study for other sectors, because one of the databases on which it relies, the Pollution Abatement Cost and Expenditure survey, has been conducted infrequently since 1994, with the last survey conducted in 2005. The empirical estimates provided by Morgenstern et al. are not relevant to the case of fuel economy standards, which are very different from the pollution control standards on industrial facilities that were considered in

[xxxxxxxx] As will be discussed below, the demand effect in this rule is potentially an exception to this rule. While the vehicles become more expensive, they also produce reduced fuel expenditures; the reduced fuel costs provide a countervailing impact on vehicle sales. As discussed in Preamble Section III.H.1, this possibility that vehicles may become more attractive to consumers after the program poses a conundrum: why have interactions between vehicle buyers and producers not provided these benefits without government intervention?

that study. In addition, it does not examine the effects of regulation on employment in sectors related to but outside of the regulated sector. Nevertheless, the theory that Morgenstern et al. developed continues to be useful in this context.

The following discussion of additional methodologies draws from Berck and Hoffmann's review of employment models.[544]

8.2.2.2 Computable General Equilibrium (CGE) Models

Computable general equilibrium (CGE) models are often used to assess the impacts of policy. These models include a stylized representation of supply and demand curves for all major markets in the economy. The labor market is commonly included. CGE models are very useful for looking at interaction effects of markets: "they allow for substitution among inputs in production and goods in consumption." Thus, if one market experiences a change, such as a new regulation, then the effects can be observed in all other markets. As a result, they can measure the employment changes in the economy due to a regulation. Because they usually assume equilibrium in all markets, though, they typically lack involuntary unemployment. If the total amount of labor changes, it is due to people voluntarily entering or leaving the workforce. As a result, these models may not be appropriate for measuring effects of a policy on unemployment, because of the assumption that there is no involuntary unemployment. In addition, because of the assumptions of equilibrium in all markets and forward-looking consumers and firms, they are designed for examining the long-run effects of a policy but may offer little insight into its short-run effects.

8.2.2.3 Input-Output (IO) Models

Input-output models represent the economy through a matrix of coefficients that describe the connections between supplying and consuming sectors. In that sense, like CGE models, they describe the interconnections of the economy. These interconnections look at how changes in one sector ripple through the rest of the economy. For instance, a requirement for additional technology for vehicles requires additional steel, which requires more workers in both the auto and steel sectors; the additional workers in those sectors then have more money to spend, which leads to more employment in retail sectors. These are known as "multiplier" effects, because an initial impact in one sector gets multiplied through the economy. Unlike CGE models, input-output models have fixed, linear relationships among the sectors (e.g., substitution among inputs or goods is not allowed), and quantity supplied need not equal quantity demanded. In particular, these models do not allow for price changes – an increase in the demand for labor or capital does not result in a change in its price to help reallocate it to its best use. As a result, these models cannot capture opportunity costs from using resources in one area of the economy over another. The multipliers take an initial impact and can increase it substantially.

IO models are commonly used for regional analysis of projects. In a regional analysis, the markets are commonly considered small enough that wages and prices are determined outside the region, and any excess supply or demand is due to exports and imports (or, in the case of labor, emigration or immigration). For national-level employment analysis, the use of input-output models requires the assumption that workers flow into or out of the labor market perfectly freely. Wages do not adjust; instead, people join into or depart from the labor pool as production requires them. For other markets as well, there is no substitution of less expensive inputs for more expensive ones. As a result, IO models provide an upper bound on employment impacts. As Berck and Hoffmann note, "For the same reason, they can be thought of as simulating very short-run adjustment," in contrast to the CGE's implicit assumption of long-run adjustment. Changes in production processes, introductions of new technologies, or learning over time due to new regulatory requirements are also generally not captured by IO models, as they are calibrated to already established relationships between inputs and outputs.

8.2.2.4 Hybrid Models

As Berck and Hoffmann note, input-output models and CGE models "represent a continuum of closely related models." Though not separately discussed by Berck and Hoffmann, some hybrid models combine some of the features of CGE models (e.g., prices that can change) with input-output relationships. For instance, a hybrid model may include the ability to examine disequilibrium phenomena, such as labor being at less than full employment. Hybrid models depend on assumptions about how adjustments in the economy occur. CGE models characterize equilibria but say little about the pathway between them, while IO models assume that adjustments are largely constrained by previously defined relationships; the effectiveness of hybrid models depends on their success in overcoming the limitations of each of these approaches. Hybrid models could potentially be used to model labor market impacts of various vehicle policy options although a number of judgments need to be made about the appropriate assumptions underlying the model as well the empirical basis for the modeling results.

8.2.2.5 Single Sectors

It is possible to conduct a bottom-up analysis of the partial effect of regulation on employment in a single sector by estimating the change in output or expenditures in a sector and multiplying it by an estimate of the number of workers per unit of output or expenditures, under the assumption that labor demand is proportional to output or expenditures. As Berck and Hoffmann note, though, "Compliance with regulations may create additional jobs that are not accounted for." While such an analysis can approximate the effects in that one sector in a simple way, it also may miss important connections to related sectors.

8.2.2.6 Ex-Post Econometric Studies

A number of ex-post econometric analyses examine the net effect of regulation on employment in regulated sectors. Morgenstern, Pizer, and Shih (2002), discussed above, and Berman and Bui (2001) are two notable examples that rely on highly disaggregated establishment-level time series data to estimate longer-run employment effects.[545] While often a sophisticated treatment of the issues analyzed, these studies commonly analyze specific scenarios or sectors in the past; care needs to be taken in extrapolating their results to other scenarios and to the future. For instance, neither of these two studies examines the auto industry and are therefore of limited applicability in this context.

8.2.2.7 Summary

All methods of estimating employment impacts of a regulation have advantages and limitations. CGE models may be most appropriate for long-term impacts, but the usual assumption of equilibrium in the employment market means that it is not useful for looking at changes in overall employment: overall levels are likely to be premised on full employment. IO models, on the other hand, may be most appropriate for small-scale, short-term effects, because they assume fixed relationships across sectors and do not require market equilibria. Hybrid models, which combine some features of CGEs with IO models, depend upon key assumptions and economic relationships that are built into them. Single-sector models are simple and straightforward, but they are often based on the assumptions that labor demand is proportional to output, and that other sectors are not affected. Finally, econometric models have been developed to evaluate the longer-run net effects of regulation on sector employment, though these are ex-post analyses commonly of specific sectors or situations, and the results may not have direct bearing for the regulation being reviewed.

8.2.3 Employment Analysis of This Rule

As mentioned above, this program is expected to affect employment in the regulated sector (auto manufacturing) and in other sectors directly affected by the rule: auto parts suppliers, auto dealers, and the fuel supply market (which will face reduced petroleum production due to reduced fuel demand but which may see additional demand for electricity or other fuels). Changes in consumer expenditures due to higher vehicle costs and lower fuel expenses will also affect employment. In addition, as the discussion above suggests, each of these sectors could potentially have ripple effects in the rest of the economy. These ripple effects depend much more heavily on the state of the macroeconomy than do the direct effects. At the national level, employment may increase in one industry or region and decrease in another, with the net effect being smaller than either individual-sector effect. EPA does not attempt to quantify the net effects of the regulation on overall national employment.

The discussion that follows provides a partial, bottom-up quantitative estimate of the effects of this rule on the regulated sector (i.e., the auto industry; for reasons discussed below, we include some quantitative assessment of effects on suppliers to the auto industry although suppliers are not regulated directly). It also includes qualitative discussion of the effects of the rule on other sectors. Focusing quantification of employment impacts on the regulated sector has some advantages over quantifying all impacts. First, the analysis relies on data generated as part of the rulemaking process, which focuses on the regulated sector; as a result, what is presented here is based on internally consistent assumptions and estimates made in this rule. Second, as discussed above, net effects on employment in the economy as a whole depend heavily on the overall state of the economy when this rule has its effects. Focusing on the regulated sector provides insight into employment effects in that sector without having to make assumptions about the state of the economy when this rule has its impacts. We include a qualitative discussion of employment effects on other sectors to provide a broader perspective on the impacts of this rule.

As noted above, in a full-employment economy, any changes in employment will result from people changing jobs or voluntarily entering or exiting the workforce. In a full-employment economy, employment impacts of this rule will change employment in specific sectors, but it will have small, if any, effect on aggregate employment. This rule would take effect in model years 2017 through 2025; by then, the current high unemployment may be moderated or ended. For that reason, this analysis does not include multiplier effects, but instead focuses on employment impacts in the most directly affected industries. Those sectors are likely to face the most concentrated employment impacts.

8.2.3.1 Employment Impacts in the Auto Industry

Following the Morgenstern et al. conceptual framework for the impacts of regulation on employment in the regulated sector, we consider three effects for the auto sector: the demand effect, the cost effect, and the factor shift effect. However, we are only able to offer quantitative estimates for the cost effect. We note that these estimates, based on extrapolations from current data, become more uncertain as time goes on.

8.2.3.1.1 The Demand Effect

The demand effect depends on the effects of this rule on vehicle sales. If vehicle sales increase, then more people will be required to assemble vehicles and their components. If vehicle sales decrease, employment associated with these activities will unambiguously decrease. Unlike in Morgenstern et al.'s study, where the demand effect decreased employment, there are countervailing effects in the vehicle market due to the fuel savings resulting from this program. On one hand, this rule will increase vehicle costs; by itself, this effect would reduce vehicle sales. On the other hand, this rule will reduce the fuel costs of operating the vehicle; by itself, this effect would increase vehicle sales, especially if potential buyers have an expectation of higher fuel prices. The sign of demand effect will depend on which of these effects dominates. Because, as described in Chapter 8.1, we have not quantified the impact on sales for this rule, we do not quantify the demand effect.

8.2.3.2 The Cost Effect

The demand effect, discussed above, measures employment changes due to new vehicle sales only. The cost effect measures employment impacts due to the development, manufacturing, and installation by auto suppliers and manufacturers of the new or additional technologies needed for vehicles to comply with the standards.

One way to estimate the cost effect, given the cost estimates for complying with the rule, is to use the ratio of workers to each $1 million of expenditures in that sector. The use of these ratios has both advantages and limitations. It is often possible to estimate these ratios for quite specific sectors of the economy: for instance, it is possible to estimate the average number of workers in the light-duty vehicle manufacturing sector per $1 million spent in the sector, rather than use the ratio from another, more aggregated sector, such as motor vehicle manufacturing. As a result, it is not necessary to extrapolate employment ratios from possibly unrelated sectors. On the other hand, these estimates are averages for the sectors, covering all the activities in those sectors; they may not be representative of the labor required when expenditures are required on specific activities, as the factor shift effect (discussed below) indicates. For instance, the ratio for the motor vehicle manufacturing sector represents the ratio for all vehicle manufacturing, not just for fuel efficiency improvements. In addition, these estimates do not include changes in sectors that supply these sectors, such as steel or electronics producers. They thus may best be viewed as the effects on employment in the auto sector due to the changes in expenditures in that sector, rather than as an assessment of all employment changes due to these changes in expenditures.

Some of the costs of this rule will be spent directly in the auto manufacturing sector, but some of the costs will be spent in the auto parts manufacturing sector. Because we do not have information on the proportion of expenditures in each sector, we separately present the ratios for both the auto manufacturing sector and the auto parts manufacturing sector. These are not additive, but should instead be considered as a range of estimates for the cost effect, depending on which sector adds technologies to the vehicles to comply with the regulation.

We use several sources for estimates of employment per $1 million expenditures. The U.S. Bureau of Labor Statistics (BLS) provides its Employment Requirements Matrix (ERM),[546] which provides direct estimates of the employment per $1 million in sales of goods in 202 sectors. The estimates used here, updated from the NPRM, are from 2010 (adjusted to 2010$). Not all expenditures are for domestically produced vehicles, however. To estimate the proportion of domestic expenditures affected by the rule, we use data from Ward's Automotive Group for total car and truck production in the U.S. compared to total car and truck sales in the U.S.[547] For the period 2001-2010, the proportion is 66.7%. We thus weight sales by this factor to get an estimate of the effect on employment in the motor vehicle manufacturing sector due to this rule.

The Annual Survey of Manufactures[548] (ASM) provides another source of estimates based on a sample of 50,000 establishments out of a universe of 346,000 manufacturing establishments. It includes more sectoral detail than the BLS ERM: for instance, while the ERM includes the Motor Vehicle Manufacturing sector, the ASM has detail at the 6-digit NAICS code level (e.g., automobile manufacturing vs. light truck and utility vehicle manufacturing). While the ERM provides direct estimates of employees/$1 million in expenditures, the ASM separately provides number of employees and value of shipments; the direct employment estimates here are the ratio of those values. The data in the ASM are updated annually, except for years when the full Economic Census occurs. The tables presented here use data from 2010 (also updated from the NPRM). As with the ERM, we adjust for the ratio of domestic production to domestic sales. The values reported are for Motor Vehicle Manufacturing (NAICS 3361), Automobile and Light Duty Motor Vehicle Manufacturing (NAICS 33611), and Motor Vehicle Parts Manufacturing (NAICS 3363).

The Economic Census includes all large companies and a sample of smaller ones. The ASM is a subset of the Economic Census; though the Census itself is more complete, it is conducted only every 5 years, while the ASM is annual. The values presented here use data from 2007 (adjusted to 2010$), with the domestic production-to-sales adjustment. The values reported are for Motor Vehicle Manufacturing (NAICS 3361), Automobile and Light Duty Motor Vehicle Manufacturing (NAICS 33611), and Motor Vehicle Parts Manufacturing (NAICS 3363).

Table 8.2-2 provides the values, either given (BLS) or calculated (ASM, Economic Census) for employment per $1 million of expenditures, all based on 2010 dollars, though the underlying data come from different years (which may account for some of the differences). The different data sources provide similar magnitudes for the estimates for the sectors. Parts manufacturing appears to be more labor-intensive than vehicle manufacturing; light-duty vehicle manufacturing appears to be slightly less labor-intensive than motor vehicle manufacturing as a whole.

Table 8.2-2 Employment per $1 Million Expenditures (2010$) in the Motor Vehicle Manufacturing Sector*

Source	Sector	Ratio of workers per $1 million expenditures	Ratio of workers per $1 million expenditures, adjusted for domestic vs. foreign production
BLS ERM	Motor Vehicle Mfg	0.770	0.514
ASM	Motor Vehicle Mfg	0.655	0.437
ASM	Light Duty Vehicle Mfg	0.609	0.406
Economic Census	Motor Vehicle Mfg	0.665	0.443
Economic Census	Light Duty Vehicle Mfg	0.602	0.402
BLS ERM	Motor Vehicle Parts Mfg	2.614	1.743
ASM	Motor Vehicle Parts Mfg	2.309	1.540
Economic Census	Motor Vehicle Parts Mfg	2.712	1.809

BLS ERM refers to the U.S. Bureau of Labor Statistics' Employment Requirement Matrix. ASM refers to the U.S. Census Bureau's Annual Survey of Manufactures. Economic Census refers to the U.S. Census Bureau's Economic Census.

Over time, the amount of labor needed in the auto industry has changed: automation and improved production methods have led to significant productivity increases. The BLS ERM, for instance, provided estimates that, in 1993, 1.64 workers in the Motor Vehicle Manufacturing sector were needed per $1 million of 2005$, but only 0.86 workers by 2010 (in 2005$). Because the ERM is available annually for 1993-2010, we used these data to estimate productivity improvements over time. We regressed logged ERM values on year for both the Motor Vehicle Manufacturing and Motor Vehicle Parts Manufacturing sectors. We used this approach because the coefficient describing the relationship between time and productivity is a direct measure of the percent change in productivity per year. The results suggest a 3.9 percent per year productivity improvement in the Motor Vehicle Manufacturing

Sector, and a 3.8 percent per year improvement in the Motor Vehicle Parts Manufacturing Sector. We then used the equation resulting from the regression to project the ERM through 2025. In the results presented below, these projected values (adjusted to 2010$) were used directly for the BLS ERM estimates. For the ASM, we used the ratio of the projected value in the future to the projected value in 2010 (the base year for the ASM); for the Economic Census estimates, we used the ratio of the projected value in the future to the projected value in 2007 (the base year for that estimate). This is a simple way to examine the relationship between labor required and expenditure.

Table 8.2-3 shows the cost estimates developed for this rule, discussed in Chapter 5. The maximum value in Table 8.2-2 for employment impacts per $1 million expenditures (after accounting for the share of domestic production) is 1.809 in 2010 if all the additional costs are in the parts sector; the minimum value is 0.402 in 2010, if all the additional costs are in the light-duty vehicle manufacturing sector: that is, the range of employment impacts is between 0.4 and 2 additional jobs per $1 million expenditures in the sector in 2010. The results in Table 8.2-3 include the productivity adjustment described above.

While we estimate employment impacts, measured in job-years, beginning with the first year of the standard (2017), some of these employment gains may occur earlier as auto manufacturers and parts suppliers hire staff in anticipation of compliance with the standard. A job-year is a way to calculate the amount of work needed to complete a specific task. For example, a job-year is one year of work for one person.

Table 8.2-3 Employment per $1 Million in the Motor Vehicle Manufacturing Sector, in job-years

Year	Costs (before adjustment for domestic proportion of production) ($Millions)	Minimum employment effect (if all expenditures are in the parts sector)	Maximum employment effect (if all expenditures are in the light duty vehicle mfg sector)
2017	$ 2,435	700	3,200
2018	$ 4,848	1,300	6,200
2019	$ 6,818	1,700	8,400
2020	$ 8,858	2,100	10,500
2021	$ 12,400	2,900	14,200
2022	$ 18,323	4,100	20,200
2023	$ 23,734	5,100	25,200
2024	$ 29,101	6,000	29,700
2025	$ 31,678	6,300	31,100
Total		30,300	148,800

We note that the cost effect depends only on technology costs, not vehicle sales. It is therefore not sensitive to assumptions about how consumers consider fuel savings at the time of vehicle purchase.

8.2.3.2.1 The Factor Shift Effect

The factor shift effect looks at the effects on employment due to changes in labor intensity associated with a regulation. As noted above, the estimates of the cost effect assume constant labor per $1 million in expenditures, though the new technologies may be either more or less labor-intensive than the existing ones. An estimate of the factor shift effect would either increase or decrease the estimate used for the cost effect.

We are not quantifying the factor shift effect here, for lack of data on the labor intensity of all the possible technologies that manufacturers could use to comply with the standards. For a subset of the technologies, though, EPA-sponsored research (discussed in Chapter 3.2.1.1 of the Joint TSD) which compared new technologies to existing ones at the level of individual components provides some insights into the factor shift effect.

The comparison involved tearing down the selected technologies to their individual components and looking at the differences in materials and labor needs in moving from the conventional to the new technologies. For instance, the analysis compared all the parts and labor associated with an 8-speed automatic transmission to those needed for a 6-speed automatic transmission.

Because labor cost was one of the sources of differences between the technologies, it is possible, for those technologies, to see whether labor needs increase or decrease with the switch to technologies that might contribute to compliance with the standards. An increase in labor cost for the new technology indicates an increase in the labor needed for the new technology compared to the baseline technology. For instance, an 8-speed transmission requires $15.11 more in labor costs than a 6-speed transmission (as accounted for in EPA's cost estimates for the rule). Dividing the labor cost by a wage per hour estimate provides an estimate of the additional hours (and thus the additional labor) needed for the new technology compared to the baseline technology. As with labor cost, an increase in labor hours per technology indicates greater employment needs for the new technologies. For this conversion, a weighted average wage rate (90 percent of the average wage in the Motor Vehicle Parts Manufacturing sector, and 10 percent of the average wage in the Motor Vehicle Manufacturing Sector) of $46.36/hour in 2015, using 2008 dollars (the unit of analysis for the FEV study). For the change from a 6-speed to an 8-speed transmission, we thus estimate an additional 0.33 hours of labor per transmission.

Table 8.2-4 shows the changes in labor hours in moving from baseline to new fuel-saving technologies for technologies in the FEV study. It indicates that, in switching from the baseline to the new technologies, labor use per technology increased: the fuel-saving technologies use more labor than the baseline technologies. For a subset of the technologies likely to be used to meet the standards in this rule, then, the factor shift effect increases labor demand, at least in the short run; in the long run, as with all technologies, the cost structure is likely to change due to learning, economies of scale, etc. The technologies examined in this research are, however, only a subset of the technologies that auto makers may use to comply with the standards in this program. As a result, these results cannot be considered definitive evidence that the factor shift effect increases employment for this rule. We therefore do not quantify the factor shift effect for this rule.

Table 8.2-4 Estimated Change in Labor for Selected Compliance Technologies

Technology	FEV Case Study	Vehicle Class	Labor Costs	Total Costs	Hours/ Technology
Downsized Turbo GDI 4	0101	Compact C	$72.58	$537.70	1.57
Downsized Turbo GDI V6	0102	Mid/Large C	$25.76	$87.38	0.56
Downsized Turbo GDI V6	0104	SUV/Trucks	$84.19	$789.53	1.82
Electric A/C compressor	0602		$4.68	$167.54	0.10
Power split hybrid	0502	Mid/Large C	$395.85	$3,435.01	8.54
6- to 8-speed transmission	0803	Mid/Large C	$15.11	$61.84	0.33

8.2.3.2.2 Summary of Employment Effects in the Auto Sector

While we are not able to quantify the demand or factor shift effects, the cost effect results show that the employment effects of the increased spending in the regulated sector (and, possibly, the parts sector) are expected to be positive and on the order of a few thousand in the initial years of the program. As noted above, motor vehicle and parts manufacturing sectors employed about 677,000 people in 2010, with automobile and light truck manufacturing accounting for about 129,000 of that total.

8.2.4 Effects on Employment for Auto Dealers

The effects of the standards on employment for auto dealers depend principally on the effects of the standards on light duty vehicle sales: increases in sales are likely to contribute to employment at dealerships, while reductions in sales are likely to have the opposite effect. In addition, auto dealers may be affected by changes in maintenance and service costs. Increases in those costs are likely to increase labor demand in dealerships, and reductions are likely to decrease labor demand.

Although this rule predicts very small penetration of plug-in hybrid and electric vehicles, the uncertainty on consumer acceptance of such technology vehicles is even greater. As discussed in Chapter 8.1.2.7, consumers may find some characteristics of electric vehicles and plug-in hybrid electric vehicles, such as the ability to fuel with electricity rather than gasoline, attractive; they may find other characteristics, such as the limited range for electric vehicles, undesirable. As a result, some consumers will find that EVs will meet their needs, but other buyers will choose more conventional vehicles. Auto dealers may play a major role in explaining the merits and disadvantages of these new technologies to vehicle buyers. There may be a temporary need for increased employment to train sales staff in the new technologies as the new technologies become available.

8.2.5 Effects on Employment in the Auto Parts Sector

As discussed in the context of employment in the auto industry, some vehicle parts are made in-house by auto manufacturers; others are made by independent suppliers who are not directly regulated, but who will be affected by the standards as well. The additional expenditures on technologies are expected to have a positive effect on employment in the parts sector as well as the manufacturing sector; the breakdown in employment between the two sectors is difficult to predict. The effects on the parts sector also depend on the effects of the standards on vehicle sales and on the labor intensity of the new technologies, qualitatively in the same ways as for the auto manufacturing sector.

8.2.6 Effects on Employment for Fuel Suppliers

In addition to the effects on the auto manufacturing and parts sectors, these rules will result in changes in fuel use that lower GHG emissions. Fuel saving, principally reductions in liquid fuels such as gasoline and diesel, will affect employment in the fuel suppliers industry sectors throughout the supply chain, from refineries to gasoline stations. To the extent that the standards result in increased use of electricity or other new fuels, employment effects will result from providing these fuels and developing the infrastructure to supply them to consumers.

Expected petroleum fuel consumption reductions can be found in RIA Chapter 5.4. While this reduced consumption represents fuel savings for purchasers of fuel, it represents a loss in value of output for the petroleum refinery industry, fuel distributors, and gasoline stations. The loss of expenditures to petroleum fuel suppliers throughout the petroleum fuel supply chain, from the petroleum refiners to the gasoline stations, is likely to result in reduced employment in these sectors.

This rule is also expected to lead to increases in electricity consumption by vehicles, as discussed in RIA Chapter 5.4. This new fuel may require additional infrastructure, such as electricity charging locations. Providing this infrastructure, as well as infrastructure for other alternative fuels (such as CNG), will require some increased employment. In addition, the generation of electricity is likely to require some additional labor. We have insufficient information at this time to predict whether the increases in labor associated with increased infrastructure provision and generation for electricity will be greater or less than the employment reductions associated with reduced demand for petroleum fuels.

8.2.7 Effects on Employment due to Impacts on Consumer Expenditures

As a result of these standards, consumers will pay a higher up-front cost for the vehicles, but they will recover those costs in a fairly short payback period (see Preamble Section III.H.5 and Chapter 5.5 of this RIA); indeed, people who finance their vehicles are expected to find that their fuel savings per month exceed the increase in the loan cost (though this depends on the particular loan rate a consumer receives). As a result, consumers will have additional money to spend on other goods and services, though, for those who do not finance their vehicles, it will occur after the initial payback period. These increased expenditures will support employment in those sectors where consumers spend their savings.

These increased expenditures will occur in 2017 and beyond. If the economy returns to full employment by that time, any change in consumer expenditures would primarily represent a shift in employment among sectors. If, on the other hand, the economy still has substantial unemployment, these expenditures would contribute to employment through increased consumer demand.

8.2.8 Summary

The primary employment effects of this rule are expected to be found throughout several key sectors: auto manufacturers, auto dealers, auto parts manufacturing, fuel production and supply, and consumers. These standards initially take effect in model year 2017, a time period sufficiently far in the future that the current sustained high unemployment at the national level may be moderated or ended. In an economy with full employment, the primary employment effect of a rulemaking is likely to be to move employment from one sector to another, rather than to increase or decrease employment. For that reason, we focus our partial quantitative analysis on employment in the regulated sector, to examine the impacts on that sector directly. We discuss the likely direction of other impacts in the regulated sector as well as in other directly related sectors, but we do not quantify those impacts, because they are more difficult to quantify with reasonable accuracy, particularly so far into the future.

For the regulated sector, the cost effect is expected to increase employment by 700 – 3,200 job-years in 2017, depending on the share of that employment that is in the auto manufacturing sector compared to the auto parts manufacturing sector. As mentioned above, some of these job gains may occur earlier as auto manufacturers and parts suppliers hire staff to prepare to comply with the standard. The demand effect depends on changes in vehicle sales, which are not quantified for this rule. Though we do not have estimates of the factor shift effect for all potential compliance technologies, the evidence which we do have for some technologies suggests that many of the technologies will have increased labor needs.

Effects in other sectors that are predicated on vehicle sales are also ambiguous. Changes in vehicle sales are expected to affect labor needs in auto dealerships and in parts manufacturing. Increased expenditures for auto parts are expected to require increased labor to build parts, though this effect also depends on any changes in the labor intensity of production; as noted, the subset of potential compliance technologies for which data are available show increased labor requirements. Reduced petroleum fuel production implies less employment in the petroleum sectors, although there could be increases in employment related to providing infrastructure for alternative fuels such as electricity and CNG. Finally, consumer spending is expected to affect employment through changes in expenditures in general retail sectors; net fuel savings by consumers are expected to increase demand (and therefore employment) in other sectors.

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9 Small Business Flexibility Analysis

The Regulatory Flexibility Act, as amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA), generally requires an agency to prepare a regulatory flexibility analysis of any rule subject to notice-and-comment rulemaking requirements under the Administrative Procedure Act or any other statute. As a part of this analysis, an agency is directed to convene a Small Business Advocacy Review Panel (SBAR Panel or 'the Panel'), unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities. During such a Panel process, the agency would gather information and recommendations from Small Entity Representatives (SERs) on how to reduce the impact of the rule on small entities. As discussed below, EPA is certifying that this rule will not have a significant economic impact on a substantial number of small entities, and thus we have not conducted an SBAR Panel for this rulemaking.

The following discussion provides an overview of small entities in the vehicle market. Small entities include small businesses, small organizations, and small governmental jurisdictions. For the purposes of assessing the impacts of the rule on small entities, a small entity is defined as: (1) a small business that meets the definition for business based on the Small Business Administration's (SBA) size standards (see Table 9.1-1); (2) a small governmental jurisdiction that is a government of a city, county, town, school district or special district with a population of less than 50,000; and (3) a small organization that is any not-for-profit enterprise which is independently owned and operated and is not dominant in its field. Table 9.1-1 provides an overview of the primary SBA small business categories potentially affected by this regulation.

Table 9.1-1 Primary Vehicle SBA Small Business Categories

Industry [a]	Defined as Small Entity by SBA if Less Than or Equal to:	NAICS Codes [b]
Vehicle manufacturers (including small volume manufacturers)	1,000 employees	336111, 336112
Independent commercial importers	\$7 million annual sales \$23 million annual sales 100 employees	811111, 811112, 811198 441120 423110
Alternative Fuel Vehicle Converters	750 employees 1,000 employees \$7 million annual sales	336312, 336322, 336399 335312 811198

[a.] Light-duty vehicle entities that qualify as small businesses are not be subject to this rule. We are exempting small business entities from the GHG standards.
[b.] North American Industrial Classification System

We compiled a list of vehicle manufacturers, independent commercial importers (ICIs), and alternative fuel converters that would be potentially affected by the rule from our 2011 and 2012 model year certification databases. These companies are already certifying their vehicles for compliance with applicable EPA emissions standards (e.g., Tier 2). We then identified companies that appear to meet the definition of small business provided in the table above. We were able to identify companies based on certification information and previous rulemakings where we conducted Regulatory Flexibility Analyses.

Based on this assessment, EPA identified a total of about 24 entities that appear to fit the Small Business Administration (SBA) criterion of a small business. EPA estimates there are about 5 small vehicle manufacturers, including three electric vehicle manufacturers, 8 independent commercial importers (ICIs), and 11 alternative fuel vehicle converters in the light-duty vehicle market which may qualify as small businesses.[549] Independent commercial importers (ICIs) are companies that hold a Certificate (or Certificates) of Conformity permitting them to import nonconforming vehicles and to modify these vehicles to meet U.S. emission standards. ICIs are not required to meet the emission standards in effect when the vehicle is modified, but instead they must meet the emission standards in effect when the vehicle was originally produced (with an annual production cap of a total of 50 light-duty vehicles and trucks). Alternative fuel vehicle converters are businesses that convert gasoline or diesel vehicles to operate on alternative fuel (e.g., compressed natural gas), and converters must seek a certificate for all of their vehicle models. Model year 1993 and newer vehicles that are converted are required to meet the standards applicable at the time the vehicle was originally certified. Converters serve a niche market, and these businesses primarily convert vehicles to operate on compressed natural gas (CNG) and liquefied petroleum gas (LPG), on a dedicated or dual fuel basis.

EPA is exempting from the GHG standards any manufacturer, domestic or foreign, meeting SBA's size definitions of small business as described in 13 CFR 121.201. EPA adopted the same type of exemption for small businesses in the MY 2012-2016 rulemaking.[550] Together, we estimate that small entities comprise less than 0.1 percent of total annual vehicle sales and exempting them will have a negligible impact on the GHG emissions reductions from the standards. Because we are exempting small businesses from the GHG standards, we are certifying that the rule will not have a significant economic impact on a substantial number of small entities. Therefore, EPA has not conducted a Regulatory Flexibility Analysis or a SBREFA SBAR Panel for the rule.

EPA is finalizing provisions to allow small businesses to voluntarily waive their small business exemption and optionally certify to the GHG standards. This will allow small entity manufacturers to earn CO_2 credits under the GHG program, if their actual fleetwide CO_2 performance is better than their fleetwide CO_2 target standard. Manufacturers may choose to opt-in as early as MY 2013. Once the small business manufacturer opting into the GHG program in MY 2013 completes certification for MY 2013, the company will also be eligible to generate GHG credits for their MY 2012 production. Manufacturers waiving their small business exemption are required to meet all aspects of the GHG standards and program requirements across their entire product line. However, the exemption waiver is optional for small entities and thus we believe that manufacturers would only opt into the GHG program if it is economically advantageous for them to do so, for example in order to generate and sell CO_2 credits. Therefore, EPA believes adding this voluntary option does not affect EPA's determination that the standards will impose no significant adverse impact on small entities.

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10 Alternate Analysis Using 2010 MY Baseline

10.1 Why an Alternate Analysis?

For this final rulemaking, the agencies have analyzed the costs and benefits of the standards using two different forecasts of the light vehicle fleet through MY 2025. The agencies have concluded that the significant uncertainty associated with forecasting sales volumes, vehicle technologies, fuel prices, consumer demand, and so forth out to MY 2025, make it reasonable and appropriate to evaluate the impacts of the final CAFE and GHG standards using two baselines.[YYYYYYYY] One market forecast (or fleet projection), very similar to the one used for the NPRM, uses (corrected) MY 2008 CAFE certification data, information from AEO 2011, and information purchased from CSM in December of 2009. See Joint TSD Chapter 1.3. The agencies received comments regarding the market forecast used in the NPRM suggesting that updates in several respects could be helpful to the agencies' analysis of final standards; given those comments and since the agencies were already considering producing an updated fleet projection, the final rulemakings also utilize a second market forecast using MY 2010 CAFE certification data, information from AEO 2012, and information purchased from LMC Automotive (formerly J.D. Powers Forecasting). See Joint TSD Chapter 1.4.

These two market forecasts contain certain differences, although as discussed in TSD Chapter 1, the differences are not significant enough to change the agencies' decision as to the structure and stringency of the final standards, and indeed corroborate the reasonableness of the final standards. See Joint TSD Chapter 1.5. For example, the predicted fleet penetrations of advanced technologies for the final rule are identical or virtually identical under either market forecast. See RIA Tables 10-27 and 10-30 and preamble tables III-47 and III-52 (fleet penetration values for TDS 24, TDS-27, HEV, and EV/PHEV in MYs 2021 and 2025). For this reason, EPA did not model alternative standards 1-4 in this sensitivity analysis since the analysis and conclusions would mirror those set forth in section III.D.6.

The 2008 based fleet forecast uses the MY 2008 "baseline" fleet, which represents the most recent model year for which the industry had sales data that was not affected by the subsequent economic recession. On the other hand, the 2010 based fleet projection employs a market forecast (provided by LMC Automotive) which is more current than the projection provided by CSM (utilized for the MY 2008 based fleet projection). The CSM forecast appears to have been particularly influenced by the recession and shows major declines in market share for some manufacturers (*e.g.*, Chrysler) which the agencies do not believe are reasonably reflective of future trends.

However, the MY 2010 based fleet projection also is highly influenced by the economic recession. The MY 2010 CAFE certification data has become available since the proposal (see section 1.2.1 of the Joint TSD for the proposed rule, which noted the possibility

[YYYYYYYY] We refer to these baselines as "fleet projections" or "market forecasts" in Section II.B of the preamble and Chapter 1 of the TSD and elsewhere in the administrative record. The term "baseline" has a specific definition and is described in Chapter 1 of the TSD.

of these data becoming available), and continues to show the effects of the recession. For example, industry-wide sales were skewed down 20% compared to pre-recession MY 2008 levels. For some companies like Chrysler, Mitsubishi, and Subaru, sales were down 30-40% from MY 2008 levels. For BMW, General Motors, Jaguar/Land Rover, Porsche, and Suzuki, sales were down more than 40% from 2008 levels.[zzzzzzzz] Using the MY 2008 vehicle data avoids projecting these abnormalities in predicting the future fleet, although it also perpetuates vehicle brands and models (and thus, their outdated fuel economy levels and engineering characteristics) that have since been discontinued. The MY 2010 CAFE certification data accounts for the phase-out of some brands (*e.g.*, Saab) and the introduction of some technologies (*e.g.*, Ford's Ecoboost engine), which may be more reflective of the future fleet in this respect.

Thus, given the volume of information that goes into creating a baseline forecast and given the significant uncertainty in any projection out to MY 2025, the agencies think that the best way to illustrate the possible impacts of that uncertainty for purposes of this rulemaking is the approach taken here of analyzing the effects of the final standards under both the MY 2008-based and the MY 2010-based fleet projections. EPA is presenting its primary analysis of the standards using essentially the same baseline/future fleet projection that was used in the NPRM (i.e., corrected MY 2008 CAFE certification data, information from AEO 2011, and a future fleet forecast purchased from CSM). EPA also conducted an alternative analysis of the standards based on MY2010 CAFE certification data, updated AEO 2012 (early release) projections of the future fleet sales volumes, and a forecast of the future fleet mix projections to MY 2025 purchased from LMC Automotive. We have concluded that the final standards are likewise appropriate using this alternative baseline/fleet projection.

This chapter presents the analysis of the alternative baseline. For details on how the numbers presented here were generated, please see all the relevant portions of this rulemaking, in particular, RIA chapters 1, 3, and 4, and the technical support document. In general, the same methodology was used here as used for the 2008 baseline, except in those specific sections where those documents describe differences.

10.2 Level of the standard

Table 10-1 – Projected Level of Targets - Cars

	MY								
	2017	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Aston Martin	220	209	199	189	179	171	163	156	149
BMW	217	206	195	186	176	168	161	153	147
Chrysler/Fiat	221	211	200	190	180	172	164	156	149
Daimler	224	213	203	192	182	174	167	159	152
Ferrari	221	210	200	189	179	172	164	156	149
Ford	216	205	195	185	175	167	160	152	146
Geely	212	202	192	182	173	165	158	151	144
General Motors	217	206	196	186	176	168	161	154	147

[zzzzzzzz] See TSD chapter 1.

Honda	215	204	194	184	175	167	159	152	145
Hyundai	214	203	193	183	174	166	158	151	144
Kia	209	198	188	178	169	162	154	147	141
Lotus	203	193	183	174	165	157	150	143	137
Mazda	212	202	192	182	173	165	158	150	144
Mitsubishi	203	193	183	174	165	157	150	143	137
Nissan	215	205	195	185	175	167	160	153	146
Porsche	218	208	197	187	178	170	162	155	148
Subaru	207	197	187	178	168	161	154	147	140
Suzuki	202	192	182	173	164	157	150	143	136
Tata	228	217	205	195	185	176	169	161	153
Toyota	214	204	194	184	174	166	159	152	145
Volkswagen	187	178	168	159	151	144	137	131	125
Fleet	214	203	193	184	174	166	159	152	145

Table 10-2 – Projected Level of Targets - Trucks

	MY								
	2017	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	278	267	259	250	231	220	209	199	189
Chrysler/Fiat	293	283	276	267	248	235	224	213	203
Daimler	288	278	269	261	241	229	218	208	197
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	316	308	304	297	277	263	251	239	227
Geely	276	264	256	247	228	217	207	196	187
General Motors	313	305	298	289	267	254	242	230	218
Honda	285	275	267	258	239	227	216	205	195
Hyundai	270	258	250	242	223	212	202	192	182
Kia	286	276	267	258	238	226	215	204	194
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	274	263	255	247	228	217	206	196	186
Mitsubishi	254	242	235	227	209	199	189	180	171
Nissan	293	284	278	270	252	240	228	217	207
Porsche	287	274	266	258	238	227	216	205	195
Subaru	248	236	229	221	204	194	184	175	166
Suzuki	253	241	234	226	208	198	188	179	170
Tata	274	262	254	246	227	216	206	195	186
Toyota	295	285	278	270	253	241	229	218	207
Volkswagen	281	270	261	253	234	222	211	201	191
Fleet	299	289	283	274	255	243	231	219	209

Table 10-3 – Projected Level of Targets – Fleet (sales weighted)

	MY								
	2017	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Aston Martin	220	209	199	189	179	171	163	156	149
BMW	232	221	211	201	189	180	171	163	156
Chrysler/Fiat	258	247	238	227	212	202	192	182	173
Daimler	242	233	223	213	200	191	183	174	166
Ferrari	221	210	200	189	179	172	164	156	149
Ford	259	250	242	232	218	207	198	188	179
Geely	236	224	215	205	192	183	174	166	158
General Motors	258	248	240	230	215	205	195	186	177
Honda	238	226	217	207	194	185	176	167	159

Hyundai	222	211	200	190	180	171	163	156	149
Kia	217	207	197	187	176	168	160	153	146
Lotus	203	193	183	174	165	157	150	143	137
Mazda	224	213	203	194	182	174	166	158	151
Mitsubishi	213	203	193	184	173	165	157	150	143
Nissan	235	225	216	207	195	186	177	169	161
Porsche	254	242	234	224	209	199	190	181	172
Subaru	220	209	200	191	179	171	163	155	148
Suzuki	206	195	186	177	167	160	153	146	139
Tata	259	247	237	228	212	202	192	182	174
Toyota	246	235	226	217	204	194	185	176	168
Volkswagen	203	194	185	176	166	158	151	143	137
Fleet	244	234	225	215	202	192	183	174	166

10.3 Targets and Achieved Levels

10.3.1.1 Reference Case

Table 10-4 Reference Case Targets and Projected Shortfall in MY 2021

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	243	-	243	243	325	-	82
BMW	239	292	252	253	244	286	2
Chrysler/Fiat	244	307	274	276	229	301	-
Daimler	247	301	264	265	267	324	21
Ferrari	244	-	244	244	371	-	128
Ford	238	331	277	280	230	317	-
Geely	236	289	254	256	230	291	-
General Motors	240	324	276	279	230	312	-
Honda	238	299	256	258	221	297	-
Hyundai	236	285	242	243	227	267	-
Kia	231	299	238	239	219	301	-
Lotus	225	-	225	225	255	-	30
Mazda	235	289	245	246	226	274	-
Mitsubishi	225	271	234	235	221	239	-
Nissan	238	309	256	258	226	303	-
Porsche	241	299	271	273	268	323	25
Subaru	230	266	241	242	235	226	-
Suzuki	224	270	228	229	215	253	-
Tata	250	288	274	276	274	354	52
Toyota	237	308	264	267	216	312	-
Volkswagen	233	294	244	245	220	294	-
Fleet	238	312	264	266	227	306	-

Table 10-5 Reference Case Targets and Projected Shortfall in MY 2025

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	243	-	243	243	326	-	83
BMW	239	292	251	252	246	286	3
Chrysler/Fiat	243	308	272	274	228	302	-
Daimler	247	301	264	266	267	323	21
Ferrari	244	-	244	244	373	-	129
Ford	238	331	276	279	230	317	-
Geely	236	289	253	255	231	291	-
General Motors	240	323	275	278	230	311	-
Honda	238	299	255	257	221	301	-
Hyundai	236	285	242	242	227	267	-
Kia	231	298	237	238	219	301	-
Lotus	225	-	225	225	256	-	31
Mazda	235	289	244	246	226	275	-
Mitsubishi	225	271	234	235	220	239	-
Nissan	238	310	256	258	226	304	-
Porsche	242	299	271	273	269	323	26
Subaru	230	266	241	242	234	226	-
Suzuki	225	270	228	229	215	253	-
Tata	249	288	274	275	274	354	52
Toyota	237	308	263	265	217	312	-
Volkswagen	233	294	244	245	220	293	-
Fleet	238	312	263	265	227	306	-

10.3.1.2 Final rule

Table 10-6 Final rule Targets and Projected Shortfall in MY 2021

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	179	-	179	179	179	-	0
BMW	176	231	189	190	179	223	-
Chrysler/Fiat	180	248	212	215	184	242	-
Daimler	182	241	200	202	172	261	-
Ferrari	179	-	179	179	212	-	33
Ford	175	277	218	222	191	258	-
Geely	173	228	192	194	174	226	-
General Motors	176	267	215	219	188	253	-
Honda	175	239	194	196	179	230	-
Hyundai	174	223	180	180	177	197	-
Kia	169	238	176	177	172	217	-
Lotus	165	-	165	165	163	-	-
Mazda	173	228	182	184	178	206	-
Mitsubishi	165	209	173	174	173	179	-
Nissan	175	252	195	197	184	230	-
Porsche	178	238	209	212	161	252	-
Subaru	168	204	179	180	186	169	-
Suzuki	164	208	167	168	165	186	-
Tata	185	227	212	213	149	275	20
Toyota	174	253	204	207	180	245	-
Volkswagen	171	234	182	184	172	229	-
Fleet	175	255	203	205	182	243	-

Table 10-7 Final rule Targets and Projected Shortfall in MY 2025

Manufacturer	Car Target	Truck Target	Fleet Target (Sales Weighted)	Fleet Target (VMT and Sales weighted)	Car Achieved	Truck Achieved	Shortfall
Aston Martin	149	-	149	149	148	-	-
BMW	147	189	156	157	143	197	-
Chrysler/Fiat	149	203	173	175	154	196	-
Daimler	152	197	166	168	134	231	-
Ferrari	149	-	149	149	157	-	8
Ford	146	227	179	182	158	211	-
Geely	144	187	158	159	138	197	-
General Motors	147	218	177	180	158	203	-
Honda	145	195	159	161	149	186	-
Hyundai	144	182	149	149	147	161	-
Kia	141	194	146	147	142	182	-
Lotus	137	-	137	137	137	-	-
Mazda	144	186	151	152	147	170	-
Mitsubishi	137	171	143	144	144	141	-
Nissan	146	207	161	163	151	193	-
Porsche	148	195	172	174	115	220	-
Subaru	140	166	148	149	151	145	-
Suzuki	136	170	139	139	138	145	-
Tata	153	186	174	175	108	239	19
Toyota	145	207	168	170	148	202	-
Volkswagen	142	191	151	152	138	203	-
Fleet	145	209	167	169	150	200	-

10.4 Manufacturer Compliance Costs

Interpolated costs by manufacturer by model year, inclusive of AC-related costs and stranded capital (Note that AC and stranded capital costs are identical to those used for the 2008 baseline), are shown in Table 10-8 through Table 10-10.

Table 10-8 – Control Case Costs by Manufacturer by MY including AC & Stranded Capital Costs -- Cars (2010$)

Company	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	$1,824	$3,385	$4,559	$5,741	$6,909	$7,009	$7,055	$7,056	$6,478
BMW	$432	$786	$1,057	$1,314	$1,582	$2,012	$2,397	$2,763	$2,851
Chrysler/Fiat	$229	$359	$471	$576	$684	$1,012	$1,309	$1,597	$1,715
Daimler	$852	$1,590	$2,163	$2,710	$3,268	$3,704	$4,086	$4,434	$4,371
Ferrari	$1,740	$3,287	$4,454	$5,629	$6,789	$7,450	$8,019	$8,511	$8,244
Ford	$146	$257	$344	$425	$510	$824	$1,107	$1,375	$1,500
Geely-Volvo	$276	$496	$668	$835	$1,006	$1,514	$1,981	$2,420	$2,609
GM	$169	$295	$390	$482	$578	$883	$1,158	$1,419	$1,534
Honda	$138	$241	$321	$396	$475	$755	$1,007	$1,246	$1,357
Hyundai	$171	$307	$413	$513	$617	$907	$1,168	$1,416	$1,520
Kia	$151	$273	$370	$461	$555	$826	$1,070	$1,301	$1,402
Lotus	$1,050	$1,952	$2,633	$3,314	$3,990	$4,134	$4,240	$4,316	$4,031
Mazda	$229	$415	$553	$692	$834	$1,149	$1,432	$1,699	$1,795
Mitsubishi	$262	$484	$660	$832	$1,005	$1,333	$1,632	$1,908	$1,998
Nissan	$161	$283	$380	$471	$566	$893	$1,189	$1,469	$1,598
Porsche	$44	$61	$2,233	$3,149	$4,884	$5,524	$6,076	$6,575	$6,465
Subaru	$235	$438	$588	$736	$885	$1,273	$1,622	$1,951	$2,081
Suzuki	$54	$65	$522	$707	$1,078	$1,409	$1,705	$1,981	$2,064
Tata-JLR	$43	$58	$2,871	$4,129	$6,398	$7,034	$7,579	$8,062	$7,810
Toyota	$90	$161	$219	$271	$327	$599	$844	$1,079	$1,200
Volkswagen	$292	$531	$713	$891	$1,073	$1,481	$1,849	$2,194	$2,317
Fleet	$195	$346	$464	$577	$695	$1,011	$1,295	$1,565	$1,675

Note: Results correspond to the 2010 baseline fleet.

Table 10-9 – Control Case Costs by Manufacturer by MY including AC & Stranded Capital Costs -- Trucks (2010$)

Company	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	$0	$0	$0	$0	$0	$0	$0	$0	$0
BMW	$53	$198	$299	$408	$680	$1,588	$1,565	$1,536	$1,391
Chrysler/Fiat	$76	$217	$313	$455	$809	$1,268	$1,773	$2,230	$2,465
Daimler	$34	$160	$258	$358	$615	$2,817	$2,362	$1,914	$1,377
Ferrari	$0	$0	$0	$0	$0	$0	$0	$0	$0
Ford	$58	$153	$198	$307	$688	$990	$1,406	$1,809	$2,008
Geely-Volvo	$48	$205	$298	$401	$657	$1,217	$1,386	$1,540	$1,555
GM	$30	$128	$223	$342	$673	$1,142	$1,643	$2,113	$2,351
Honda	$40	$182	$290	$408	$710	$960	$1,385	$1,785	$1,993
Hyundai	$73	$266	$377	$508	$846	$1,041	$1,411	$1,754	$1,918
Kia	$69	$218	$360	$508	$863	$904	$1,198	$1,477	$1,603
Lotus	$0	$0	$0	$0	$0	$0	$0	$0	$0

Mazda	$100	$366	$513	$709	$1,220	$1,345	$1,788	$2,206	$2,389
Mitsubishi	$216	$474	$617	$804	$1,290	$1,573	$2,076	$2,540	$2,743
Nissan	$92	$259	$379	$574	$1,100	$1,100	$1,566	$2,016	$2,246
Porsche	$21	$67	$197	$276	$636	$4,026	$3,181	$2,366	$1,464
Subaru	$202	$413	$527	$674	$1,062	$1,248	$1,561	$1,849	$1,956
Suzuki	$31	$71	$572	$735	$1,570	$1,699	$2,250	$2,758	$2,983
Tata-JLR	$20	$65	$363	$516	$1,243	$5,477	$4,569	$3,679	$2,609
Toyota	$40	$177	$271	$379	$665	$746	$1,115	$1,465	$1,655
Volkswagen	$57	$274	$425	$603	$1,053	$1,299	$1,479	$1,646	$1,660
Fleet	$50	$178	$272	$398	$751	$1,144	$1,535	$1,902	$2,071

Note: Results correspond to the 2010 baseline fleet.

Table 10-10 – Control Case Costs by Manufacturer by MY including AC & Stranded Capital Costs -- Trucks (2010$)

Company	2017	2018	2019	2020	2021	2022	2023	2024	2025
Aston Martin	$1,824	$3,385	$4,559	$5,741	$6,909	$7,009	$7,055	$7,056	$6,478
BMW	$344	$650	$881	$1,104	$1,373	$1,920	$2,216	$2,496	$2,534
Chrysler/Fiat	$156	$291	$396	$518	$744	$1,126	$1,517	$1,879	$2,050
Daimler	$601	$1,152	$1,579	$1,989	$2,454	$3,426	$3,546	$3,645	$3,433
Ferrari	$1,740	$3,287	$4,454	$5,629	$6,789	$7,450	$8,019	$8,511	$8,244
Ford	$109	$213	$282	$376	$585	$892	$1,230	$1,553	$1,708
Geely-Volvo	$198	$396	$542	$686	$887	$1,417	$1,788	$2,135	$2,268
GM	$110	$223	$318	$422	$619	$993	$1,365	$1,715	$1,883
Honda	$108	$223	$312	$400	$546	$812	$1,112	$1,397	$1,536
Hyundai	$159	$302	$409	$513	$644	$922	$1,195	$1,454	$1,564
Kia	$142	$267	$369	$466	$588	$833	$1,083	$1,318	$1,421
Lotus	$1,050	$1,952	$2,633	$3,314	$3,990	$4,134	$4,240	$4,316	$4,031
Mazda	$206	$406	$546	$695	$902	$1,182	$1,492	$1,784	$1,895
Mitsubishi	$253	$482	$652	$827	$1,059	$1,377	$1,714	$2,025	$2,136
Nissan	$144	$277	$379	$497	$703	$945	$1,285	$1,608	$1,762
Porsche	$32	$64	$1,170	$1,650	$2,668	$4,744	$4,570	$4,385	$3,863
Subaru	$225	$430	$569	$717	$940	$1,266	$1,604	$1,920	$2,043
Suzuki	$52	$65	$526	$709	$1,116	$1,432	$1,748	$2,043	$2,136
Tata-JLR	$28	$62	$1,272	$1,825	$3,111	$6,069	$5,714	$5,347	$4,589
Toyota	$71	$167	$239	$312	$455	$652	$943	$1,219	$1,365
Volkswagen	$249	$485	$661	$839	$1,069	$1,448	$1,782	$2,095	$2,199
Fleet	$145	$288	$398	$515	$714	$1,055	$1,375	$1,677	$1,807

Note: Results correspond to the 2010 baseline fleet.

These costs per vehicle are then carried forward for future MYs to arrive at the costs presented in Table 10-11, including costs associated with the air conditioning program and estimates of stranded capital.

Table 10-11 – Industry Average Vehicle Costs Associated with the Proposed Standards (2010$)

Model Year	2017	2018	2019	2020	2021	2022	2023	2024	2025	2030	2040	2050
$/car	$195	$346	$464	$577	$695	$1,011	$1,295	$1,565	$1,675	$1,660	$1,660	$1,660
$/truck	$50	$178	$272	$398	$751	$1,144	$1,535	$1,902	$2,071	$2,055	$2,055	$2,055
Combined	$145	$288	$398	$515	$714	$1,055	$1,375	$1,677	$1,807	$1,788	$1,785	$1,785

Note: Results correspond to the 2010 baseline fleet.

The costs presented here represent the costs for newly added technology to comply with the program incremental to the costs of the 2012-2016 standards. Together with the projected increases in car and truck sales, the increases in per-car and per-truck average costs shown in Table 10-11 above result in the total annual technology costs presented in Table 10-12 below. Note that the costs presented in Table 10-12 do not include the fuel savings that consumers would realize as a result of driving a vehicle with improved fuel economy.

Table 10-12 – Undiscounted Annual Technology Costs & Costs Discounted back to 2012 at 3% and 7% Discount Rates (2010 dollars)

Calendar Year	Sales		$/unit		$Million/year		
	Cars	Trucks	$/car	$/truck	Cars	Trucks	Combined
2017	10,213,312	5,598,788	$195	$50	$1,990	$280	$2,300
2018	10,088,966	5,516,434	$346	$178	$3,490	$980	$4,490
2019	10,139,761	5,522,339	$464	$272	$4,700	$1,500	$6,230
2020	10,194,353	5,435,847	$577	$398	$5,880	$2,160	$8,050
2021	10,310,594	5,419,506	$695	$751	$7,160	$4,070	$11,200
2022	10,455,061	5,432,139	$1,011	$1,144	$10,600	$6,220	$16,800
2023	10,593,727	5,413,473	$1,295	$1,535	$13,700	$8,310	$22,000
2024	10,811,530	5,435,470	$1,565	$1,902	$16,900	$10,300	$27,200
2025	10,981,082	5,473,718	$1,675	$2,071	$18,400	$11,300	$29,700
2030	11,467,094	5,591,140	$1,660	$2,055	$19,000	$11,500	$30,500
2040	12,264,435	5,910,536	$1,660	$2,055	$20,400	$12,100	$32,400
2050	13,122,182	6,323,905	$1,660	$2,055	$21,800	$13,000	$34,700
NPV, 3%					$292,000	$172,000	$463,000
NPV, 7%					$132,000	$76,200	$208,000

Note: Results correspond to the 2010 baseline fleet.

Note that costs are estimated to decrease slightly in years beyond 2025. This represents the elimination of stranded capital that is included in the costs for 2017 through 2025. These costs are described in detail in Chapter 3 of the Joint TSD.

Looking at these costs by model year gives us the technology costs as shown in Table 10-13.

Table 10-13 – Model Year Lifetime Present Value Technology Costs, Discounted back to the 1st Year of each MY at 3% and 7% Discount Rates (millions of 2010 dollars)

NPV at		2017	2018	2019	2020	2021	2022	2023	2024	2025	Sum
3%	Car	$1,960	$3,440	$4,640	$5,800	$7,060	$10,400	$13,500	$16,700	$18,100	$81,600
	Truck	$276	$965	$1,480	$2,130	$4,010	$6,130	$8,190	$10,200	$11,200	$44,500
	Fleet	$2,260	$4,430	$6,140	$7,940	$11,100	$16,500	$21,700	$26,900	$29,300	$126,000
7%	Car	$1,930	$3,370	$4,550	$5,690	$6,930	$10,200	$13,300	$16,400	$17,800	$80,100
	Truck	$271	$947	$1,450	$2,090	$3,940	$6,010	$8,040	$10,000	$11,000	$43,700
	Fleet	$2,220	$4,340	$6,030	$7,790	$10,900	$16,200	$21,300	$26,400	$28,800	$124,000

Note: Results correspond to the 2010 baseline fleet.

Using the maintenance event costs, the maintenance intervals and the technology penetration rates, we can estimate the maintenance cost changes resulting from the new standards. These are shown in Table 10-14 through Table 10-16.

Table 10-14 – Undiscounted Sales Weighted Annual Maintenance Costs & Costs Discounted back to 2012 at 3% and 7% Discount Rates (millions of 2010 dollars)

CY	LRRT1		LRRT2		Diesel		EV		PHEV		Total		
	Car	Truck	Car	Truck	Car	Truck	Car	Truck	Car	Truck	Car	Truck	Vehicle
2017	$0	$0	$25	$15	-$1	$0	-$1	$0	$0	$0	$24	$15	$39
2018	-$4	-$2	$75	$45	-$3	-$1	-$3	$0	$1	$0	$67	$42	$108
2019	-$11	-$7	$150	$88	-$5	-$1	-$5	$0	$1	$0	$130	$80	$210
2020	-$22	-$13	$249	$143	-$8	-$2	-$9	$0	$2	$0	$212	$128	$340
2021	-$37	-$21	$377	$213	-$13	-$3	-$14	$0	$3	$0	$317	$189	$505
2022	-$54	-$30	$516	$287	-$16	-$4	-$21	$0	$4	$0	$430	$253	$683
2023	-$73	-$40	$669	$363	-$19	-$4	-$29	$0	$5	$0	$554	$319	$872
2024	-$94	-$51	$836	$446	-$21	-$5	-$41	$0	$6	$0	$688	$390	$1,080
2025	-$116	-$62	$1,010	$533	-$21	-$5	-$54	-$1	$7	$0	$826	$465	$1,290
2030	-$217	-$111	$1,790	$914	-$22	-$7	-$117	-$2	$11	$0	$1,440	$794	$2,240
2040	-$348	-$175	$2,800	$1,400	-$20	-$10	-$203	-$3	$15	$0	$2,240	$1,220	$3,460
2050	-$413	-$214	$3,310	$1,710	-$20	-$11	-$244	-$4	$18	$0	$2,650	$1,480	$4,130
NPV, 3%	-$3,700	-$1,900	$30,400	$15,600	-$322	-$120	-$2,060	-$33	$180	$0	$24,500	$13,500	$38,000
NPV, 7%	-$1,450	-$747	$12,100	$6,220	-$150	-$51	-$790	-$12	$75	$0	$9,780	$5,410	$15,200

Note: Costs include maintenance incurred during rebound miles; results correspond to the 2008 baseline fleet.

Table 10-15 – Model Year Lifetime Present Value Maintenance Costs and Savings, Discounted to the 1st Year of each MY at 3% (millions of 2010 dollars)

MY	Tires		Diesel		EV		PHEV		Total			$Million per MY		
	$/c	$/t	$/c	$/t	$/c	$/t	$/c	$/t	$/c	$/t	$/veh	$/c	$/t	$/veh
2017	$25	$27	-$1	$0	-$1	$0	$0	$0	$24	$27	$25	$243	$149	$392
2018	$47	$50	-$2	-$1	-$2	$0	$0	$0	$44	$50	$46	$445	$274	$719
2019	$70	$74	-$3	-$1	-$3	$0	$1	$0	$65	$73	$68	$658	$403	$1,060
2020	$93	$98	-$4	-$1	-$4	$0	$1	$0	$86	$96	$90	$879	$524	$1,400
2021	$116	$124	-$4	-$2	-$5	$0	$1	$0	$108	$122	$112	$1,110	$659	$1,770
2022	$126	$135	-$4	-$2	-$7	$0	$1	$0	$116	$133	$122	$1,220	$721	$1,940
2023	$137	$146	-$3	-$2	-$9	$0	$1	$0	$126	$144	$132	$1,340	$778	$2,120
2024	$147	$158	-$2	-$1	-$11	$0	$1	$0	$135	$156	$142	$1,460	$847	$2,310
2025	$158	$170	-$1	-$1	-$13	-$1	$1	$0	$145	$168	$153	$1,590	$919	$2,510
Sum	$919	$980	-$23	-$11	-$55	-$1	$8	$0	$849	$968	$890	$8,940	$5,280	$14,200

Note: Costs include maintenance incurred during rebound miles; results correspond to the 2008 baseline fleet.

Table 10-16 – Model Year Lifetime Present Value Maintenance Costs and Savings, Discounted to the 1st Year of each MY at 7% (millions of 2010 dollars)

MY	Tires		Diesel		EV		PHEV		Total			$Million per MY		
	$/c	$/t	$/c	$/t	$/c	$/t	$/c	$/t	$/c	$/t	$/veh	$/c	$/t	$/veh
2017	$20	$21	-$1	$0	-$1	$0	$0	$0	$18	$20	$19	$188	$114	$302
2018	$37	$39	-$1	-$1	-$1	$0	$0	$0	$34	$38	$36	$345	$210	$555
2019	$54	$57	-$2	-$1	-$2	$0	$1	$0	$50	$56	$52	$509	$309	$818
2020	$72	$75	-$3	-$1	-$3	$0	$1	$0	$67	$74	$69	$680	$403	$1,080
2021	$89	$94	-$3	-$1	-$4	$0	$1	$0	$83	$93	$86	$854	$503	$1,360
2022	$98	$103	-$3	-$1	-$5	$0	$1	$0	$90	$102	$94	$945	$551	$1,500
2023	$106	$111	-$2	-$1	-$7	$0	$1	$0	$98	$110	$102	$1,040	$596	$1,630
2024	$114	$121	-$2	-$1	-$9	$0	$1	$0	$105	$120	$110	$1,130	$650	$1,780
2025	$122	$129	-$1	-$1	-$10	$0	$1	$0	$112	$128	$117	$1,230	$700	$1,930
Sum	$711	$750	-$18	-$9	-$42	-$1	$6	$0	$657	$741	$686	$6,920	$4,040	$11,000

Note: Costs include maintenance incurred during rebound miles; results correspond to the 2008 baseline fleet.

Annual costs of the vehicle program are the annual technology costs shown in Table 10-12 and the annual maintenance costs shown in Table 10-14. Those results are shown in Table 10-17.

Table 10-17 – Undiscounted Annual Program Costs & Costs Discounted back to 2012 at 3% and 7% Discount Rates (2010 dollars)

Calendar Year	Car	Truck	Total Annual Costs
2017	$2,020	$295	$2,330
2018	$3,550	$1,020	$4,600
2019	$4,830	$1,580	$6,440
2020	$6,090	$2,290	$8,390
2021	$7,480	$4,260	$11,700
2022	$11,000	$6,470	$17,400
2023	$14,300	$8,630	$22,900
2024	$17,600	$10,700	$28,300
2025	$19,200	$11,800	$31,000
2030	$20,500	$12,300	$32,700
2040	$22,600	$13,400	$35,900
2050	$24,400	$14,500	$38,800
NPV, 3%	$317,000	$185,000	$501,000
NPV, 7%	$141,000	$81,600	$223,000

Note: Results correspond to the 2010 baseline fleet.

Model year lifetime costs of the vehicle program are the MY lifetime technology costs shown in Table 10-13 and the MY lifetime maintenance costs shown in Table 10-15 and Table 10-16. Those results are shown in Table 10-18.

Table 10-18 – Model Year Lifetime Present Value Vehicle Program Costs Discounted to the 1st Year of each MY at 3% & 7% (millions of 2010 dollars)

NPV at	MY →	2017	2018	2019	2020	2021	2022	2023	2024	2025	Sum
3%	Cars	$2,210	$3,880	$5,290	$6,680	$8,170	$11,600	$14,900	$18,100	$19,700	$90,600
	Trucks	$425	$1,240	$1,880	$2,660	$4,670	$6,850	$8,970	$11,000	$12,100	$49,800
	Combined	$2,650	$5,150	$7,200	$9,340	$12,800	$18,500	$23,800	$29,200	$31,800	$140,000
7%	Cars	$2,120	$3,720	$5,060	$6,370	$7,780	$11,200	$14,300	$17,500	$19,000	$87,000
	Trucks	$386	$1,160	$1,760	$2,500	$4,440	$6,560	$8,630	$10,700	$11,700	$47,700
	Combined	$2,520	$4,900	$6,840	$8,870	$12,200	$17,700	$22,900	$28,100	$30,700	$135,000

Note: Results correspond to the 2010 baseline fleet.

10.5 Technology Penetrations

10.5.1 Projected Technology Penetrations in Reference Case

Table 10-19 Reference Car Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-8%	-7%	1%	40%	15%	0%	9%	0%	53%	26%	12%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
BMW	-6%	-5%	1%	44%	15%	0%	13%	2%	49%	27%	8%	0%	15%	15%	0%	0%	55%	0%	30%	0%	74%	16%	0%
Chrysler/Fiat	-5%	-5%	0%	68%	15%	0%	11%	4%	48%	26%	1%	0%	15%	0%	0%	0%	0%	0%	30%	0%	83%	0%	0%
Daimler	-8%	-7%	1%	40%	15%	0%	0%	52%	18%	30%	0%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
Ferrari	-8%	-7%	1%	40%	15%	0%	0%	0%	20%	79%	0%	0%	15%	15%	0%	0%	55%	0%	30%	0%	83%	15%	0%
Ford	-3%	-3%	0%	35%	0%	0%	18%	5%	43%	23%	5%	0%	0%	3%	0%	0%	0%	0%	29%	0%	34%	0%	0%
Geely	-4%	-3%	1%	47%	15%	0%	10%	3%	48%	26%	5%	0%	15%	15%	0%	0%	56%	0%	30%	0%	71%	14%	0%
General Motors	-6%	-6%	0%	27%	5%	0%	8%	1%	53%	28%	5%	0%	0%	0%	0%	0%	0%	0%	30%	0%	41%	0%	0%
Honda	-1%	-1%	0%	0%	0%	0%	1%	1%	50%	26%	3%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Hyundai	-2%	-2%	0%	3%	0%	0%	6%	1%	53%	24%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%
Kia	0%	0%	0%	0%	0%	0%	0%	0%	66%	12%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Lotus	-1%	0%	1%	42%	15%	0%	0%	0%	15%	0%	85%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
Mazda	-1%	-1%	0%	11%	0%	0%	3%	1%	47%	25%	14%	0%	0%	0%	0%	0%	0%	0%	30%	0%	10%	0%	0%
Mitsubishi	-3%	-3%	0%	46%	7%	0%	11%	3%	46%	25%	7%	0%	2%	0%	0%	0%	0%	0%	30%	0%	53%	0%	0%
Nissan	-1%	-1%	0%	28%	0%	0%	3%	10%	44%	27%	2%	0%	0%	1%	0%	0%	0%	0%	26%	0%	28%	0%	0%
Porsche	-5%	-4%	1%	43%	15%	0%	0%	40%	15%	22%	24%	0%	15%	15%	0%	0%	55%	0%	30%	0%	83%	15%	0%
Spyker	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Subaru	-5%	-5%	0%	32%	9%	0%	1%	1%	47%	25%	13%	0%	1%	0%	0%	0%	0%	0%	30%	0%	40%	0%	0%
Suzuki	-1%	-1%	0%	48%	7%	0%	1%	1%	49%	27%	9%	0%	0%	0%	0%	0%	0%	0%	30%	0%	55%	0%	0%
Tata	-9%	-8%	1%	43%	15%	0%	10%	0%	55%	30%	0%	0%	15%	15%	0%	0%	55%	0%	30%	0%	78%	15%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-1%	-1%	0%	2%	0%	0%	10%	2%	52%	16%	2%	0%	10%	12%	0%	0%	0%	0%	0%	0%	7%	0%	0%
Volkswagen	-4%	-3%	0%	68%	13%	0%	14%	2%	50%	26%	8%	0%	13%	3%	0%	0%	56%	0%	30%	0%	85%	11%	12%
Fleet	-3%	-3%	0%	24%	4%	0%	8%	4%	49%	24%	4%	0%	4%	4%	0%	0%	6%	0%	18%	0%	31%	2%	1%

Table 10-20 Reference Truck Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-8%	-8%	1%	62%	13%	0%	69%	30%	0%	0%	1%	0%	13%	15%	0%	0%	66%	0%	30%	0%	75%	14%	0%
Chrysler/Fiat	-8%	-8%	0%	51%	15%	0%	64%	28%	2%	1%	4%	0%	15%	0%	0%	0%	8%	0%	30%	0%	66%	0%	0%
Daimler	-9%	-8%	1%	60%	14%	0%	1%	99%	0%	0%	0%	0%	14%	15%	0%	0%	64%	0%	30%	0%	74%	13%	0%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-8%	-8%	0%	25%	2%	0%	60%	26%	7%	4%	0%	0%	0%	1%	0%	0%	0%	0%	30%	0%	27%	0%	0%
Geely	-8%	-8%	1%	70%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	63%	0%	30%	0%	78%	7%	0%
General Motors	-8%	-8%	0%	29%	6%	0%	64%	28%	3%	2%	0%	0%	6%	0%	0%	0%	0%	0%	30%	0%	40%	0%	0%
Honda	-4%	-4%	0%	47%	0%	0%	46%	24%	10%	6%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	46%	0%	0%
Hyundai	-4%	-4%	0%	0%	0%	0%	43%	15%	27%	15%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Kia	-3%	-3%	0%	0%	0%	0%	36%	30%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-7%	-7%	0%	58%	0%	0%	47%	20%	17%	9%	2%	0%	0%	0%	0%	0%	0%	0%	30%	0%	57%	0%	0%
Mitsubishi	-8%	-8%	0%	70%	15%	0%	29%	12%	33%	18%	0%	0%	15%	0%	0%	0%	0%	0%	30%	0%	85%	0%	0%
Nissan	-4%	-4%	0%	44%	2%	0%	37%	29%	13%	7%	1%	0%	0%	0%	0%	0%	0%	0%	30%	0%	47%	0%	0%
Porsche	-8%	-8%	1%	65%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	64%	0%	30%	0%	94%	6%	0%
Spyker	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Subaru	-8%	-8%	0%	44%	2%	0%	7%	4%	45%	24%	5%	0%	2%	0%	0%	0%	0%	0%	30%	0%	46%	0%	0%
Suzuki	0%	0%	0%	70%	15%	0%	15%	8%	40%	22%	0%	0%	15%	0%	0%	0%	0%	0%	30%	0%	85%	0%	0%
Tata	-8%	-7%	1%	60%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	58%	0%	30%	0%	84%	12%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-3%	-3%	0%	13%	0%	0%	51%	25%	6%	3%	3%	0%	9%	3%	0%	0%	0%	0%	9%	0%	13%	0%	0%
Volkswagen	-8%	-8%	0%	61%	12%	0%	69%	30%	1%	0%	0%	0%	12%	0%	0%	0%	67%	0%	30%	0%	83%	17%	15%
Fleet	-7%	-7%	0%	33%	5%	0%	55%	28%	7%	4%	1%	0%	6%	2%	0%	0%	6%	0%	23%	0%	39%	1%	0%

Table 10-21 Reference Fleet (Sales-Weighted) Technology Penetration in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-8%	-7%	1%	40%	15%	0%	9%	0%	53%	26%	12%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
BMW	-6%	-5%	1%	48%	14%	0%	26%	9%	38%	21%	7%	0%	14%	15%	0%	0%	57%	0%	30%	0%	74%	16%	0%
Chrysler/Fiat	-6%	-6%	0%	60%	15%	0%	36%	15%	26%	14%	2%	0%	15%	0%	0%	0%	4%	0%	30%	0%	75%	0%	0%
Daimler	-8%	-7%	1%	46%	15%	0%	0%	66%	13%	21%	0%	0%	15%	15%	0%	0%	58%	0%	30%	0%	71%	14%	0%
Ferrari	-8%	-7%	1%	40%	15%	0%	0%	0%	20%	79%	0%	0%	15%	15%	0%	0%	55%	0%	30%	0%	83%	15%	0%
Ford	-5%	-5%	0%	31%	1%	0%	36%	14%	28%	15%	3%	0%	0%	2%	0%	0%	0%	0%	29%	0%	31%	0%	0%
Geely	-6%	-5%	1%	55%	15%	0%	31%	12%	31%	17%	3%	0%	15%	15%	0%	0%	59%	0%	30%	0%	74%	11%	0%
General Motors	-7%	-7%	0%	28%	6%	0%	32%	12%	32%	17%	3%	0%	2%	0%	0%	0%	0%	0%	30%	0%	41%	0%	0%
Honda	-2%	-2%	0%	15%	0%	0%	15%	8%	38%	20%	2%	0%	0%	4%	0%	0%	0%	0%	0%	0%	14%	0%	0%
Hyundai	-2%	-2%	0%	3%	0%	0%	10%	3%	50%	23%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Kia	-1%	-1%	0%	0%	0%	0%	4%	3%	59%	11%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Lotus	-1%	0%	1%	42%	15%	0%	0%	0%	15%	0%	85%	0%	15%	15%	0%	0%	55%	0%	30%	0%	70%	15%	0%
Mazda	-2%	-2%	0%	19%	0%	0%	11%	4%	41%	23%	12%	0%	0%	0%	0%	0%	0%	0%	30%	0%	19%	0%	0%
Mitsubishi	-4%	-4%	0%	51%	9%	0%	14%	5%	44%	24%	6%	0%	4%	0%	0%	0%	0%	0%	30%	0%	59%	0%	0%
Nissan	-2%	-2%	0%	32%	1%	0%	11%	15%	36%	22%	2%	0%	0%	1%	0%	0%	0%	0%	27%	0%	33%	0%	0%
Porsche	-7%	-6%	1%	54%	15%	0%	36%	35%	7%	10%	11%	0%	15%	15%	0%	0%	60%	0%	30%	0%	89%	10%	0%
Spyker	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Subaru	-6%	-6%	0%	36%	7%	0%	3%	2%	46%	25%	11%	0%	2%	0%	0%	0%	0%	0%	30%	0%	42%	0%	0%
Suzuki	-1%	-1%	0%	50%	7%	0%	2%	1%	48%	26%	8%	0%	1%	0%	0%	0%	0%	0%	30%	0%	57%	0%	0%
Tata	-8%	-7%	1%	54%	15%	0%	48%	19%	20%	11%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	82%	13%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-2%	-2%	0%	6%	0%	0%	25%	11%	35%	11%	3%	0%	9%	9%	0%	0%	0%	0%	4%	0%	9%	0%	0%
Volkswagen	-4%	-4%	0%	67%	13%	0%	24%	7%	41%	21%	7%	0%	13%	2%	0%	0%	58%	0%	30%	0%	85%	12%	13%
Fleet	-4%	-4%	0%	27%	4%	0%	24%	12%	34%	17%	3%	0%	5%	3%	0%	0%	6%	0%	20%	0%	34%	1%	0%

Table 10-22 Reference Car Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-8%	-7%	1%	55%	15%	0%	9%	0%	53%	26%	12%	0%	15%	15%	0%	0%	55%	0%	30%	0%	85%	0%	0%
BMW	-6%	-5%	1%	59%	15%	0%	13%	2%	49%	27%	8%	0%	15%	15%	0%	0%	55%	0%	30%	0%	89%	1%	0%
Chrysler/Fiat	-5%	-5%	0%	68%	15%	0%	10%	4%	48%	26%	1%	0%	15%	0%	0%	0%	0%	0%	30%	0%	83%	0%	0%
Daimler	-8%	-7%	1%	55%	15%	0%	0%	52%	18%	30%	0%	0%	15%	15%	0%	0%	55%	0%	30%	0%	85%	0%	0%
Ferrari	-8%	-7%	1%	55%	15%	0%	0%	0%	20%	79%	0%	0%	15%	15%	0%	0%	55%	0%	30%	0%	98%	0%	0%
Ford	-3%	-3%	0%	35%	0%	0%	18%	5%	43%	23%	5%	0%	0%	3%	0%	0%	0%	0%	29%	0%	34%	0%	0%
Geely	-4%	-4%	1%	60%	15%	0%	10%	3%	48%	26%	4%	0%	15%	15%	0%	0%	56%	0%	30%	0%	85%	0%	0%
General Motors	-6%	-6%	0%	27%	5%	0%	7%	1%	54%	28%	5%	0%	0%	0%	0%	0%	0%	0%	30%	0%	40%	0%	0%
Honda	-1%	-1%	0%	0%	0%	0%	1%	1%	50%	26%	3%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Hyundai	-2%	-2%	0%	3%	0%	0%	6%	1%	53%	24%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%
Kia	0%	0%	0%	0%	0%	0%	0%	0%	71%	8%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Lotus	-1%	0%	1%	57%	15%	0%	0%	0%	15%	0%	85%	0%	15%	15%	0%	0%	55%	0%	30%	0%	85%	0%	0%
Mazda	-1%	-1%	0%	11%	0%	0%	3%	0%	47%	25%	13%	0%	0%	0%	0%	0%	0%	0%	30%	0%	10%	0%	0%
Mitsubishi	-3%	-3%	0%	46%	7%	0%	11%	3%	46%	25%	7%	0%	2%	0%	0%	0%	0%	0%	30%	0%	52%	0%	0%
Nissan	-1%	-1%	0%	28%	0%	0%	3%	10%	44%	27%	2%	0%	0%	1%	0%	0%	0%	0%	28%	0%	28%	0%	0%
Porsche	-5%	-4%	1%	58%	15%	0%	0%	40%	15%	22%	24%	0%	15%	15%	0%	0%	55%	0%	30%	0%	98%	0%	0%
Spyker	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Subaru	-5%	-5%	0%	34%	10%	0%	1%	0%	47%	25%	14%	0%	1%	0%	0%	0%	0%	0%	30%	0%	43%	0%	0%
Suzuki	-1%	-1%	0%	48%	7%	0%	1%	1%	49%	27%	9%	0%	0%	0%	0%	0%	0%	0%	30%	0%	55%	0%	0%
Tata	-9%	-8%	1%	58%	15%	0%	10%	0%	55%	30%	0%	0%	15%	15%	0%	0%	55%	0%	30%	0%	93%	0%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-1%	-1%	0%	0%	0%	0%	10%	2%	52%	16%	2%	0%	9%	12%	0%	0%	0%	0%	0%	0%	5%	0%	0%
Volkswagen	-4%	-3%	0%	70%	13%	0%	14%	2%	50%	26%	8%	0%	13%	1%	0%	0%	55%	0%	30%	0%	85%	10%	14%
Fleet	-3%	-3%	0%	25%	4%	0%	8%	4%	49%	24%	4%	0%	4%	4%	0%	0%	6%	0%	18%	0%	32%	0%	1%

Table 10-23 Reference Truck Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-8%	-8%	1%	64%	13%	0%	69%	30%	0%	0%	1%	0%	13%	15%	0%	0%	66%	0%	30%	0%	77%	11%	0%
Chrysler/Fiat	-8%	-8%	0%	51%	15%	0%	64%	27%	2%	1%	4%	0%	15%	0%	0%	0%	2%	0%	30%	0%	66%	0%	0%
Daimler	-9%	-8%	1%	65%	14%	0%	1%	99%	0%	0%	0%	0%	14%	15%	0%	0%	64%	0%	30%	0%	78%	8%	0%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-8%	-8%	0%	27%	0%	0%	60%	26%	7%	4%	0%	0%	0%	1%	0%	0%	0%	0%	30%	0%	27%	0%	0%
Geely	-8%	-8%	1%	77%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	63%	0%	30%	0%	85%	0%	0%
General Motors	-8%	-8%	0%	30%	6%	0%	64%	28%	4%	2%	1%	0%	6%	0%	0%	0%	0%	0%	30%	0%	41%	0%	0%
Honda	-4%	-4%	0%	27%	0%	0%	46%	24%	10%	6%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	26%	0%	0%
Hyundai	-4%	-4%	0%	0%	0%	0%	42%	15%	28%	15%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Kia	-3%	-3%	0%	0%	0%	0%	35%	30%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-7%	-7%	0%	59%	0%	0%	48%	20%	17%	9%	2%	0%	0%	0%	0%	0%	0%	0%	30%	0%	58%	0%	0%
Mitsubishi	-9%	-9%	0%	70%	15%	0%	29%	12%	33%	18%	0%	0%	15%	0%	0%	0%	0%	0%	30%	0%	85%	0%	0%
Nissan	-4%	-4%	0%	44%	2%	0%	37%	29%	12%	7%	1%	0%	0%	0%	0%	0%	0%	0%	30%	0%	46%	0%	0%
Porsche	-8%	-8%	1%	70%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	64%	0%	30%	0%	100%	0%	0%
Spyker	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Subaru	-9%	-9%	0%	44%	2%	0%	7%	4%	45%	24%	5%	0%	2%	0%	0%	0%	0%	0%	30%	0%	46%	0%	0%
Suzuki	0%	0%	0%	70%	15%	0%	15%	8%	40%	22%	0%	0%	15%	0%	0%	0%	0%	0%	30%	0%	85%	0%	0%
Tata	-8%	-7%	1%	73%	15%	0%	70%	30%	0%	0%	0%	0%	15%	15%	0%	0%	58%	0%	30%	0%	96%	0%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-3%	-3%	0%	12%	0%	0%	51%	25%	6%	3%	3%	0%	9%	3%	0%	0%	0%	0%	9%	0%	12%	0%	0%
Volkswagen	-8%	-8%	0%	61%	12%	0%	69%	30%	1%	0%	0%	0%	12%	0%	0%	0%	67%	0%	30%	0%	84%	16%	15%
Fleet	-7%	-6%	0%	32%	5%	0%	55%	28%	7%	4%	1%	0%	6%	2%	0%	0%	5%	0%	23%	0%	38%	1%	0%

Table 10-24 Reference Fleet (Sales-Weighted) Technology Penetration in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-8%	-7%	1%	55%	15%	0%	9%	0%	53%	26%	12%	0%	15%	15%	0%	0%	55%	0%	30%	0%	85%	0%	0%
BMW	-6%	-5%	1%	60%	14%	0%	25%	8%	39%	21%	7%	0%	14%	15%	0%	0%	57%	0%	30%	0%	86%	4%	0%
Chrysler/Fiat	-6%	-6%	0%	60%	15%	0%	34%	14%	28%	15%	3%	0%	15%	0%	0%	0%	1%	0%	30%	0%	75%	0%	0%
Daimler	-8%	-7%	1%	58%	15%	0%	0%	66%	13%	21%	0%	0%	15%	15%	0%	0%	58%	0%	30%	0%	83%	3%	0%
Ferrari	-8%	-7%	1%	55%	15%	0%	0%	0%	20%	79%	0%	0%	15%	15%	0%	0%	55%	0%	30%	0%	98%	0%	0%
Ford	-5%	-5%	0%	32%	0%	0%	35%	13%	28%	15%	3%	0%	0%	2%	0%	0%	0%	0%	29%	0%	31%	0%	0%
Geely	-6%	-5%	1%	66%	15%	0%	30%	12%	32%	17%	3%	0%	15%	15%	0%	0%	59%	0%	30%	0%	85%	0%	0%
General Motors	-7%	-7%	0%	28%	6%	0%	31%	12%	32%	17%	3%	0%	2%	0%	0%	0%	0%	0%	30%	0%	41%	0%	0%
Honda	-2%	-2%	0%	8%	0%	0%	14%	7%	39%	20%	2%	0%	0%	4%	0%	0%	0%	0%	0%	0%	7%	0%	0%
Hyundai	-2%	-2%	0%	3%	0%	0%	10%	3%	50%	23%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Kia	0%	0%	0%	0%	0%	0%	4%	3%	64%	7%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Lotus	-1%	0%	1%	57%	15%	0%	0%	0%	15%	0%	85%	0%	15%	15%	0%	0%	55%	0%	30%	0%	85%	0%	0%
Mazda	-2%	-2%	0%	19%	0%	0%	11%	4%	42%	23%	11%	0%	0%	0%	0%	0%	0%	0%	30%	0%	18%	0%	0%
Mitsubishi	-4%	-4%	0%	50%	8%	0%	14%	4%	44%	24%	6%	0%	4%	0%	0%	0%	0%	0%	30%	0%	58%	0%	0%
Nissan	-2%	-2%	0%	32%	0%	0%	11%	15%	36%	22%	2%	0%	0%	1%	0%	0%	0%	0%	28%	0%	33%	0%	0%
Porsche	-7%	-6%	1%	64%	15%	0%	36%	35%	7%	10%	11%	0%	15%	15%	0%	0%	60%	0%	30%	0%	99%	0%	0%
Spyker	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Subaru	-6%	-6%	0%	37%	8%	0%	3%	2%	46%	25%	11%	0%	2%	0%	0%	0%	0%	0%	30%	0%	44%	0%	0%
Suzuki	-1%	-1%	0%	50%	8%	0%	2%	1%	48%	26%	8%	0%	1%	0%	0%	0%	0%	0%	30%	0%	57%	0%	0%
Tata	-8%	-7%	1%	67%	15%	0%	47%	19%	21%	11%	0%	0%	15%	15%	0%	0%	57%	0%	30%	0%	95%	0%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-2%	-2%	0%	4%	0%	0%	25%	10%	36%	12%	3%	0%	9%	9%	0%	0%	0%	0%	4%	0%	7%	0%	0%
Volkswagen	-4%	-4%	0%	68%	13%	0%	24%	7%	41%	21%	6%	0%	13%	1%	0%	0%	57%	0%	30%	0%	85%	11%	14%
Fleet	-4%	-4%	0%	28%	4%	0%	23%	12%	35%	17%	3%	0%	5%	3%	0%	0%	6%	0%	20%	0%	34%	1%	1%

10.5.2 Projected Technology Penetrations in Final rule case

Table 10-25 Final rule Car Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-14%	-9%	6%	9%	15%	15%	0%	0%	8%	70%	6%	59%	25%	30%	16%	15%	30%	75%	24%	60%	84%	0%	0%
BMW	-8%	-7%	1%	44%	28%	8%	0%	0%	13%	73%	6%	58%	30%	11%	7%	0%	42%	75%	55%	60%	92%	1%	19%
Chrysler/Fiat	-6%	-6%	0%	74%	23%	1%	3%	11%	19%	67%	1%	56%	22%	0%	0%	0%	3%	75%	77%	53%	97%	0%	1%
Daimler	-14%	-11%	3%	17%	30%	14%	0%	9%	1%	79%	0%	59%	30%	22%	10%	6%	42%	75%	46%	60%	90%	0%	8%
Ferrari	-14%	-8%	6%	9%	15%	15%	0%	0%	1%	83%	0%	59%	25%	30%	16%	15%	30%	75%	24%	60%	84%	0%	0%
Ford	-4%	-4%	0%	35%	5%	1%	3%	13%	19%	57%	5%	32%	3%	3%	0%	0%	0%	73%	74%	14%	41%	0%	1%
Geely	-7%	-6%	1%	55%	30%	6%	2%	8%	14%	69%	4%	59%	30%	5%	5%	0%	42%	75%	56%	60%	95%	0%	25%
General Motors	-6%	-6%	0%	42%	13%	1%	0%	2%	22%	71%	5%	40%	8%	0%	0%	0%	0%	75%	79%	33%	60%	0%	0%
Honda	-2%	-2%	0%	16%	0%	0%	0%	2%	22%	67%	3%	9%	0%	6%	0%	0%	0%	71%	75%	23%	16%	0%	0%
Hyundai	-3%	-3%	0%	18%	0%	0%	1%	3%	23%	68%	5%	23%	0%	0%	0%	0%	0%	75%	79%	29%	19%	0%	0%
Kia	0%	0%	0%	2%	0%	0%	0%	0%	23%	69%	7%	0%	0%	0%	0%	0%	0%	75%	71%	0%	2%	0%	0%
Lotus	-3%	0%	3%	15%	30%	14%	0%	0%	0%	42%	47%	59%	30%	18%	11%	12%	36%	75%	42%	59%	89%	0%	12%
Mazda	-2%	-2%	0%	22%	20%	0%	0%	1%	21%	64%	14%	54%	3%	0%	0%	0%	0%	75%	80%	54%	43%	0%	0%
Mitsubishi	-4%	-4%	0%	73%	27%	0%	2%	7%	19%	65%	7%	52%	27%	0%	0%	0%	6%	75%	78%	57%	100%	0%	3%
Nissan	-3%	-3%	0%	32%	11%	0%	1%	8%	20%	68%	2%	31%	1%	1%	0%	0%	0%	74%	78%	31%	43%	0%	0%
Porsche	-10%	-7%	3%	7%	29%	15%	0%	7%	0%	66%	11%	55%	30%	25%	16%	8%	33%	75%	36%	55%	84%	0%	5%
Spyker	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Subaru	-6%	-6%	0%	83%	17%	0%	0%	1%	20%	65%	13%	54%	10%	0%	0%	0%	0%	75%	80%	44%	100%	0%	0%
Suzuki	-1%	-1%	0%	73%	27%	0%	0%	1%	21%	70%	7%	57%	27%	0%	0%	0%	1%	75%	79%	58%	100%	0%	14%
Tata	-16%	-10%	6%	6%	19%	15%	0%	0%	9%	75%	0%	59%	26%	29%	16%	15%	30%	75%	27%	60%	84%	0%	1%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-2%	-2%	0%	20%	0%	0%	1%	4%	20%	61%	2%	0%	10%	12%	0%	0%	0%	66%	12%	0%	22%	0%	0%
Volkswagen	-5%	-5%	1%	57%	26%	2%	1%	3%	15%	72%	6%	60%	26%	4%	2%	0%	39%	75%	61%	60%	89%	9%	26%
Fleet	-4%	-4%	0%	34%	10%	1%	1%	5%	20%	66%	4%	30%	9%	4%	1%	0%	5%	73%	65%	28%	47%	0%	2%

Table 10-26 Final rule Truck Technology Penetrations in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-15%	-14%	1%	55%	28%	8%	20%	80%	0%	0%	1%	60%	29%	0%	0%	0%	69%	75%	56%	60%	91%	9%	30%
Chrysler/Fiat	-9%	-8%	0%	30%	24%	5%	18%	74%	1%	3%	3%	59%	28%	0%	0%	0%	11%	75%	64%	45%	59%	0%	17%
Daimler	-15%	-14%	1%	56%	29%	9%	8%	92%	0%	0%	0%	60%	30%	0%	0%	0%	68%	75%	58%	60%	93%	7%	30%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-8%	-8%	0%	20%	8%	10%	17%	70%	3%	9%	0%	60%	14%	1%	0%	0%	0%	75%	75%	10%	38%	0%	4%
Geely	-15%	-14%	1%	60%	30%	10%	20%	80%	0%	0%	0%	60%	30%	0%	0%	0%	68%	75%	59%	60%	100%	0%	30%
General Motors	-9%	-9%	0%	27%	10%	9%	19%	75%	1%	5%	0%	58%	12%	0%	0%	0%	0%	75%	67%	23%	47%	0%	9%
Honda	-9%	-9%	0%	61%	17%	0%	16%	65%	5%	14%	0%	52%	0%	0%	0%	0%	0%	75%	65%	17%	77%	0%	0%
Hyundai	-9%	-9%	0%	38%	10%	0%	10%	40%	12%	37%	0%	40%	0%	0%	0%	0%	0%	75%	70%	10%	48%	0%	0%
Kia	-5%	-5%	0%	95%	0%	0%	20%	80%	0%	0%	0%	40%	0%	0%	0%	0%	0%	75%	40%	0%	95%	0%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-11%	-10%	0%	78%	17%	0%	13%	54%	8%	23%	2%	60%	17%	0%	0%	0%	13%	75%	67%	30%	95%	0%	13%
Mitsubishi	-12%	-11%	1%	73%	27%	0%	8%	33%	15%	44%	0%	60%	27%	0%	0%	0%	29%	75%	68%	51%	100%	0%	24%
Nissan	-7%	-7%	0%	69%	17%	3%	13%	63%	6%	17%	1%	60%	10%	0%	0%	0%	0%	75%	69%	31%	89%	0%	10%
Porsche	-15%	-14%	1%	61%	30%	9%	20%	80%	0%	0%	0%	60%	30%	2%	0%	0%	68%	75%	57%	60%	100%	0%	28%
Spyker	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Subaru	-11%	-11%	0%	75%	25%	0%	3%	11%	20%	61%	5%	60%	25%	0%	0%	0%	3%	75%	77%	42%	100%	0%	1%
Suzuki	-1%	0%	1%	48%	30%	0%	5%	22%	15%	58%	0%	60%	30%	22%	0%	0%	23%	75%	61%	56%	100%	0%	8%
Tata	-13%	-12%	1%	55%	30%	15%	20%	80%	0%	0%	0%	60%	30%	30%	0%	0%	66%	75%	66%	60%	100%	0%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-4%	-4%	0%	57%	0%	4%	17%	66%	3%	8%	3%	38%	11%	3%	0%	0%	0%	73%	55%	0%	61%	0%	0%
Volkswagen	-15%	-14%	1%	52%	27%	7%	20%	80%	0%	0%	0%	60%	29%	0%	0%	0%	69%	75%	54%	60%	86%	14%	30%
Fleet	-8%	-8%	0%	41%	12%	6%	17%	69%	3%	9%	1%	54%	14%	1%	0%	0%	7%	75%	65%	22%	60%	1%	8%

Table 10-27 Final rule Fleet Technology Penetration in MY 2021

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-14%	-9%	6%	9%	15%	15%	0%	0%	8%	70%	6%	59%	25%	30%	16%	15%	30%	75%	24%	60%	84%	0%	0%
BMW	-10%	-9%	1%	46%	28%	8%	5%	19%	10%	56%	5%	59%	30%	9%	6%	0%	48%	75%	55%	60%	91%	3%	21%
Chrysler/Fiat	-7%	-7%	0%	53%	23%	2%	10%	41%	10%	37%	2%	57%	25%	0%	0%	0%	7%	75%	71%	49%	79%	0%	9%
Daimler	-14%	-12%	2%	29%	29%	13%	3%	34%	1%	55%	0%	60%	30%	16%	7%	4%	50%	75%	50%	60%	91%	2%	14%
Ferrari	-14%	-8%	6%	9%	15%	15%	0%	0%	1%	83%	0%	59%	25%	30%	16%	15%	30%	75%	24%	60%	84%	0%	0%
Ford	-6%	-6%	0%	29%	6%	5%	9%	37%	12%	37%	3%	44%	7%	2%	0%	0%	0%	73%	75%	13%	40%	0%	2%
Geely	-9%	-8%	1%	57%	30%	7%	8%	32%	9%	45%	2%	59%	30%	3%	3%	0%	51%	75%	57%	60%	97%	0%	27%
General Motors	-7%	-7%	0%	36%	11%	4%	8%	33%	13%	42%	3%	48%	10%	0%	0%	0%	0%	75%	74%	29%	55%	0%	4%
Honda	-4%	-4%	0%	30%	5%	0%	5%	21%	17%	51%	2%	22%	0%	4%	0%	0%	0%	72%	72%	21%	35%	0%	0%
Hyundai	-4%	-4%	0%	21%	1%	0%	2%	8%	21%	64%	5%	25%	0%	0%	0%	0%	0%	75%	78%	27%	22%	0%	0%
Kia	-1%	-1%	0%	12%	0%	0%	2%	9%	21%	62%	7%	4%	0%	0%	0%	0%	0%	75%	67%	0%	12%	0%	0%
Lotus	-3%	0%	3%	15%	30%	14%	0%	0%	0%	42%	47%	59%	30%	18%	11%	12%	36%	75%	42%	59%	89%	0%	12%
Mazda	-3%	-3%	0%	32%	19%	0%	3%	11%	19%	57%	12%	55%	6%	0%	0%	0%	2%	75%	77%	50%	52%	0%	2%
Mitsubishi	-5%	-5%	0%	73%	27%	0%	3%	12%	18%	61%	6%	54%	27%	0%	0%	0%	11%	75%	76%	56%	100%	0%	7%
Nissan	-4%	-4%	0%	42%	12%	1%	4%	22%	16%	55%	2%	39%	3%	1%	0%	0%	0%	74%	76%	31%	55%	0%	3%
Porsche	-13%	-10%	2%	36%	29%	12%	10%	45%	0%	32%	5%	57%	30%	13%	7%	4%	51%	75%	47%	58%	93%	0%	17%
Spyker	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Subaru	-8%	-8%	0%	80%	20%	0%	1%	4%	20%	64%	11%	56%	15%	0%	0%	0%	1%	75%	79%	44%	100%	0%	0%
Suzuki	-1%	-1%	1%	71%	27%	0%	1%	3%	20%	69%	7%	57%	27%	2%	0%	0%	3%	75%	78%	58%	100%	0%	14%
Tata	-14%	-11%	3%	37%	26%	15%	13%	51%	3%	27%	0%	60%	29%	30%	6%	5%	53%	75%	52%	60%	94%	0%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-3%	-3%	0%	34%	0%	2%	7%	27%	13%	41%	3%	15%	10%	9%	0%	0%	0%	69%	28%	0%	37%	0%	0%
Volkswagen	-7%	-6%	1%	56%	26%	3%	4%	17%	13%	59%	5%	60%	27%	4%	2%	0%	45%	75%	60%	60%	88%	10%	26%
Fleet	-6%	-5%	0%	37%	11%	3%	7%	27%	14%	47%	3%	39%	11%	3%	0%	0%	6%	73%	65%	26%	52%	0%	4%

Table 10-28 Final rule Car Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-16%	-11%	6%	0%	4%	40%	0%	0%	0%	75%	2%	77%	44%	23%	23%	10%	17%	100%	17%	77%	77%	0%	27%
BMW	-10%	-8%	2%	5%	57%	17%	0%	0%	0%	81%	3%	85%	74%	5%	15%	0%	35%	100%	35%	85%	84%	1%	45%
Chrysler/Fiat	-10%	-9%	1%	23%	73%	2%	0%	12%	0%	86%	1%	98%	74%	0%	2%	0%	6%	100%	65%	98%	97%	0%	33%
Daimler	-17%	-13%	4%	2%	60%	11%	0%	0%	0%	78%	0%	78%	70%	3%	22%	3%	25%	100%	25%	78%	78%	0%	47%
Ferrari	-17%	-8%	9%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	5%	77%	77%	0%	0%
Ford	-6%	-6%	0%	22%	67%	5%	0%	16%	0%	78%	3%	97%	71%	3%	0%	0%	0%	97%	86%	97%	93%	0%	10%
Geely	-8%	-6%	2%	8%	64%	14%	0%	9%	0%	76%	2%	87%	75%	1%	13%	0%	38%	100%	38%	87%	87%	0%	49%
General Motors	-8%	-8%	0%	23%	70%	5%	0%	2%	0%	95%	3%	100%	74%	0%	0%	0%	0%	100%	84%	100%	97%	0%	16%
Honda	-3%	-3%	0%	27%	67%	0%	0%	2%	0%	89%	3%	94%	46%	6%	0%	0%	0%	94%	94%	94%	94%	0%	0%
Hyundai	-4%	-4%	0%	35%	64%	1%	0%	4%	0%	91%	5%	100%	25%	0%	0%	0%	0%	100%	100%	100%	100%	0%	0%
Kia	0%	0%	0%	4%	67%	0%	0%	0%	0%	93%	7%	100%	4%	0%	0%	0%	0%	100%	100%	100%	71%	0%	0%
Lotus	-3%	0%	3%	3%	70%	0%	0%	0%	0%	52%	26%	78%	70%	4%	22%	2%	26%	100%	26%	78%	78%	0%	46%
Mazda	-3%	-3%	0%	24%	75%	0%	0%	2%	0%	87%	10%	99%	75%	0%	1%	0%	1%	100%	86%	99%	99%	0%	13%
Mitsubishi	-7%	-6%	1%	22%	75%	0%	0%	9%	0%	85%	3%	97%	75%	0%	3%	0%	6%	100%	68%	97%	97%	0%	29%
Nissan	-3%	-3%	0%	25%	74%	0%	0%	6%	0%	91%	1%	99%	74%	1%	0%	0%	0%	99%	82%	99%	99%	0%	17%
Porsche	-13%	-7%	6%	0%	26%	21%	0%	0%	0%	75%	2%	77%	46%	15%	23%	16%	11%	100%	11%	77%	77%	0%	35%
Spyker	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Subaru	-10%	-9%	1%	19%	75%	0%	0%	2%	0%	88%	8%	98%	75%	4%	2%	0%	1%	100%	65%	98%	98%	0%	29%
Suzuki	-2%	-1%	1%	18%	75%	0%	0%	2%	0%	87%	6%	95%	75%	2%	5%	0%	1%	100%	62%	95%	95%	0%	30%
Tata	-20%	-11%	9%	0%	2%	3%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	5%	77%	77%	0%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-3%	-3%	0%	41%	41%	1%	0%	4%	0%	82%	2%	88%	28%	12%	0%	0%	0%	88%	88%	88%	83%	0%	0%
Volkswagen	-7%	-5%	2%	11%	66%	6%	0%	4%	0%	82%	4%	90%	70%	2%	10%	0%	36%	100%	40%	90%	85%	5%	48%
Fleet	-6%	-5%	1%	25%	64%	3%	0%	5%	0%	87%	3%	95%	57%	4%	2%	0%	4%	97%	80%	95%	92%	0%	14%

Table 10-29 Final rule Truck Technology Penetrations in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BMW	-20%	-18%	1%	18%	64%	11%	0%	100%	0%	0%	0%	100%	68%	0%	0%	0%	50%	100%	50%	100%	93%	7%	50%
Chrysler/Fiat	-12%	-11%	1%	16%	67%	15%	0%	93%	0%	4%	2%	100%	75%	6%	0%	0%	48%	100%	50%	100%	100%	0%	44%
Daimler	-20%	-19%	2%	15%	63%	17%	0%	100%	0%	0%	0%	100%	70%	0%	0%	0%	50%	100%	50%	100%	95%	5%	50%
Ferrari	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ford	-13%	-13%	0%	8%	57%	33%	0%	87%	0%	12%	0%	99%	74%	1%	0%	0%	22%	99%	89%	99%	98%	0%	11%
Geely	-20%	-19%	2%	13%	63%	23%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
General Motors	-14%	-13%	1%	11%	47%	28%	0%	93%	0%	7%	0%	100%	75%	0%	0%	0%	59%	100%	64%	100%	86%	0%	36%
Honda	-12%	-11%	1%	25%	75%	0%	0%	81%	0%	19%	0%	100%	75%	0%	0%	0%	23%	100%	60%	100%	100%	0%	40%
Hyundai	-15%	-15%	0%	25%	75%	0%	0%	50%	0%	50%	0%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%	0%
Kia	-11%	-11%	0%	25%	75%	0%	0%	99%	0%	0%	1%	100%	75%	0%	0%	0%	0%	100%	100%	100%	100%	0%	0%
Lotus	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mazda	-19%	-18%	1%	25%	75%	0%	0%	68%	0%	30%	2%	100%	75%	0%	0%	0%	34%	100%	66%	100%	100%	0%	34%
Mitsubishi	-19%	-18%	2%	10%	75%	0%	0%	41%	0%	55%	0%	95%	75%	10%	5%	0%	20%	100%	45%	95%	95%	0%	40%
Nissan	-11%	-10%	1%	19%	69%	12%	0%	77%	0%	23%	1%	100%	75%	0%	0%	0%	38%	100%	60%	100%	100%	0%	40%
Porsche	-20%	-18%	1%	16%	66%	19%	0%	100%	0%	0%	0%	100%	75%	0%	0%	0%	50%	100%	50%	100%	100%	0%	50%
Spyker	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Subaru	-20%	-19%	0%	25%	75%	0%	0%	13%	0%	81%	5%	100%	75%	0%	0%	0%	7%	100%	93%	100%	100%	0%	7%
Suzuki	-2%	0%	2%	7%	69%	0%	0%	27%	0%	61%	0%	89%	69%	13%	11%	0%	14%	100%	39%	89%	89%	0%	37%
Tata	-17%	-15%	2%	0%	50%	50%	0%	100%	0%	0%	0%	100%	75%	50%	0%	0%	50%	100%	50%	100%	100%	0%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-8%	-8%	0%	18%	67%	12%	0%	83%	0%	11%	3%	97%	74%	3%	0%	0%	0%	97%	94%	97%	97%	0%	3%
Volkswagen	-20%	-18%	1%	20%	65%	6%	0%	100%	0%	0%	0%	100%	65%	0%	0%	0%	50%	100%	50%	100%	90%	10%	50%
Fleet	-13%	-12%	1%	15%	62%	19%	0%	86%	0%	12%	1%	99%	74%	2%	0%	0%	33%	99%	71%	99%	95%	0%	27%

Table 10-30 Final rule Fleet Technology Penetration in MY 2025

	Mass Tech Applied	True Mass	Mass Penalty	TDS18	TDS24	TDS27	AT6	AT8	DCT6	DCT8	MT	HEG	EGR	HEV	EV	PHEV	SS	LRRT2	IACC2	EFR2	DI	DSL	MHEV
Aston Martin	-16%	-11%	6%	0%	4%	40%	0%	0%	0%	75%	2%	77%	44%	23%	23%	10%	17%	100%	17%	77%	77%	0%	27%
BMW	-12%	-10%	2%	8%	59%	15%	0%	22%	0%	64%	3%	88%	73%	4%	12%	0%	38%	100%	38%	88%	86%	2%	46%
Chrysler/Fiat	-11%	-10%	1%	20%	70%	8%	0%	48%	0%	49%	1%	99%	75%	3%	1%	0%	25%	100%	58%	99%	98%	0%	38%
Daimler	-18%	-15%	3%	6%	61%	13%	0%	31%	0%	54%	0%	85%	70%	2%	15%	2%	33%	100%	33%	85%	83%	2%	48%
Ferrari	-17%	-8%	9%	0%	0%	5%	0%	0%	0%	77%	0%	77%	5%	50%	23%	22%	5%	100%	5%	77%	77%	0%	0%
Ford	-9%	-9%	0%	16%	63%	16%	0%	45%	0%	51%	2%	98%	72%	2%	0%	0%	9%	98%	87%	98%	95%	0%	11%
Geely	-12%	-10%	2%	10%	64%	17%	0%	38%	0%	51%	1%	91%	75%	0%	9%	0%	42%	100%	42%	91%	91%	0%	49%
General Motors	-11%	-10%	1%	18%	60%	15%	0%	41%	0%	57%	2%	100%	74%	0%	0%	0%	25%	100%	76%	100%	92%	0%	24%
Honda	-5%	-5%	0%	27%	69%	0%	0%	24%	0%	70%	2%	96%	54%	4%	0%	0%	6%	96%	85%	96%	96%	0%	11%
Hyundai	-5%	-5%	0%	34%	65%	1%	0%	9%	0%	86%	5%	100%	30%	0%	0%	0%	0%	100%	100%	100%	100%	0%	0%
Kia	-1%	-1%	0%	6%	68%	0%	0%	10%	0%	84%	6%	100%	11%	0%	0%	0%	0%	100%	100%	100%	74%	0%	0%
Lotus	-3%	0%	3%	3%	70%	0%	0%	0%	0%	52%	26%	78%	70%	4%	22%	2%	26%	100%	26%	78%	78%	0%	46%
Mazda	-6%	-5%	1%	24%	75%	0%	0%	13%	0%	77%	9%	99%	75%	0%	1%	0%	6%	100%	82%	99%	99%	0%	17%
Mitsubishi	-9%	-8%	1%	20%	75%	0%	0%	15%	0%	79%	3%	97%	75%	2%	3%	0%	9%	100%	64%	97%	97%	0%	31%
Nissan	-5%	-4%	1%	23%	73%	3%	0%	24%	0%	74%	1%	99%	74%	1%	0%	0%	10%	99%	77%	99%	99%	0%	22%
Porsche	-17%	-13%	4%	8%	46%	20%	0%	52%	0%	36%	1%	89%	61%	7%	11%	8%	31%	100%	31%	89%	89%	0%	43%
Spyker	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Subaru	-13%	-12%	1%	20%	75%	0%	0%	5%	0%	86%	7%	99%	75%	3%	1%	0%	3%	100%	73%	99%	99%	0%	22%
Suzuki	-2%	-1%	1%	17%	75%	0%	0%	4%	0%	85%	6%	94%	75%	3%	6%	0%	2%	100%	61%	94%	94%	0%	31%
Tata	-18%	-14%	5%	0%	32%	32%	0%	62%	0%	29%	0%	91%	49%	50%	9%	8%	33%	100%	33%	91%	91%	0%	0%
Tesla	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	-5%	-5%	0%	33%	50%	5%	0%	33%	0%	56%	3%	91%	45%	9%	0%	0%	0%	91%	90%	91%	88%	0%	1%
Volkswagen	-9%	-8%	2%	13%	66%	6%	0%	21%	0%	68%	3%	92%	69%	1%	8%	0%	39%	100%	42%	92%	86%	6%	48%
Fleet	-8%	-7%	1%	21%	63%	8%	0%	32%	0%	62%	2%	97%	62%	3%	1%	0%	14%	98%	77%	97%	93%	0%	18%

10.6 GHG Impacts

The GHG reductions and fuel savings are shown in this section.

Table 10-31 Calendar year GHG impacts

Calendar Year:	**2020**	**2030**	**2040**	**2050**
Net Reduction*	**-28**	**-262**	**-423**	**-506**
Net CO_2	*-24*	*-238*	*-387*	*-464*
Net other GHG	*-4*	*-24*	*-35*	*-42*
Downstream Reduction	**-23**	**-213**	**-344**	**-412**
CO_2 (excluding A/C)	*-18*	*-193*	*-314*	*-377*
A/C – indirect CO_2	*-1*	*-3*	*-4*	*-5*
A/C – direct HFCs	*-3*	*-18*	*-26*	*-30*
CH_4 (rebound effect)	*0*	*0*	*0*	*0*
N_2O (rebound effect)	*0*	*0*	*0*	*0*
Gasoline Upstream Reduction	**-5**	***-55***	***-89***	***-106***
CO_2	*-5*	*-48*	*-77*	*-93*
CH_4	*-1*	*-7*	*-11*	*-13*
N_2O	*0*	*0*	*0*	*0*
Electricity Upstream Increase	**1**	**6**	**10**	**12**
CO_2	*0*	*5*	*9*	*10*
CH_4	*0*	*1*	*1*	*2*
N_2O	*0*	*0*	*0*	*0*

Table 10-32 Model year GHG impacts

MY	Downstream	Upstream Gasoline	Upstream Electricity	**Total CO2e**
2017	-27	-7	1	**-33**
2018	-59	-14	1	**-72**
2019	-90	-21	2	**-110**
2020	-124	-29	3	**-150**
2021	-174	-42	4	**-213**
2022	-216	-54	5	**-264**
2023	-254	-64	7	**-312**
2024	-295	-75	8	**-362**
2025	-334	-86	10	**-411**
Sum	-1,573	-394	41	**-1,926**

Monetized values of CO_2 reductions associated with the 2010 baseline are presented in Section 10.7 below.

10.7 Fuel Savings

The expected impacts on fuel consumption are shown in Table 10-33. The gallons reduced and kilowatt hours increased (kWh) as shown in the tables reflect impacts from the final CO_2 standards, including the A/C credit program, and include the increased fuel consumption resulting from the rebound effect.

Table 10-33 – Fuel Consumption Impacts of the Final Standards and A/C Credit Programs

Calendar Year	Petroleum-based Gasoline Reference (million gallons)	Petroleum-based Gasoline Reduced (million gallons)	Electricity Increased (million kWh)
2017	125,346	209	92
2018	124,204	645	273
2019	123,247	1,297	544
2020	122,408	2,181	904
2021	121,775	3,441	1,357
2022	121,386	5,016	1,972
2023	121,210	6,866	2,751
2024	121,293	8,984	3,698
2025	121,645	11,353	4,809
2030	125,979	22,017	9,911
2040	139,497	35,838	16,748
2050	157,428	42,960	20,036
Total	5,186,805	833,756	383,605

Note: The electricity increase shown is that needed to charge EVs/PHEVs, not that generated by power plants; results correspond to the 2010 baseline fleet.

Monetized fuel savings are shown in Table 10-34 and Table 10-35.

Table 10-34 – Undiscounted Annual Fuel Savings & Fuel Savings Discounted back to 2012 at 3% and 7% Discount Rates (millions of 2010 dollars)

Calendar Year	Gasoline Savings (pre-tax)	Gasoline Savings (taxed)	Electricity Costs	Total Fuel Savings (pre-tax)	Total Fuel Savings (taxed)
2017	$704	$794	$8.5	$696	$786
2018	$2,190	$2,460	$25.2	$2,160	$2,430
2019	$4,480	$5,040	$49.9	$4,430	$4,990
2020	$7,650	$8,570	$83	$7,570	$8,480
2021	$12,200	$13,600	$126	$12,100	$13,500
2022	$17,800	$19,900	$186	$17,600	$19,700
2023	$24,400	$27,200	$263	$24,100	$26,900
2024	$32,200	$35,800	$358	$31,800	$35,500
2025	$41,400	$45,900	$472	$40,900	$45,400
2030	$84,200	$92,900	$1,030	$83,100	$91,900
2040	$145,000	$159,000	$1,900	$143,000	$157,000
2050	$190,000	$205,000	$2,460	$188,000	$203,000
NPV, 3%	$1,510,000	$1,650,000	$19,200	$1,490,000	$1,630,000
NPV, 7%	$578,000	$634,000	$7,270	$571,000	$627,000

Note: Annual values represent undiscounted values; net present values represent annual costs discounted to 2012; results correspond to the 2010 baseline fleet.

Table 10-35 – Model Year Lifetime Present Value Fuel Savings Discounted to the 1st Year of each MY at 3% & 7% (millions of 2010 dollars)

NPV at		2017	2018	2019	2020	2021	2022	2023	2024	2025	Sum
3%	Car	$7,380	$13,700	$20,400	$27,300	$34,800	$42,700	$50,100	$58,200	$66,100	$321,000
	Truck	$158	$2,330	$4,310	$6,990	$14,900	$20,700	$26,300	$30,000	$38,000	$144,000
	Total	$7,540	$16,000	$24,700	$34,300	$49,700	$63,400	$76,400	$88,200	$104,000	$465,000
7%	Car	$5,670	$10,600	$15,700	$21,000	$26,700	$32,900	$38,500	$44,800	$50,900	$247,000
	Truck	$119	$1,770	$3,270	$5,300	$11,300	$15,700	$19,900	$22,900	$28,800	$109,000
	Total	$5,790	$12,400	$19,000	$26,300	$38,000	$48,600	$58,400	$67,700	$79,700	$356,000

Note: Results correspond to the 2010 baseline fleet.

10.8 Comparison to analysis using the MY 2008 based market forecast

As noted in the introduction to this chapter, the MY 2010 baseline supports the reasonableness of the standards finalized here. While there are minor differences in costs and benefits, these minor differences support the overall analytic approach and results as robust despite a significant change in inputs. Table 10-36 presents a high level comparison of the two analyses.

Table 10-36 – Comparison of Analyses

	Analysis using the MY 2008 based market forecast.	Analysis using the MY 2010 based market forecast
MY 2025 Per Vehicle Average Costs relative to the MY 2016 standard reference case($)	$1,836	$1,785
MY Lifetime GHG emission reductions (MMT CO2eq)	1,956	1,926
MY Lifetime Fuel savings (B. Barrels)	3.9	3.8
CY 2030 GHG emission reductions (MMT CO2eq)	271	262
CY 2030 Fuel savings (B. Barrels)	0.55	0.53